The Effect of Overburden Depth on Casing Deformations of Shale Gas Wells in Longwall Chain Pillars—Recent Mine-by Experiences

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ABSTRACT

Over 2,000 shale gas wells have been drilled in the Pittsburgh Seam longwall reserves. As longwall panels are laid out, some of these shale gas wells must be located in longwall chain pillars. With longwall mining on both sides and the constraint of chain pillar size, gas wells in chain pillars are subjected to longwall-induced ground movements and stresses, which could induce deformations in gas well casings. Casing deformations are associated with several factors such as overburden geology, surface topography, setback distance, and casing construction. Overburden geology is one important factor that largely determines the locations and levels of deformations in gas well casings. Previous NIOSH gas well research has found that casing deformations above the coal seam horizon are smaller under deep cover than under shallow cover and that casing deformations could occur at the coal seam horizon under deep cover. Recent mine-by cases have provided more insights into the locations and amount of longwall-induced casing deformations as well as the potential occurrence of a large casing deformation at the coal seam horizon. This paper presents three recent mine-by cases with shale gas wells in the chain pillars between two adjacent longwall panels under different overburden depths. Casing deformations were measured by multi-finger caliper surveys and predicted with numerical modeling. With the established numerical model, the effect of overburden depth was further analyzed to investigate the potential occurrence of a large casing deformation at the coal seam horizon under deep cover. These mine-by cases not only provide a general demonstration of how overburden depths can affect longwall-induced stresses and deformations but also give a good indication about the level of casing deformations that could occur under different overburden depths. The study concludes that (1) casing deformations reduce with increase of overburden depths at the gas well; (2) a cementing alternative with production casing uncemented is an effective means to eliminate production casing deformations; and (3) large plastic casing deformation could occur in the production casing at the coal seam horizon under deep cover. The experience and knowledge gained from these mine-by cases would help longwall operators and gas companies to take appropriate measures to minimize the influence of longwall mining in shale gas wells in chain pillars.

INTRODUCTION

Gas wells drilled in longwall chain pillars are influenced by longwall mining. Over 2,000 shale gas wells have been drilled in the Pittsburgh Seam longwall reserves. As longwall panels are laid out, some of these shale gas wells must be located in longwall chain pillars. With longwall mining on both sides and the constraint of chain pillar size, gas wells in chain pillars are subjected to longwall-induced ground movements and stresses, which could induce deformations in gas well casings. Excessive stresses and deformations in gas well casings could potentially result in a casing breach. More safety concerns have been focused on unconventional shale gas wells because a casing breach could allow high-pressure gas to leak into the longwall mine with serious consequences.

Casing deformations are associated with several factors such as overburden geology, surface topography, setback distance, and casing construction. Overburden geology is one important factor that largely determines the locations and levels of deformations in gas well casings. Previous NIOSH gas well research has shown that casing deformations above the coal seam horizon are smaller under deep cover than under shallow cover and that casing deformations could occur at the coal seam horizon under deep cover (Su 2016, 2017; Su et al. 2018, 2019; Scovazzo 2018; Zhang et al. 2019, 2022, 2023b; and Zhang and Su 2021).

Su (2017) investigated the effect of overburden depth and casing cementing alternatives on the longwall-induced stresses and deformations in gas well casings. He found that under deep cover smaller lateral strata deformation was present in the overburden above the mining horizon, but higher pressure and deformation were present at and below the coal seam. Zhang et al. (2019) presented a case in which a large casing deformation occurred at a claystone layer 15 ft below the coal seam after second panel mining. The gas well was in chain pillars under an overburden depth of 960 ft.

Recent mine-by cases have provided more insights into the locations and levels of longwall-induced casing deformations as well as the potential occurrence of a large casing deformation at the coal seam horizon. This paper presents three mine-by cases with shale gas wells in the chain pillars between two adjacent longwall panels under different overburden depths. Casing deformations were measured by multi-finger caliper surveys and predicted with numerical modeling. With the established numerical model, the effect of overburden depth is further analyzed to investigate the potential occurrence of large casing deformations at the coal seam horizon under deep cover. These mine-by cases not only provide a general demonstration of how overburden depths can affect longwall-induced stresses and deformations but also give a good indication about the level of casing deformations that could occur under different overburden depths.

A MINE-BY CASE UNDER 670-FT DEPTH OF COVER

In this case, five shale gas wells were located in the chain pillars between two adjacent longwall panels in the Pittsburgh Seam under an overburden depth of 670 ft. The details of this case were provided by Zhang et al. (2023a). Figure 1 shows the longwall panel layout and shale gas well locations. The five shale gas wells were located at the center of the large abutment pillar. These gas wells were 100 ft away from the first longwall gob and 54 ft away from the second longwall gob. The longwall panels were 1,200-ft wide with a mining height of 7 ft. The wells were named 1H, 2H, 3H, 6H, and 7H. The first panel mined-by the gas wells in March 2022, and the second panel mined-by in October 2022.

Figure 2 shows the geological column, gamma logs, and density logs from the closest corehole to the well pad. The overburden at the gas well site consisted mainly of shale, sandyshale, claystone, sandstone, and limestone. No thick, massive beds were present in the overburden. Weak claystone and coal interfaces were identified by correlating the core logs, and gamma and density logs as shown in Figure 2.

Each shale gas well was constructed with five casings: surface casing, water protection casing, intermediate casing, production casing, and additional casing. Figure 3 shows a diagram of the casing construction. The production casing and intermediate casing ran past the Pittsburgh coal seam. The production casings of wells 2H, 3H, 6H, and 7H were uncemented from the Pittsburgh seam horizon to the surface leaving an open annulus of 3.335 in between production casing and intermediate casing. The cement top of the 1H production casing was detected below the surface based on the Cement Bond Log (CBL). The top of good cement was detected at 535 ft below the surface, and the top of highest lower-quality cement stringers was detected at 444 ft below the surface. The production casing in the 1H well above a 444-ft depth was uncemented. Water protection casings in all wells were set at depths ranging from 375 ft to 378 ft, all cemented to the surface. Wells 1H, 2H, and 6H each had an additional casing string set at depths ranging from 563 ft to 569 ft, all cemented to the surface.

Longwall-induced casing deformations were surveyed through the production casing with a 40-arm caliper in each of the five wells after each panel was mined. No casing deformations were detected in the uncemented production casing in the 2H, 3H, 6H, and 7H wells. For the 1H well with partially uncemented casing, a 40-arm caliper survey was also conducted after first and second panel mining. The caliper detected a small casing deformation of 0.02-in at the 444-ft depth after first panel mining and 0.04-in at the same depth after second panel mining. Figure 4 shows the caliper survey results after second panel mining. Small deformations also occurred at three other locations below the 444-ft depth where the casing was cemented with lower-quality cement.

FLAC3D modeling was used to predict longwall-induced casing deformations (ITASCA 2017; Tulu et al. 2017; Zhang et al. 2022, 2023a). A FLAC3D model was set up based on the site-specific geologic conditions in this case. To predict production casing deformations, potential deformations in the intermediate casing were predicted first. If the intermediate casing deformation was less than the

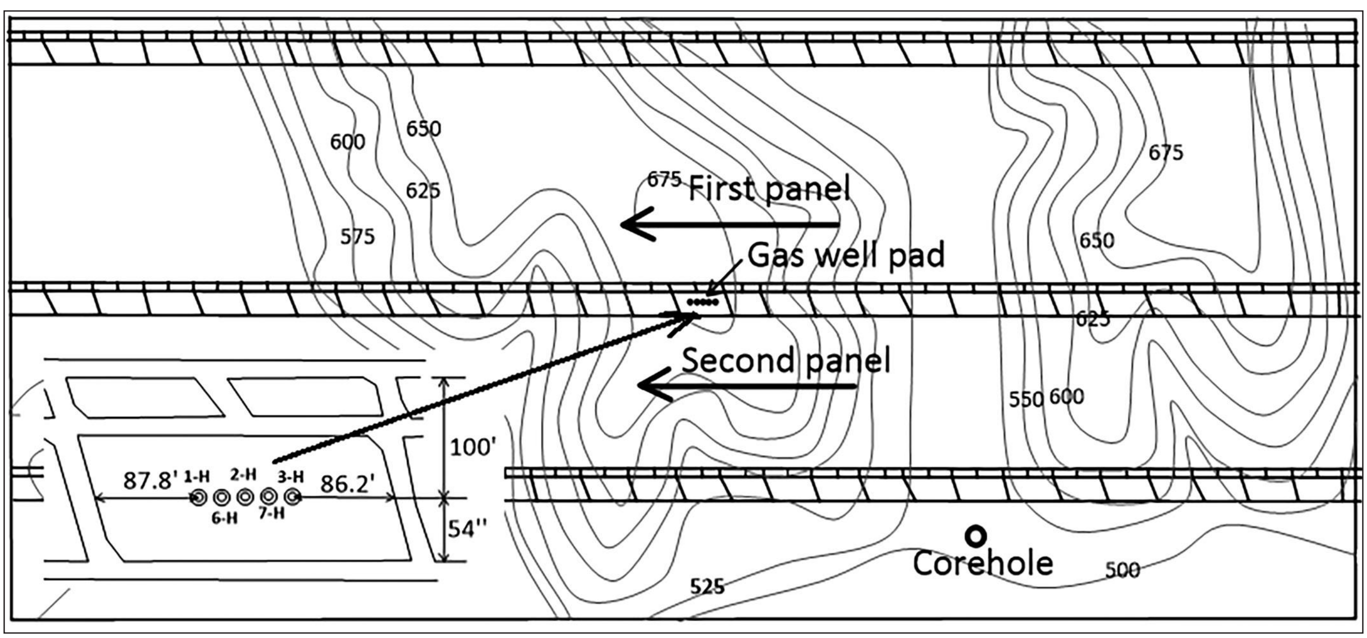


Figure 1. Longwall panel layout and locations of shale gas wells in chain pillars under an overburden depth of 670 ft.

