Load Transfer Distance Measurements at Two Mines in the Western U.S.

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ABSTRACT

Load transfer distance (LTD) is simple in concept and usually evident in underground coal mines. Many people in the mining industry recognize LTD as the distance from the panel to where the mine ribs and pillars show evidence of renewed spalling, floor heave, or other effects of increased weight due to longwall mining or pillaring. Barrier pillars, in particular, are designed to shield mains and other relatively permanent facilities from this loading. LTD is also important in determining the extent and degree to which mining increases the load on pillars and ribs in the gate roads. Generally, a long LTD reduces loads in gate roads, but may require larger barrier pillar widths to protect mains or adjacent panels from excessive loads. Therefore, a long LTD may make it easy or difficult to meet various objectives of mine layout design .- LTD reflects overburden geology in two ways: First, overburden that is weak and readily caves will limit both the amount and distance of load transfer. Second, stronger, stiffer, sandier, and more massive overburden increases both the amount and distance of load transfer. As such, LTD is central to coal mine layout design and calibration of numerical models that seek to anticipate these transfers of load during mining. However, the term does not have a consistent definition in the literature, and various instruments and observational techniques with varying sensitivities and thresholds have been used to indicate the onset of mining-induced stress increase and, subsequently, to determine an LTD. Consistency is important for meaningful comparison of ground response between mining sites and for accurate calibration of models.

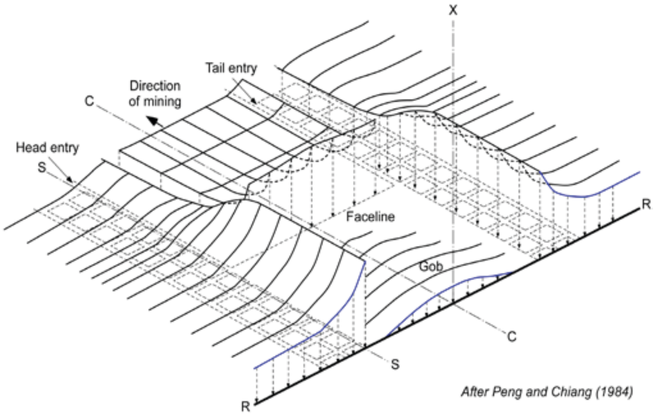
This paper adds to the body of observed and reported LTDs by presenting cases with relatively sandy and massive overburden at two western coal mines. These two cases include observation and measurement of LTD with multiple methods and provide insight into how distances reported relative to different criteria and instrumentation could be adjusted for comparison against a common base. This base is the criteria used by Peng and Chiang (1984) to determine their empirical equation. In one of these two cases, LTD was recently measured at a western U.S. coal mine (Mine A) to be approximately four times that calculated using the Peng and Chiang empirical equation. LTD measurements were examined using various instruments at Mine A and at adjacent Mine B. The measurements at Mine B showed that LTD was significantly greater than that calculated by the Peng and Chiang equation. Difficulties with BPC installation and fittings at Mine B permitted only ranges of LTD to be determined from some BPCs. Even so, the LTDs and ranges of LTDs determined were consistent with the LTDs determined at Mine A.

These new data points, obtained under relatively sandy overburden, complement a growing database of LTD observations taken by various means and referenced to various threshold criteria. An effort is made here to correct for these discrepancies on the basis of case study observations and measurements. The database is also reviewed for composition and the presence of massive overburden members where this was possible. The result is a new picture of LTD behavior where the relationship of LTD and depth varies relative to overburden geology, supplanting the view that a single equation is applicable in all cases. Preliminary relationships are proposed based on information available in the two cases presented here and on a body of reported cases in the literature. The challenges now are to refine methods for describing overburden geology relative to its influence on LTD and to improve methods for comparing observations and measurement of LTD made by various methods.