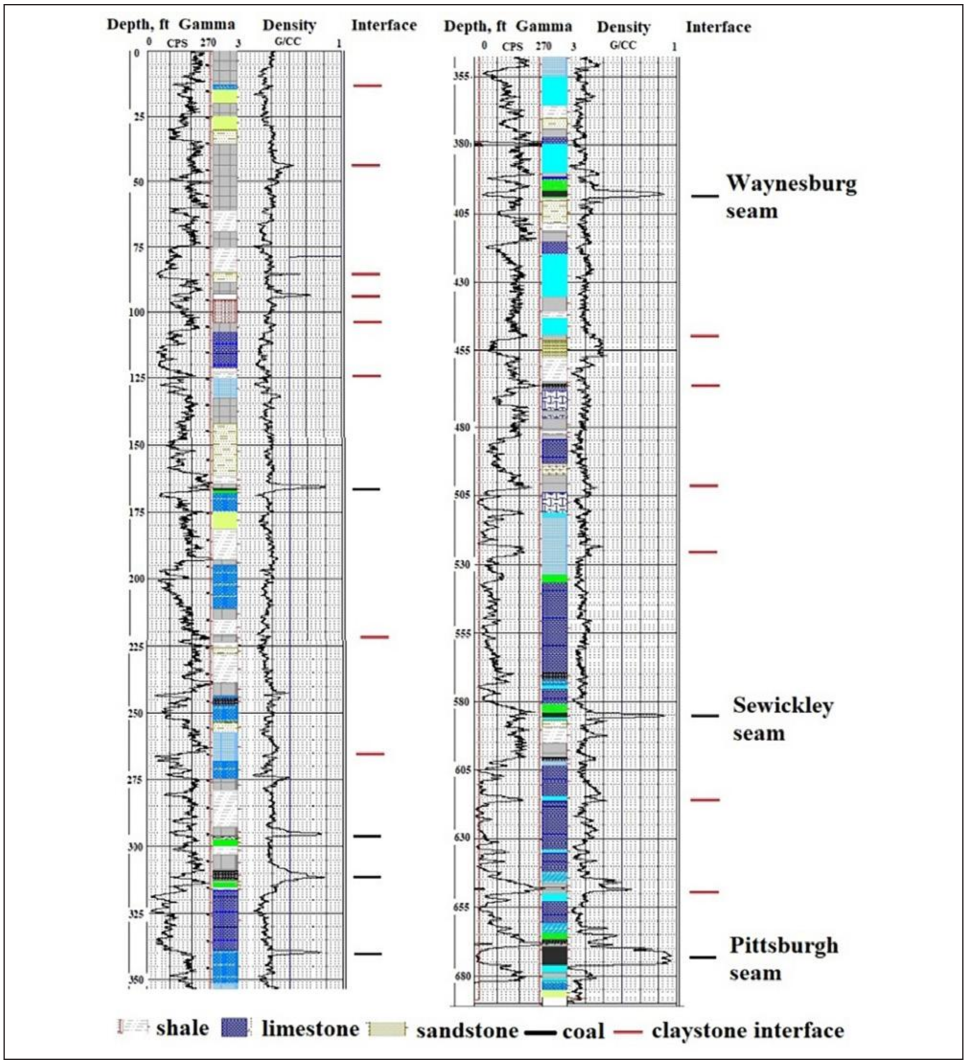


Figure 2. Geological column, gamma and density logs, and weak interface locations (Zhang et al. 2023a)

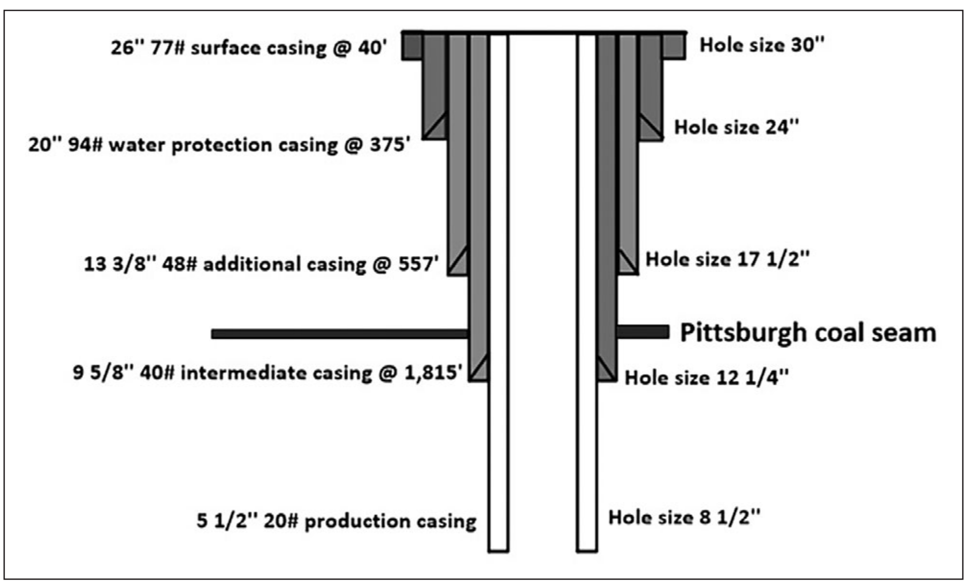


Figure 3. Gas well casing construction

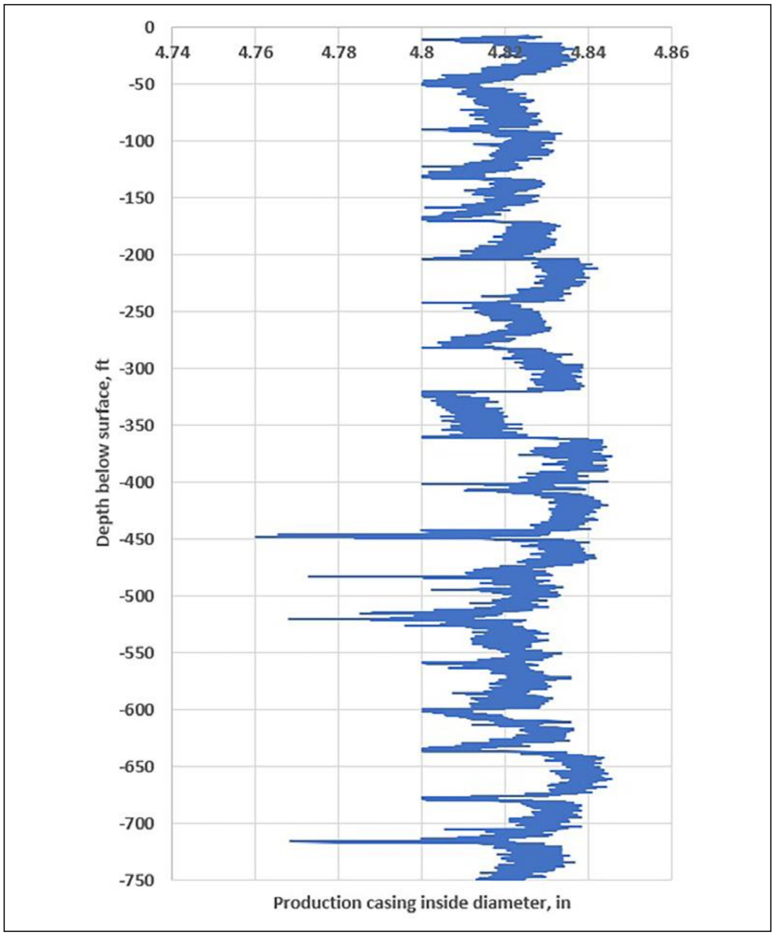


Figure 4. The 40-arm caliper survey results along the production casing in well 1H after second panel mining (Zhang et al. 2023a).

open annulus between the intermediate and production casing, no deformation would occur in the production casing. Figure 5 shows the predicted horizontal displacement along the intermediate casing after first and second panel mining. Predicted casing deformation locations are shown at the interfaces with relative horizontal displacement. The model predicted casing deformations at 8 locations below the surface. Table 1 shows a summary of the predicted deformations in the intermediate casing. The casing deformations were predicted at the same locations after second panel mining as those after first panel mining. Generally, casing deformations were small, but two relatively large deformations were predicted at 260 ft and 450 ft below the surface. As these deformations were less than the open annular space between production and intermediate casing, no deformation was predicted in the uncemented production casing.

Both measurements and model predictions in this case showed no casing deformation occurring in the uncemented production casing. This suggests that with typical Pittsburgh Seam overburden geology under medium cover, longwall-induced casing deformations in the intermediate casing is less than the open annular space of 3.335 in between intermediate and production casing, and that uncemented production casing can uncouple longwall-induced stresses and deformations. This mine-by case also shows that if casings are fully cemented, casing deformations would occur in the production casing.

A MINE-BY CASE UNDER 1,030-FT DEPTH OF COVER

This case consists of eight shale gas wells located in the chain pillars between two adjacent longwall panels in the Pittsburgh coal seam under an overburden depth of 1,030 ft. Figure 6 shows the longwall panel layout and shale gas well locations. One gas well was surveyed with a 56-arm caliper. The setback distance of the surveyed gas well was 108 ft to the first panel gob and 96 ft to the second panel gob. The longwall panels were developed with a three-entry system with a total chain pillar width of 220 ft center-to-center. The longwall panels were 1,573-ft wide with a mining height of 7 ft.

The overburden geology at the gas well site was determined by correlating the core logs with the gamma logs. The core logs were from the nearest corehole about 1,000 ft away on the eastern side of the well pad, and the gamma logs were from a gas well about 500 ft from the well pad. The locations of the corehole and the gamma-logged gas well are shown in Figure 6. According to the core logs, the overburden in the area consisted of shale, sandyshale, claystone, limestone, and sandstone. Figure 7 shows the gamma logs and weak interface locations at claystone layers and coal seams. The weak claystone layers were identified from the gamma logs, and the coal seams were identified from the core logs. Four main coal seams were present above the Pittsburgh coal seam. The weak interfaces represented the weak beddings between a weak layer and a

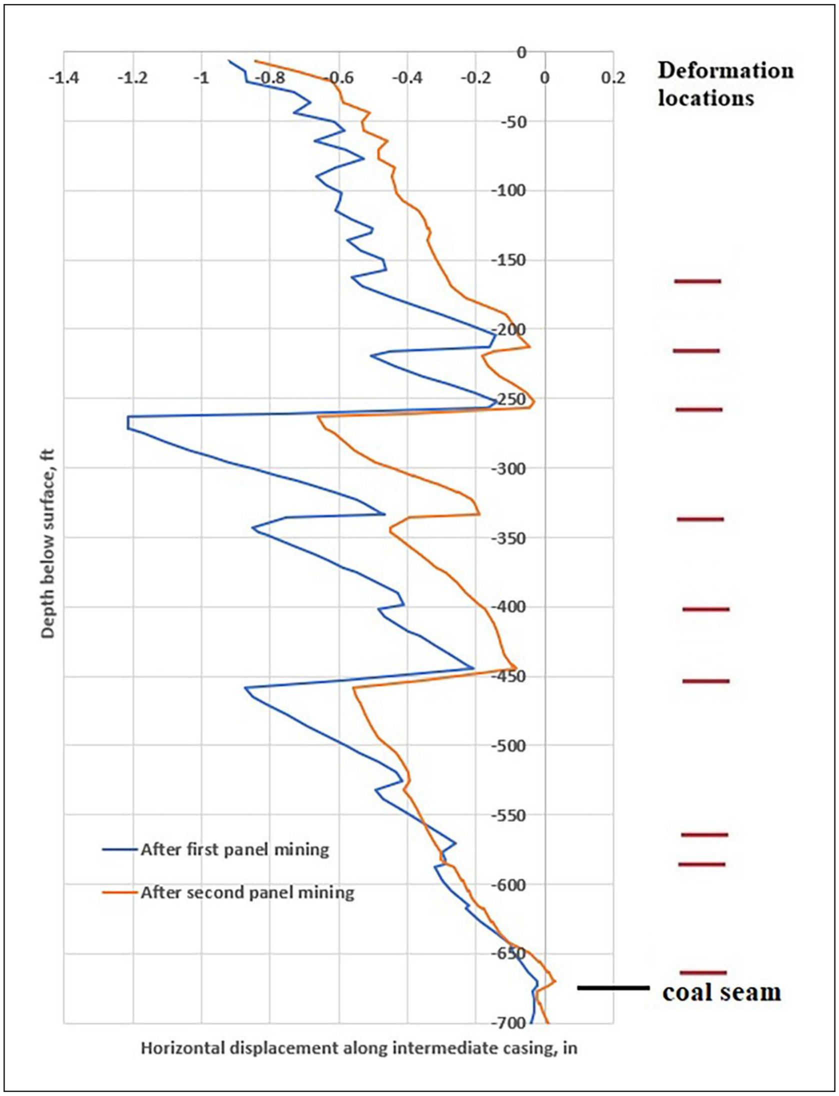


Figure 5. Predicted horizontal displacement along intermediate casing after second panel mining

Table 1. Predicted deformations in the intermediate casing after first and second panel mining

Depth below surface, ft	Predicted relative horizontal displacement after first panel mining, in	Predicted relative horizontal displacement after second panel mining, in	Predicted casing diameter change after first panel mining, in	Predicted casing diameter change after second panel mining, in
158	0.1	0	0.14	0.28
211	0.4	0.18	0.56	0.81
260	1.05	0.5	1.47	2.2
343	0.4	0.1	0.56	0.7
400	0.08	0.09	0.112	0.24
450	0.7	0.2	0.98	1.26
530	0.06	0.05	0.084	0.15
570	0.05	0.05	0.07	0.14
670	0	0.05	0	0.07

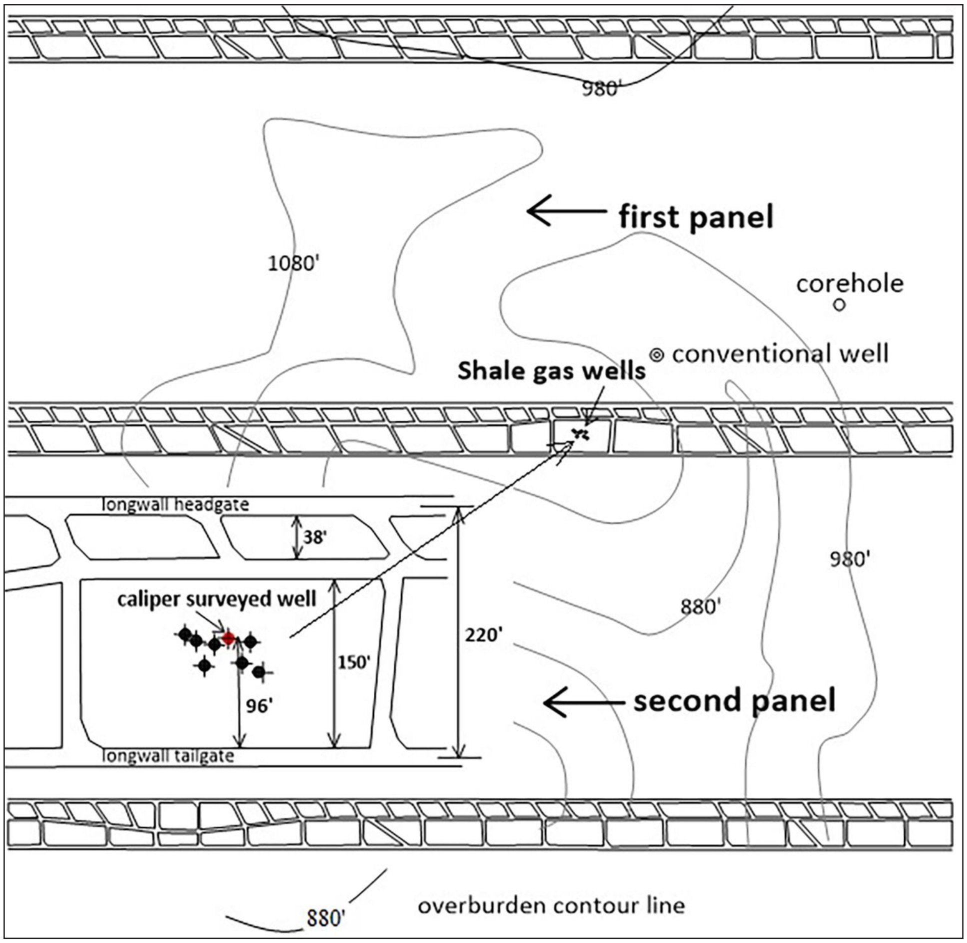


Figure 6. Longwall panel layout and locations of shale gas wells in chain pillars under an overburden depth of 1,030 ft

relatively strong massive stratum and were the potential locations where casing deformations could occur.

The gas wells were constructed with three casings all fully cemented through the Pittsburgh coal seam. The surface casing was fully cemented from the surface to a 1,424-ft depth, and the intermediate casing was fully cemented from the surface to a 3,447-ft depth. The production casing was pulled out before first panel mining.

The intermediate casing deformations were measured by a 56-arm caliper after first and second panel mining. The caliper survey measures the inside casing diameter and gives the location and magnitude of casing diameter changes. Figure 8 shows the measured minimum casing inside diameters along the intermediate casing after first and second panel mining. With the nominal casing inside diameter for the 9-5/8-in 40# casing being 8.83 in., the casing diameters are reduced at the deformation locations. Casing deformations were detected at 10 locations below the surface. A maximum casing deformation of 0.5 in. was detected at 603-ft depth after first panel mining, and this deformation increased to 0.59 in. after second panel mining. The casing deformations after second panel mining occurred at the same locations as those after first panel mining but increased slightly at the major deformation locations. The casing deformation locations are compared with the overburden geology at the gas well pad in Figure 7. By comparison, it is apparent that all the casing deformations occurred at the weak claystone or coal interfaces.