INTRODUCTION

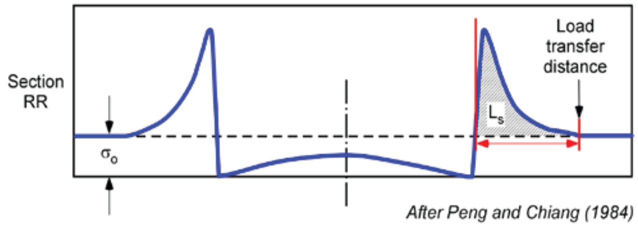
The term load transfer distance (LTD) has been used inconsistently in the literature, yet its precise definition is important for understanding changes caused by mining and the calibration of numerical models that are used to evaluate mine layout design. In the past, it was thought that LTD was a function of overburden depth only. However, an increasing body of evidence suggests that the geology of the overburden affects the amount of stress transferred to the abutment and how far that stress is transferred. Regardless, a consistent definition is needed to begin to understand what factors, such as geologic structure and depth of seam, cause LTD to differ from empirical equation calculations or an expected LTD at a mine site based on experience or previous measurements.

In this paper, the definition given by Peng and Chiang (1984) is used. This is partly because this definition is standard for the empirical methods of mine layout design—Analysis of Longwall Pillar Stability (ALPS) (Mark, 1987, 1992) and Analysis of Retreat Mining Pillar Stability (ARMPS) (Mark and Chase, 1997). This definition is also used as a calibration default for the displacement discontinuity code LaModel (Heasley, 2008 and 2010)—the maximum side distance from an extracted panel at which the stress increase resulting from panel mining is detected. Figure 1 shows the conceptualization by Peng and Chiang of the stress profile around a longwall panel that is mined. Figure 2 shows the stress profile in the vertical cross-section RR indicated in Figure 1. The LTD is shown in Figure 2. Peng and Chiang graphically show several measurements of LTD with borehole pressure cells (BPCs) and uniaxial vibrating wire stressmeters (VWS) and use these measurements to propose an empirical equation for LTD (Equation 1):



After Peng and Chiang (1984)

Figure 1. Conceptual model of the vertical stress near a longwall panel.



After Peng and Chiang (1984)

Figure 2. Vertical section through midpanel in Figure 1, showing a conceptual idea of vertical stress resulting from the mining of a longwall panel. Load transfer distance is indicated. σ0 = prepanel vertical stress on seam, and Ls = area under curve in shaded region is the amount of approximately half of the overpanel strata weight that is transferred to the abutment..

$$LTD = 9.3\sqrt{H} \quad (1)$$

where LTD is load transfer distance in ft

H is the height of the overburden in ft

The fit of Equation 1 to their measurements is shown in Figure 3.

The Peng and Chiang definition of LTD implies some standard for detecting it. However, they provided no description of the measurement threshold used to determine LTD. Larson and Whyatt (2012) examined the sensitivity of detecting the initial increase of mining-induced stress ahead of the face and chose a threshold increase of 138 kPa (20 psi) for BPCs, stating that this threshold was easily detectable with their sensors and dataloggers. The sensitivity of sensors, recorders, and other reading equipment used by Peng and Chiang was likely to be within that threshold.

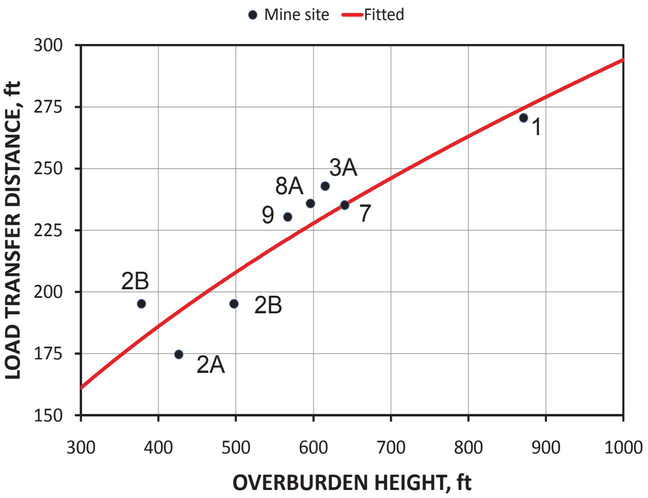


Figure 3. Measured load transfer distance versus seam depth for several cases in the eastern United States. A fitted line resulted in the empirical equation for load transfer distance. After Peng and Chiang (1984).