A site-specific FLAC3D model was set up to predict casing deformations as each longwall panel mined by the gas well pad, and the predicted casing deformations were then compared with the measurements. The model predicted horizontal displacement along the intermediate casing as shown in Figure 9. Casing deformations were predicted at interface locations with relative horizontal displacement. Table 2 shows a summary of the predicted and measured casing deformations. Both measurements and predictions show that casing deformations are small under 1,030-ft depth of cover. It should be noted that no deformation was predicted and measured in the intermediate casing at the coal seam horizon even though the coal pillar was subjected to high abutment pressure under deep cover.

To investigate potential casing deformations at the coal seam level, the stress and strain in the intermediate casing at the coal seam were obtained from the model. Figure 10 shows the stress and strain developed in the intermediate casing at the coal seam as each longwall panel is mined. The figure shows that longwall-induced

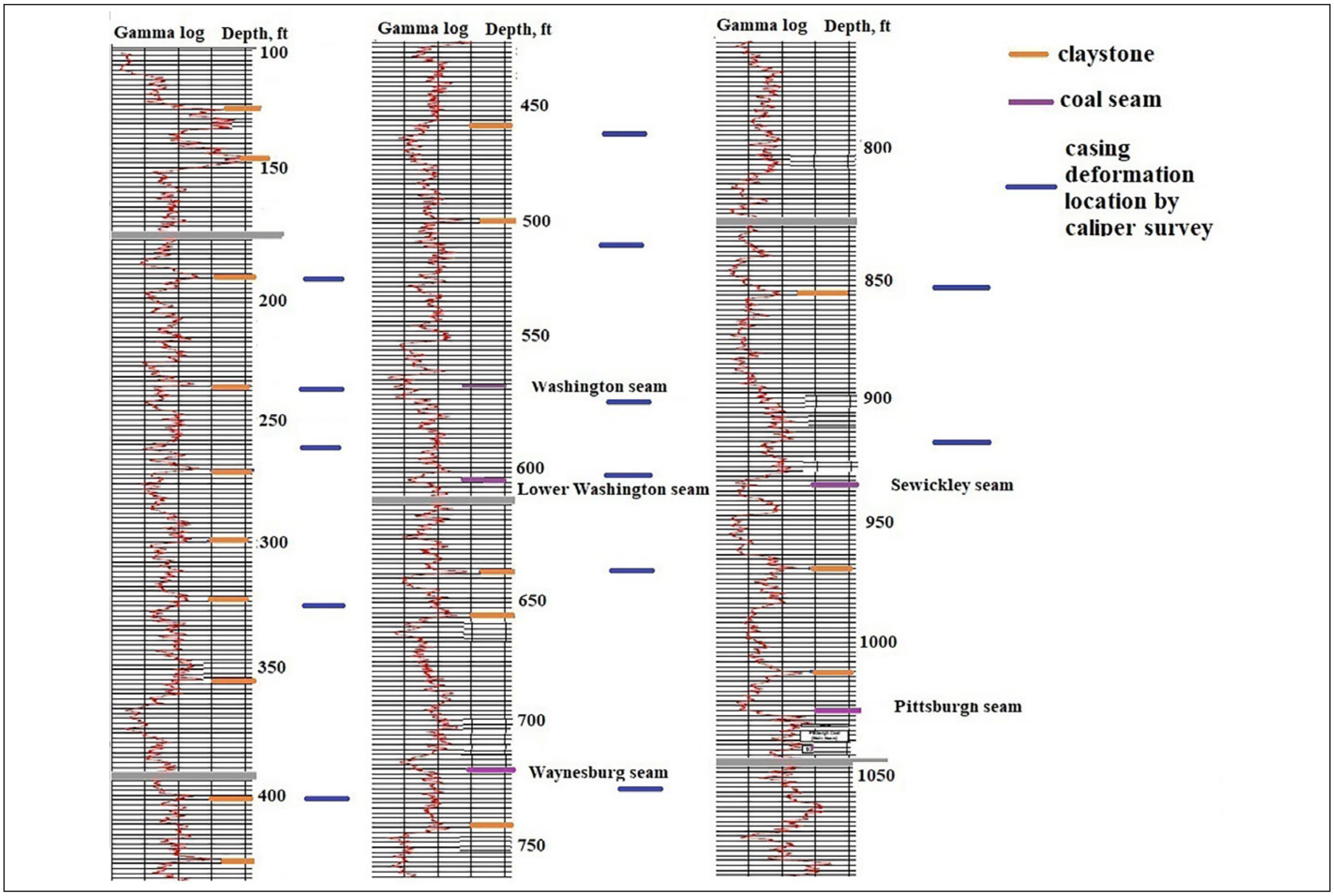


Figure 7. Gamma logs and weak interface locations

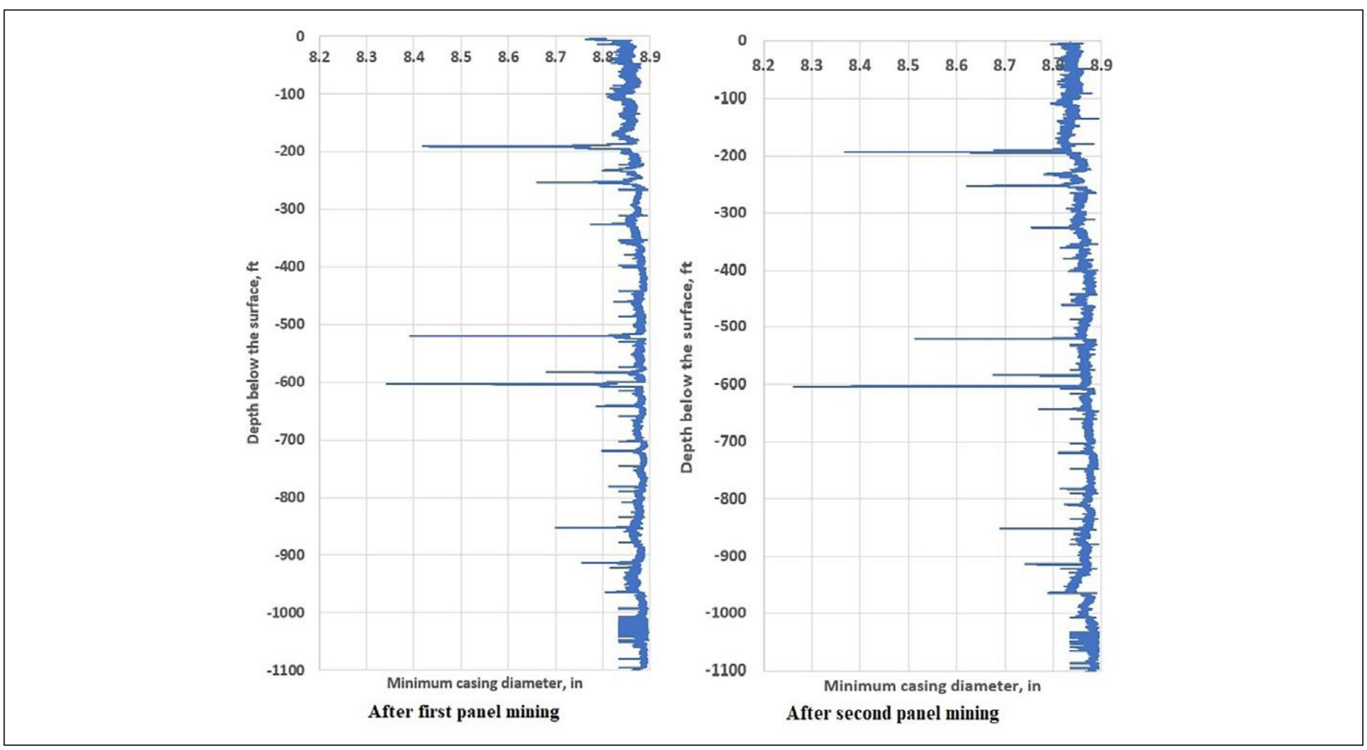


Figure 8. The 56-arm caliper survey results along the intermediate casing after first and second panel mining

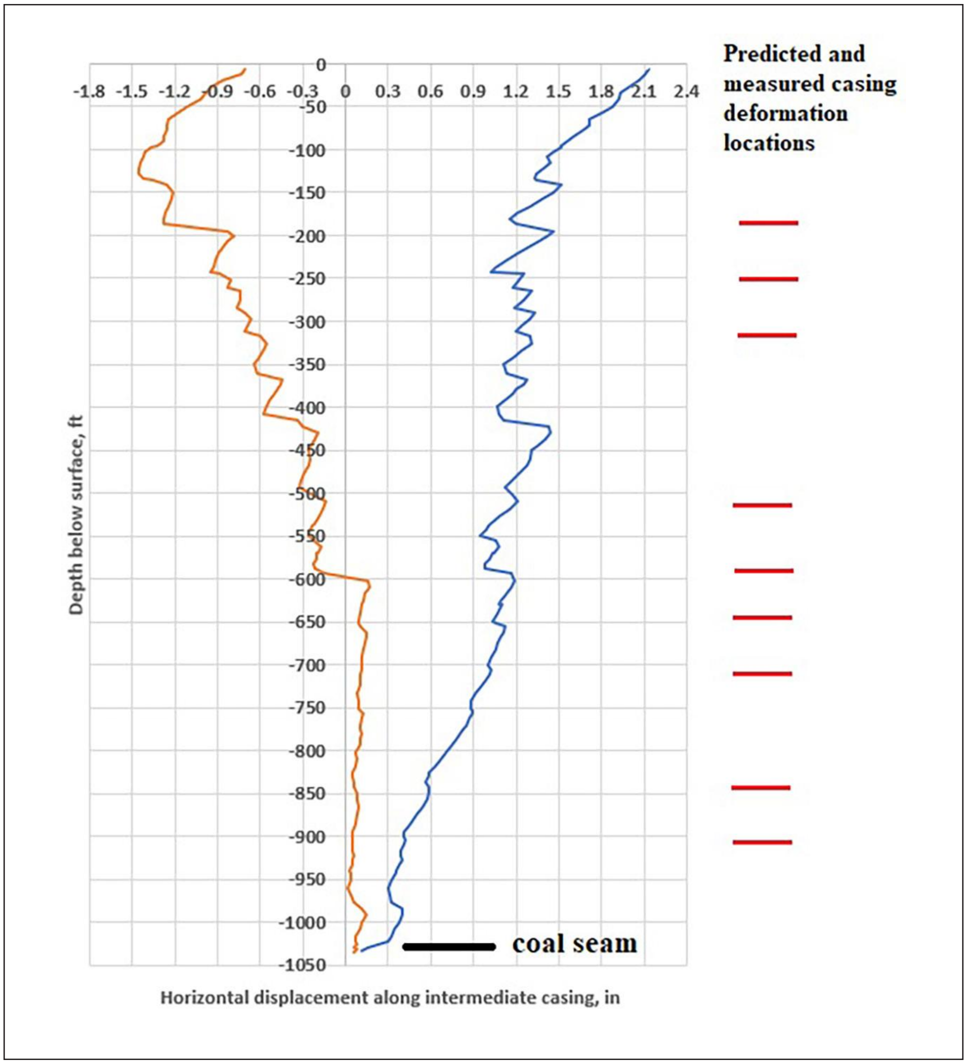


Figure 9. Predicted horizontal displacement along intermediate casing after first and second panel mining

Table 2. Predicted and measured intermediate casing deformations after first and second panel mining

Depth below surface, ft	First Panel Mining			Second Panel Mining		
	Predicted relative horizontal displacement, in	Predicted casing diameter reduction, in	Measured casing diameter reduction, in	Predicted incremental relative horizontal displacement, in	Predicted casing diameter reduction, in	Measured casing diameter reduction, in
191	0.3	0.42	0.43	0.25	0.77	0.49
253	0.25	0.35	0.2	0.1	0.49	0.23
325	0.1	0.14	0.07	0	0.14	0.1
519	0.08	0.11	0.45	0.2	0.39	0.35
582	0	0.00	0.16	0	0.16	0.16
603	0.21	0.29	0.5	0.2	0.57	0.59
640	0.1	0.14	0.05	0	0.14	0.10
720	0.02	0.03	0.04	0	0.03	0.04
850	0.03	0.04	0.14	0	0.04	0.15
914	0.02	0.03	0.09	0	0.03	0.09

von Mises stress in the intermediate casing at the coal seam is less than its yield strength after first panel mining. After second panel mining, the casing yields with small plastic strain developed in the casing. Since the stress in the casing has not reached its ultimate strength, no detectable casing deformation is anticipated. This mine-by case suggests that for gas wells in longwall chain pillars under 1,030-ft overburden depth, casing deformations are small and may not occur at the coal seam horizon because the longwall-induced stress level in the casing is less than its ultimate strength.

A MINE-BY CASE UNDER 1,307-FT DEPTH OF COVER

This is a newly mined-by case which consists of five shale gas wells located in the chain pillars between two adjacent longwall panels under a deep cover of 1,307 ft. Figure 11 shows the longwall panel layout and shale gas well locations. All the gas wells had been plugged except the 4H well that was left for a caliper survey. The setback distance of the 4H well was 152 ft to the first panel gob and 68 ft to the second panel gob at the Pittsburgh Seam horizon.

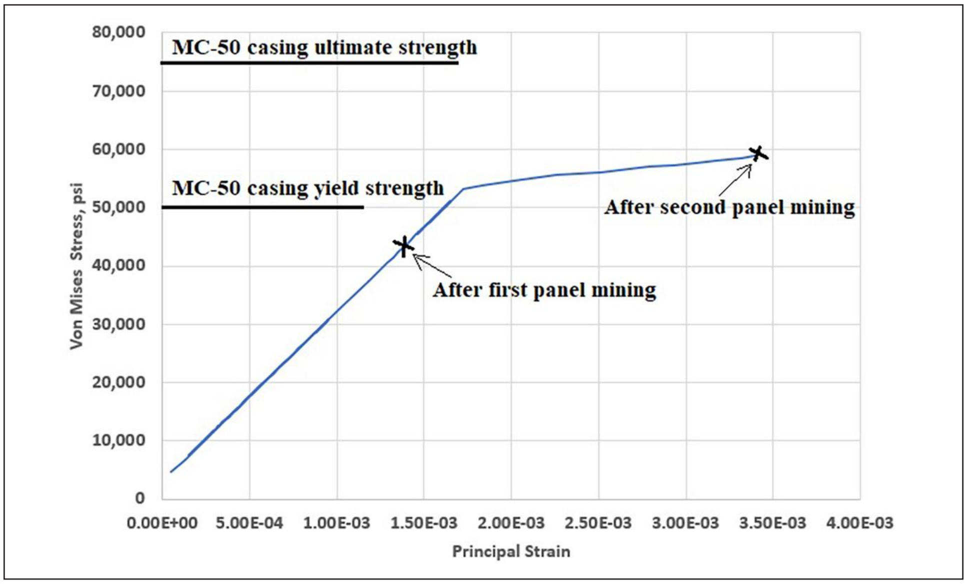


Figure 10. Predicted stress and strain developed in the intermediate casing at the coal seam after first and second panel mining.

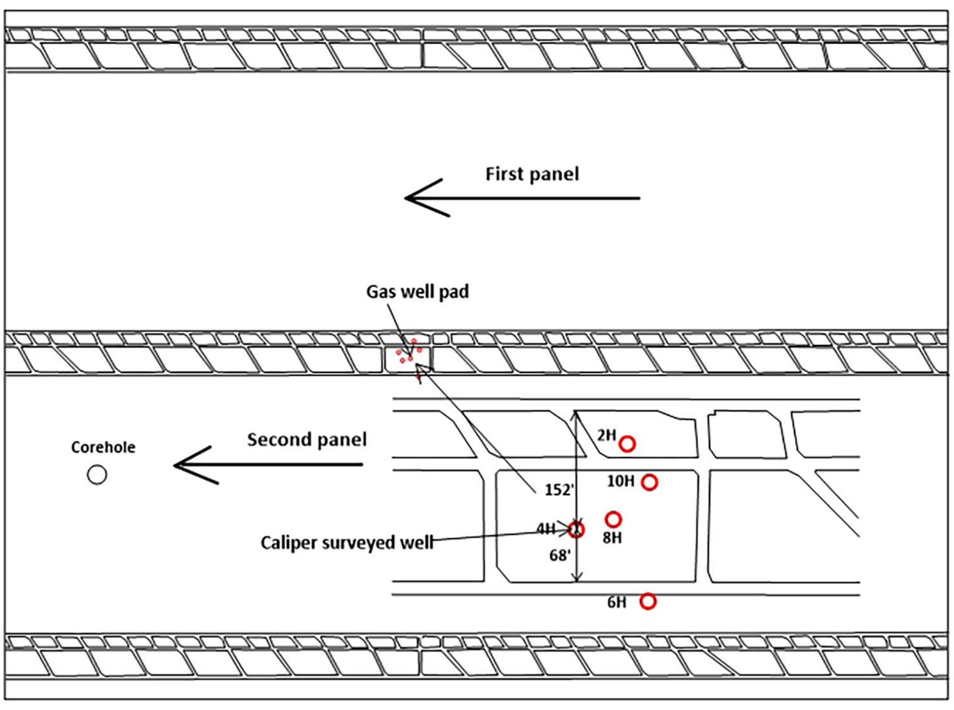


Figure 11. Longwall panel layout and locations of shale gas wells in chain pillars under an overburden depth of 1,307 ft.

The first panel mine-by was in the spring of 2022, and second panel mine-by was in November 2023.

The 4H well was constructed with three casings passing through the Pittsburgh coal seam. All three casings were fully cemented to the surface. The production casing of the 4H well was surveyed with a 40-arm caliper after first panel mining and with a 24-arm caliper after second panel mining.