Abel (1988) reported 55 measurements of LTD gathered from the literature and proposed a parabolic equation that fit the data reasonably well. He listed 17 sources, and the authors have been able to examine 14 of them. Limited information was obtained on the missing three sources (Abel, 2015). Within these 17 sources, no consistent standard for determining LTD was used, and all measurements were made ahead of the face instead of to the side of the panel. Several different methods were used to determine the influence of mining-induced stress as follows:

- observations of roof cleat deterioration (The North of England Safety in Mines Research Committee, 1948–1949)
- BPCs (Alves, 1977; Stewart, 1977; Martin and Hargraves, 1972)
- vibrating wire stressmeters (VWSs) (Thomas, 1964; Wade and Conroy, 1980; Scotese, 1984; Chugh, et al., 1984; Lama, et al., 1984; Newman, 1985)
- entry convergence meters (Alves, 1977; Frost and Zorychta, 1963; Scotese, 1984; Lama, et al., 1984; Martin and Hargraves, 1972; Briggs and Ferguson, 1932-1933)
- a crib instrumented with a flatjack (Wilson and Rao, 1982)
- a packwall dynatometer (Phillips and Jones, 1941-42)

Seymour, et al. (1998) used vibrating wire biaxial stressmeters installed in a panel and pillars in crosspanel entries at the Foidel Creek Mine under 396.2 m (1300 ft) of overburden. They sensed an increase of stress with an instrument located in a crosspanel pillar when the face was 243.8 m (800 ft) away. Similarly, Zahl, et al. (2000) installed biaxial stressmeters perpendicular to seam in the roof of a headgate entry at the Willow Creek Mine using an innovative technique to encapsulate the instrument in grout. The seam depth was 853.4 m (2800 ft). One of the sensors detected an increase of stress when the face was 518.2 m (1700 ft) away. Although this was not vertical stress, it is believed that an increase of horizontal stress and vertical stress both were related to mining-induced stress.

Using the threshold of a 138 kPa (20 psi) increase in raw BPC pressure, Larson and Whyatt (2012) detected the initial mining-induced stress in the gate road areas ahead of the face at a coal mine in the western U.S., referred to herein as Mine A. Using a model, they determined an equivalent LTD on the side of the panel. Larson, et al. (NIOSH, forthcoming-a) performed a technical audit of face positions and updated the distance ahead of the face at which mining-induced abutment stress was detected. Larson, et al. (NIOSH, forthcoming-b) then updated the equivalent LTD to be 535.2 m (1756 ft), a factor of 3.98 above that calculated with Equation 1.

Other long LTDs have been reported. Goodrich, et al. (1999) reports the influence of stress from mining a panel by observing deteriorating ground conditions in the next gate roads at the Deer Creek Mine in Utah. These gate roads were 229 m (750 ft) away from the mined panel. It was estimated through numerical models that the stress at this location was 13% above the pre-panel stress. Xuan, Xu, and Zhu (2014) reported an LTD at the Haizi Coal Mine in China that was 1.41 times of that calculated by Equation 1 for that site. In this case, there was a massive igneous sill in the overburden. They calculated stress on the seam with a numerical model and used a threshold increase of 5% vertical stress above the pre-panel vertical stress to determine LTD. In both of these cases, the threshold for the reported distances was not nearly as sensitive as the threshold of the 138 kPa (20 psi) increase in raw BPC pressure used by Larson and Whyatt (2012).