The 40-arm caliper survey after first panel mining detected casing deformations at three locations with the maximum deformation of 0.52 in. occurring at a 642-ft depth. After second panel mining, the 24-arm caliper survey detected casing deformations at 9 locations. Figure 12 shows the 24-arm caliper survey results along the production casing after second panel mining. The chart shows that the deformation at 642-ft depth increased from 0.52 in. to 0.8 in., and other deformations are small, less than 0.2 in. A large deformation was also detected at a 1,284-ft depth, but the deformation was so large that the caliper could not go through. A downhole camera was also used to view the deformations in the casing. Figure 13 shows the snapshots of casing deformation taken from the downhole video. The picture at the top (a) shows the casing at 642-ft depth with a 0.8-in deformation caused by horizontal shear displacement. The picture at the bottom (b) shows the casing deformation at a 1,284-ft depth. The casing at this location deformed so large that it was almost closed towards the center. The cause of this deformation was further investigated with FLAC3D modeling.

A site-specific FLAC3D model was used to predict casing deformations. Figure 14 shows the predicted horizontal displacement along the production casing after first and second panel mining. From the horizontal displacement curves, casing deformations were predicted at 9 locations with relative horizontal displacement. Predicted and measured production casing deformations are summarized in Table 3. All the casing deformations are small except at two locations. Over the coal seam horizon, the maximum deformation occurred at 642-ft depth. At this depth, the predicted deformation was 0.6 in, and the measured deformation was 0.52 in. after first panel mining. After second panel mining, the predicted deformation was 0.7 in., and measured deformation was 0.8 in. At the coal seam horizon, a large casing deformation occurred at the 1,284-ft depth, 23 ft above the coal seam, but this deformation was not originally predicted from the horizontal displacement along the production casing.

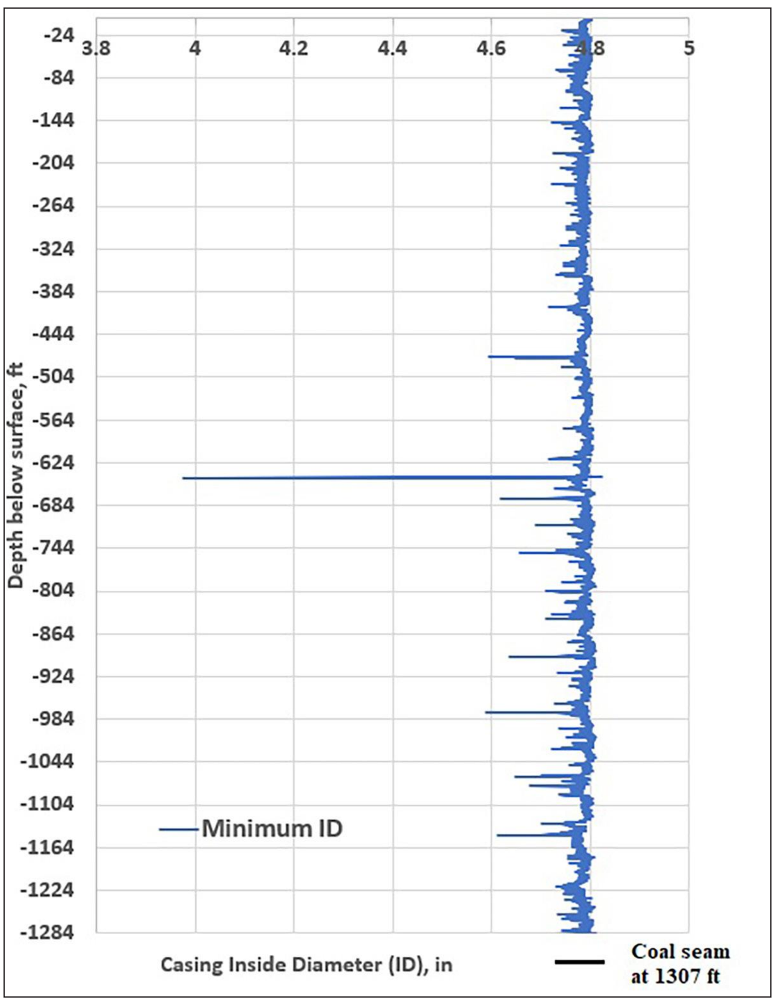
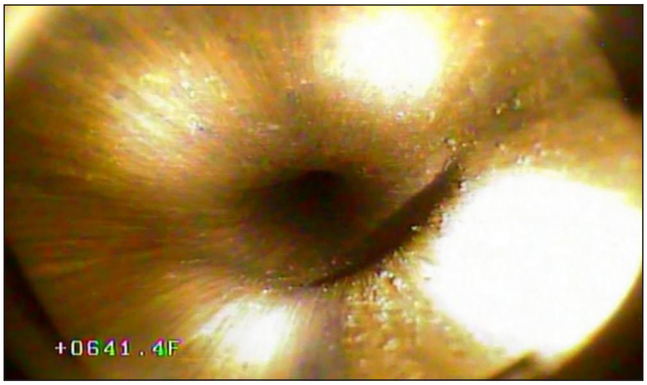
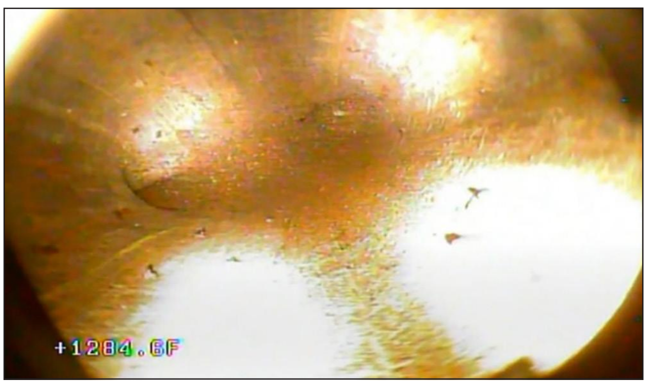


Figure 12. The 24-arm caliper survey results along the production casing after second panel mining

The cause of the large deformation at 1,284-ft depth was investigated using the site-specific FLAC3D model. The overburden geology used in the model was originally based on the core logs from the closest corehole to the gas well pad. After second panel mining, an on-site gamma log was run through the production casing. The on-site gamma log showed that a claystone layer was present at the 1,260–1,280-ft horizon. The FLAC3D model was then updated with a weak claystone layer 23 ft above the coal seam.



Casing deformation at a 642-ft depth.



Casing deformation at a 1,284-ft depth.

Figure 13. Pictures of casing deformations taken from the downhole video

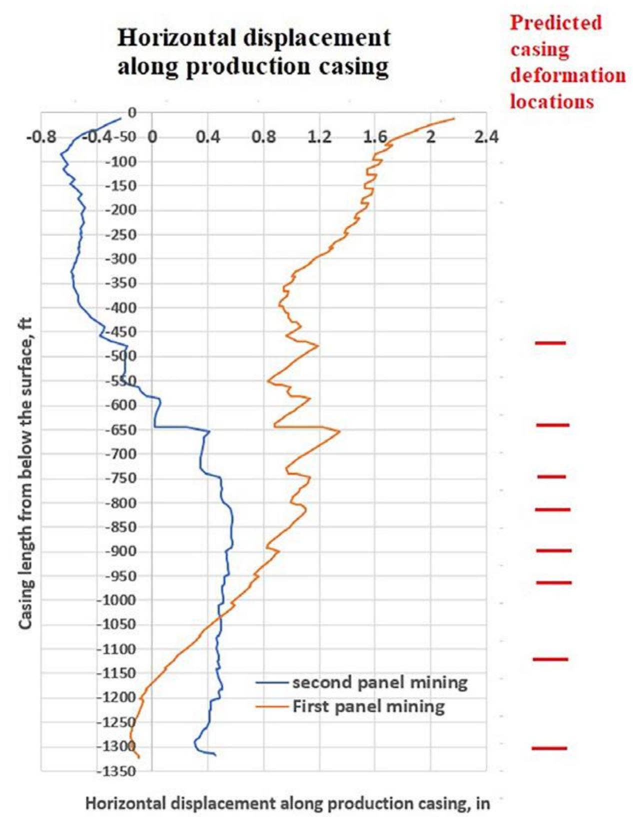


Figure 14. Predicted horizontal displacement along production casing after first and second panel mining

Table 3. Predicted and measured production casing deformations after first and second panel mining

	First panel mining		Second panel mining		
Distance below the surface along the production casing, ft	Predicted casing diameter reduction, in	Measured casing diameter reduction, in	Predicted accumulated casing diameter reduction, in	Predicted total casing diameter reduction, in	Measured casing diameter reduction, in
475	0.2	0.06	0	0.2	0.2
642	**0.6**	**0.52**	**0.1**	**0.7**	**0.8**
675					0.2
750	0.2		0	0.2	0.1
800	0.05		0.05	0.1	0.1
890	0.05		0.05	0.1	0.1
975	0.02		0.03	0.05	0.2
1150	0.01		0	0.01	0.2
1284	0.02		0.02	0.04	**large deformation**
1310	0.28	0.21			

Denser zones around the casing at the deformation horizon were used so that the stresses and strains in the casing could be predicted more accurately.

The model predicted longwall-induced stress and strain in the production casing at the deformation location at a 1,284-ft depth. Figure 15 shows the Von Mises stress and accumulated strain developed in the production casing. The amount of Von Mises stress exceeds the rated yield strength of the P-110 production casing and reaches its ultimate strength of 125,000 psi. Once the stress level reaches the ultimate strength, large plastic strain could develop in the production casing potentially resulting in a local plastic buckling.

The potential occurrence of local plastic buckling can be explained with the stress-strain curve of the P-110 casing as shown in Figure 16. This is a typical test curve for the P-110 casing under compression. When the stress level is less than the rated yield strength of 110,000 psi, the casing behaves elastically. When the stress level exceeds the yield strength but is under the ultimate strength, the casing is subjected to a strain-hardening process in which small plastic strain develops. Once the stress level passes the ultimate strength, the stress-strain curve becomes leveled and local large plastic strain could develop, which could result in a local buckling failure. In this case, the presence of weak claystone induced high stress in the production casing, and the stress level exceeded the ultimate strength of the P-110 casing. It is very likely that the large casing deformation was caused by the large plastic strain induced at a 1,284-ft depth in the production casing after the stress level has exceeded the casing ultimate strength.

EFFECT OF OVERBURDEN DEPTH ON LONGWALL-INDUCED CASING DEFORMATIONS

Casing deformations above the coal seam horizon are largely caused by relative horizontal displacements along weak interfaces. As observed by the multi-finger caliper surveys and predicted

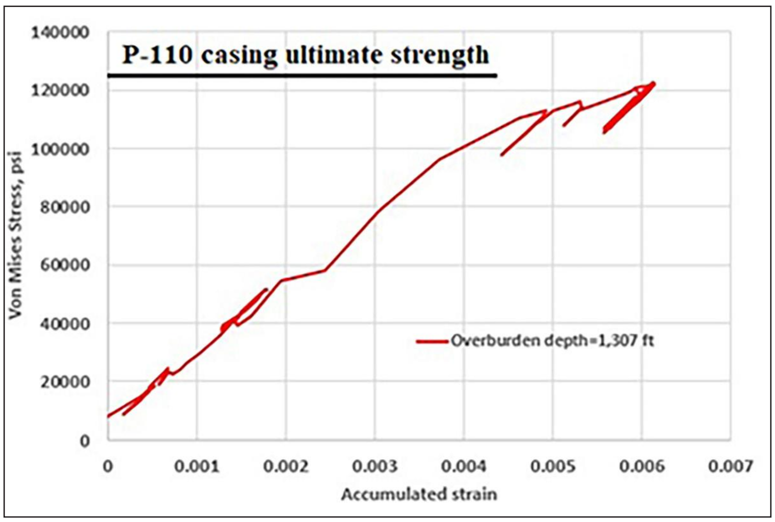


Figure 15. Predicted stress and strain developed in the production casing at the claystone location with first and second panel mining

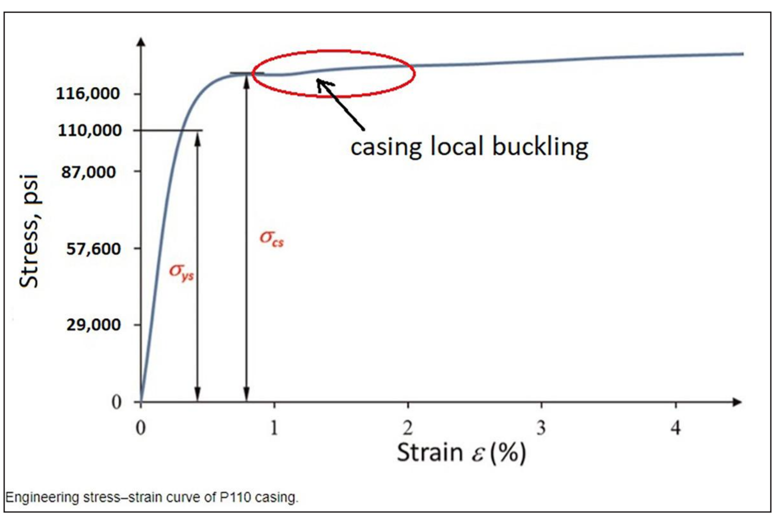


Figure 16. Stress and strain relationship for P-110 production casing

by FLAC3D modeling in these mine-by case studies, relative horizontal displacements would induce casing deformations in the form of shear displacement and casing diameter reduction at the interface locations. The amount of relative horizontal displacement mainly depends on overburden depth, massive bed thickness, interface friction, and gas well setback distance from the longwall gob. Previous NIOSH research has shown that under shallow and medium cover, the longwall-induced relative horizontal displacements are generally larger than those under deep cover (Su 2016, 2017; Scovazzo 2018; Zhang and Su 2021; Zhang et al. 2022). The effect of overburden depth on the casing deformation level can quantitatively be demonstrated by the caliper-surveyed measurements and modeling predictions of several gas wells that are recently mined past by longwall mining.

Figure 17 shows measured maximum casing deformations above the mining horizon from recent mine-by cases of gas wells in longwall chain pillars under different overburden depths. Three measurements are from the mine-by cases in this study, and three are from other case studies with shale gas wells in chain pillars (Zhang et al. 2022, and 2023b; Zhang and Su 2021). The deformation horizon at depth below the surface is also labeled at each data point. The measured data show a general trend that the casing deformation level reduces with the increase of overburden depth. Under shallow and medium cover less than 800 ft, the maximum deformation level ranges between 2 in. and 3.5 in. Under deep cover greater than 800 ft, the maximum deformation level is less than 1 in. The larger casing deformations under shallow cover are often associated with the location of the gas well close to a stream valley and smaller casing deformation under deep cover are due to high abutment pressure and high frictional resistance along weak claystone interfaces. The maximum casing deformation levels as shown in the recent mine-by cases imply that a cementing alternative, by leaving production casing uncemented, can eliminate production casing deformations that could potentially occur in the overburden over the coal seam horizon.

Under deep cover, casing deformations could potentially occur at the coal seam horizon, most likely in the roof or floor near the coal seam. Casing deformation at the coal seam horizon is mainly caused by high abutment pressure and the presence of weak claystone above or below the coal seam. The predicted pillar pressure at the gas well in longwall chain pillars for the six recent mine-by cases is shown in Figure 18. It shows that pillar pressure at the gas well increases above the overburden pressure after first and second panel mining. The longwall-induced pillar pressure increase at the gas well is generally less than about 500–600 psi after first panel mining because the gas well is subjected to abutment pressure on one site. With second panel mining, the gas well is subjected to abutment pressure on two sides, and the pillar pressure increases significantly with overburden depth. At a 1,300-ft overburden depth, the longwall-induced pillar pressure increase is over 1,500 psi and the total pillar pressure is over 3,000 psi. A high longwall-induced pillar pressure means high stress induced in the casing due to compressive pillar deformation transferred to the casing. A high total pillar pressure at the gas well also means potential

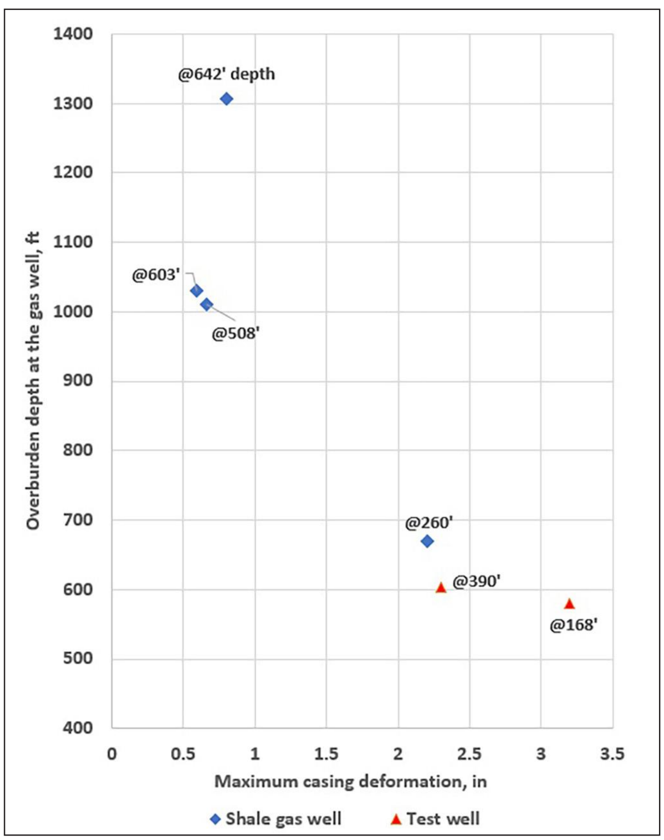


Figure 17. Measured maximum casing deformations above the mining horizon from six recent mine-by cases of gas wells in longwall chain pillars under different overburden depths