In this paper, the success and sensitivity of various methods of determining the distance ahead of the face of the initial mining-induced abutment stress are examined. An equivalent LTD determined according to the Peng and Chiang (1984) definition is reported. This is done using measurements at the former site, Mine A, and measurements of various kinds along gate road entries in a second mine, Mine B.

OBJECTIVE

The purposes of this paper are as follows:

- examine LTD measurements determined using various instruments at two mines in the western U.S.
- evaluate the effectiveness and sensitivity of using standing supports and entry closure throughout Mine B and, to a lesser extent, in Mine A to measure LTD
- adjust LTDs reported in the literature to an approximately equivalent basis and offer how results vary with depth and overburden geology

TECHNIQUES FOR MEASURING LOAD TRANSFER DISTANCE

Measurements of the initial mining-induced stress and determination of equivalent LTD were performed at Mine A, but instruments were mostly concentrated in a specific area of the headgate entries of the first panel of a new mining district (NIOSH, forthcoming-a, forthcoming-b). At Mine B, the instruments were placed in several locations in or near the gate roads of a panel. The reason for this placement was to evaluate LTD variation by location. However, several problems were encountered that made the determination of LTD less certain, as described below. Even so, the data were taken and studied to determine LTD wherever possible.

Roof lithology was similar, with some minor differences: At Mine B, in the area of the study, the immediate roof is coal for 1.0 to 1.2 m (3 to 4 ft), followed by carbonaceous mudstone and mudstone for the first 4.8 to 6.1 m (16 to 20 ft). Above that, the strata becomes more sandy and competent. At Mine A, the roof is more sandy in general. The immediate stratum is a mudstone for about 1.0 m (3 ft). Above that, it is more sandy and competent.

BOREHOLE PRESSURE CELLS

At Mine A, the average LTD determined at 686.9 m (2254 ft) of overburden height was 535.2 m (1756 ft) (NIOSH, forthcoming-b). First arrival of mining-induced abutment stress at each instrument was determined using a threshold of 138 kPa (20 psi) cell pressure increase. This threshold was judged to be approximately equivalent to what Peng and Chiang (1984) likely used in their measurements. The distance to the face was then converted to an equivalent side abutment distance using numerical modeling techniques. Details of these determinations can be found elsewhere (NIOSH, forthcoming-a, forthcoming-b; Larson and Whyatt, 2012), but a brief description is found below.

At Mine B, challenges were encountered in obtaining quality installations with BPCs because of lack of utilities and initial hydraulic leaks that had to be stopped with replacement fittings. Details are described by Larson, et al. (NIOSH, forthcoming-a). These challenges resulted in less certainty in the measurements. In several cases, a range of LTD was determined. Figure 4 shows a contour plot of stress increase, with a MulsimNL/Large model (Larson and Whyatt, 2013; Larson, 2015) using elastic coal properties with the modulus reduced in the outer element rings to account for softening of the coal near openings. The parameters of this model were found to best fit the LTD determinations in a model of Mine A and were used at Mine B because the stratigraphy is similar. Entries and crosscuts were simulated in this model, so their effects are taken into account.

Larson, et al. (NIOSH, forthcoming-b) list the details of the results at Mine B, which ranged from 227.8 m (747 ft) to 472.6 m (1551 ft), excluding one outlying measurement. The probable minimum, however, was about 255.5 m (838 ft), a factor of 2.72 times that calculated with Equation 1.