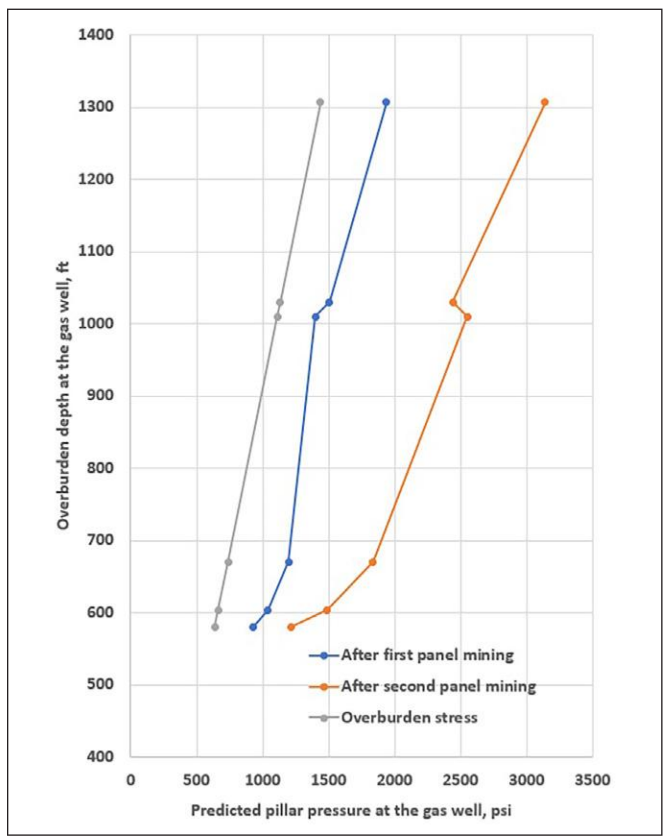


Figure 18. Predicted pillar pressure at the gas well in longwall chain pillars under different overburden depths

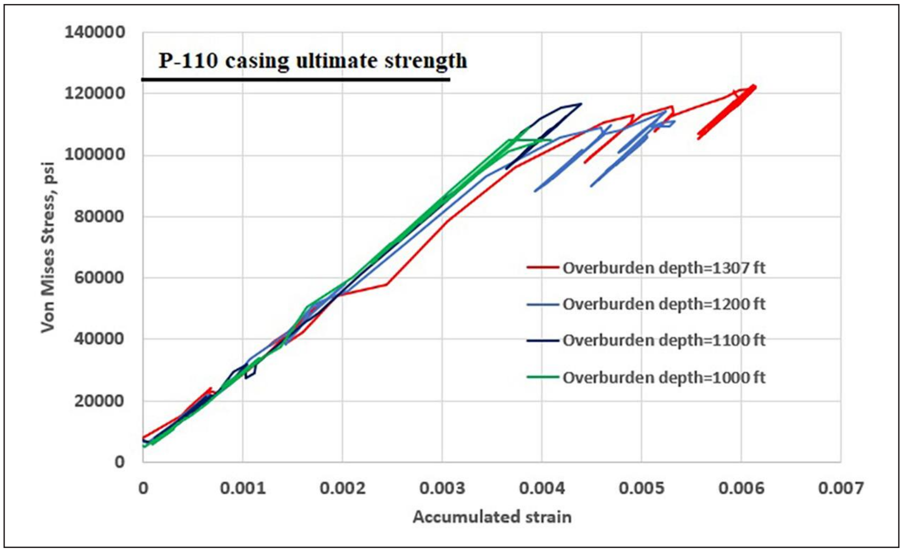


Figure 19. Stress and strain developed in the production casing at the claystone location with first and second panel mining under different overburden depths

failure of a claystone layer present in the roof or floor, resulting in additional deformation transferred to the casing.

If a weak claystone layer is present in the roof or floor of the Pittsburgh coal seam, casing deformation at the coal seam horizon is more likely to be at the claystone location than at the coal seam. The FLAC3D model set up for the third mine-by case in this study was used to investigate how overburden depth affects longwall-induced stress and casing deformation at the claystone layer 26 ft above the coal seam. Figure 19 shows the predicted stress-strain curves of the production casing at the deformation location under different overburden depths. The figure shows that under less than 1,000 ft of overburden depth, the longwall-induced stress in the production is less than P-110 yield strength, and only elastic strain is developed in the production casing. Under 1,000–1,200 ft of overburden depth, the casing experiences strain hardening with small plastic strain developing in the casing. When overburden depth is greater than 1,200 ft, significant large plastic strain develops in the production casing. Therefore, based on the modeling results, a production casing, if fully cemented, could develop large plastic deformation at a weak claystone layer in the coal seam horizon if the overburden depth at the gas well is greater than 1,200 ft.

CONCLUSIONS

This study presented three mine-by cases with shale gas wells in the chain pillars between two adjacent longwall panels under different overburden depths. Casing deformations were measured with multi-finger caliper surveys and predicted with FLAC3D modeling. The effect of overburden depth on casing deformation level was analyzed using the measured deformations from six recent mine-by cases. The potential occurrence of a large casing deformation at the coal seam horizon under deep cover was investigated using the site-specific FLAC3D model. Based on the site-specific findings at each overburden depth, the main conclusions from this study are drawn as follows:

- Casing deformations above the coal seam horizon are caused by relative horizontal displacements along weak interfaces. The level of casing deformation reduces with an increase of overburden depth at the gas well.
- Recent mine-by experiences show that the maximum casing deformation level is within 2–3.5 in. under shallow and medium cover and is less than 1 in. under deep cover. A cementing alternative by leaving production casing uncemented is an effective means to eliminate production casing deformations.
- Large plastic casing deformation could occur in the fully cemented production casing at the coal seam horizon under deep cover if longwall-induced stress in the production casing exceeds the ultimate strength of the casing.
- With fully cemented production casing, large plastic casing deformation could occur at a weak claystone layer near the coal seam horizon if overburden depth at the gas well is greater than 1,200 ft.

LIMITATIONS

This study represents three site-specific case studies differentiated by overburden depth. More data at similar cover gas well sites are needed for definitive conclusions to ensure the findings from these studies are repeatable. FLAC3D simulations are purely modeling predictions, within the variance of the variables and parameters used, and need to be validated by actual field data. Similar studies collecting similar data to expand the database of knowledge would need to be conducted to enhance the data population and make the results statistically valid.

DISCLAIMER

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH.

REFERENCES

ITASCA Consulting Group, Inc. 2017. FLAC-3D, Version 6.0, User's Guide.

Scovazzo, V. 2018. Mining effects on gas and oil wells pad NV-35 field experiment field monitoring. In *Proceedings of the 37th International Conference on Ground Control in Mining*. Morgantown, WV: West Virginia University, pp. 30–43.

Su, D.W.H., Zhang, P., Dougherty, H., Van Dyke, M., Minoski, T., Schatzel, S., Gangrade, V., Watkins, E., Addis, J., and Hollerich, C. 2019. Longwall-induced subsurface deformations and permeability changes—Shale gas well casing integrity implication. In *Proceedings of the 38th International Conference on Ground Control in Mining*. Morgantown, WV: West Virginia University, pp. 49–59.

Su, D.W.H., Zhang, P., Van Dyke, M., and Minoski, T. 2018. Effects of longwall-induced subsurface deformations on shale gas well casing stability under deep covers. In *Proceedings of the 37th International Conference on Ground Control in Mining*. Morgantown, WV: West Virginia University, pp. 63–70.

Su, D.W.H. 2017. Effects of longwall-induced subsurface deformations on the mechanical integrity of shale gas wells drilled over a longwall abutment pillar. *2017 SME Annual Meeting*, Feb.19–22, 2017, Denver, CO. Preprint 17-051, pp. 1–6.

Su, D.W.H. 2016. Effects of longwall-induced stress and deformation on the stability and mechanical integrity of shale gas wells drilled through a longwall abutment pillar. In *Proceedings of the 35th International Conference on Ground Control in Mining*. Morgantown, West Virginia, pp. 119–125.

Tulu, I.B., Esterhuizen, G.S., Mohamed, K.M., Klemetti, T.M. 2017. Verification of a calibrated longwall model with field measurements. In *Proceedings of the 51st US Rock Mechanics/ Geomechanics Symposium*, 25–28 June 2017. San Francisco, California.

Zhang, P., Su, D., and Kim, B.H. 2023a. Effect of casing cementing alternative on shale gas well casing deformations induced by longwall mining. In *Proceedings of the 42nd International Conference on Ground Control in Mining*. Canonsburg, Pennsylvania, July 25–27, 2023.

Zhang, P., Su, D., Van Dyke, M., and Kim, B.H. 2023b, A case study of shale gas well casing deformation in longwall chain pillars under deep cover. *57th U.S. Rock Mechanics Geomechanics Symposium*, Atlanta, GA, June 26–28, 2023, pp.9.

Zhang, P., Su, D.H., Kim, B.H., and Midler, E., 2022, Comparison of Measured and Modeled Casing Deformations of a Test Well in a Longwall Abutment Pillar, 56th U.S. Rock Mechanics Geomechanics Symposium, Santa Fe, NM, June 2022, pp.9.

Zhang, P. and Su, D., 2021. FLAC3D modeling evaluation of the comprehensive NV-35 gas well pillar study. In *Proceedings of the 55th US Rock Mechanics/Geomechanics Symposium*, 20–23 June 2021. Scheduled for Houston, Texas, but replaced with virtual symposium.

Zhang, P., Dougherty, H., Su, D., and Trackemas, J. 2019. Influence of longwall mining on the stability of gas wells in chain pillars. In *Proceedings of the 38*th *International Conference on Ground Control in Mining*, Morgantown, West Virginia, pp. 38–48.

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