INSTRUMENTED SUPPORT CANS

The principal challenges with using measured loads on instrumented support Cans at both sites were

1) installation too close to the arrival of mining-induced stress
2) difficulties in establishing a tight contact with the roof so that vertical closure was immediately indicated by loading of the can

Of the ten instrumented support Cans installed at Mine A, only three installations had sufficient quality to determine the initial

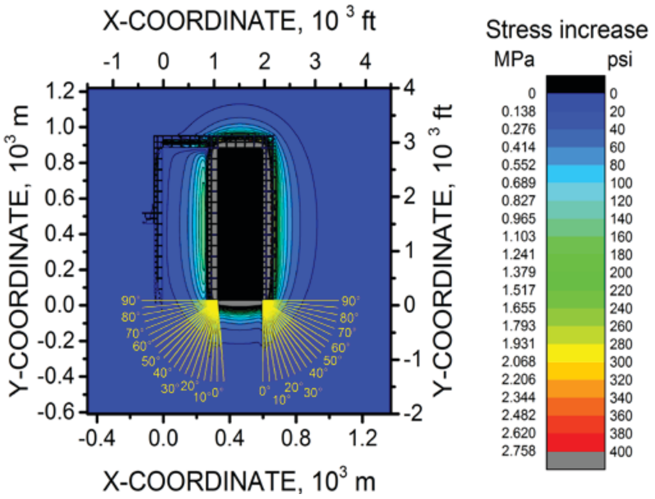


Figure 4. Contours of stress increase resulting from mining the B-13 Panel at Mine B. Lines at various angles from the gate roads are shown. Ratios of distances to the threshold contour line at various angles to the same distance at side panel were determined for headgate and tailgate with this graph.

abutment stress and equivalent LTD. The LTDs had an average of 502 m (1647 ft) with very small scatter. This average is 3.73 times that calculated by Equation 1. At Mine B, only one instrumented support Can could be used to determine an LTD, but the result was very long. It was an outlier or, perhaps, reflected a localized condition that caused early loading of this support Can. This result highlights an essential assumption in measuring LTD—that any detected change is caused by the approach of mining. In this case, the outlier was assumed to be the result of localized conditions, not representative of general conditions, and was discarded.

ENTRY CLOSURE AND SUPPORT CAN CLOSURE

String potentiometers were used for measurement of both entry closure and deformation of specific horizons of support Cans. Challenges were experienced in obtaining LTD measurements with these devices, including overcoming friction to begin registering closure and stick-slip behavior thereafter.

The average LTD measurements from closure instruments at Mine A was 381.1 m (1250 ft), or 2.83 times that calculated with Equation 1. At Mine B, only two instruments were useful in determining LTD, which resulted in an average of 256.1 m (840 ft), or 3.13 times that calculated with Equation 1.

GROUND CONDITION SURVEYS

Ground condition surveys were conducted at both mines, but only one survey was conducted at Mine B, so no trends resulting from mining were established. The surveys at Mine A were not conducted frequently enough to determine a narrow range for the distance at the initial mining-induced abutment stress. Details of the rating system can be found in Lawson, Zahl and Whyatt (2012) and NIOSH (forthcoming-a), and details for determining the LTD are described by Larson, et al. (NIOSH, forthcoming-a, forthcoming-b). Because of the infrequency of the surveys, the ranges in each gate road do not even overlap. However, an estimate of the sensitivity of the method is obtained by using the average of the tailgate minimum distance and the headgate maximum distance from the face to the initial abutment stress. Conversion to LTD is as described above. This LTD is 321.1 m (1053 ft).

DISCUSSION OF RESULTS

Equivalency and the relative sensitivities of the instruments used at Mines A and B must be discussed so that a method might be established to compare all LTD data available in the literature. Once adjustments were made, the overburden geology of each case was classified to the extent possible. Relationships between LTD and both depth and overburden geology were examined.

Adjustment factors were as follows:

1) a sensitivity factor, which adjusts for the differences in sensitivity among methods used to determine LTD
2) an equivalency factor, which adjusts for differences that would occur in detecting the initial abutment stress if that detection took place somewhere other than to the side of the panel

The sensitivity factor is determined by the method used, with the method of using BPCs with a threshold cell pressure increase of 138 kPa (20 psi) as the base. The sensitivity factor is a number representing the ratio of LTD determined by a method with respect to the LTD determined by BPCs in approximately equivalent conditions.

The equivalency factor is determined using a calibrated model of mining-induced stress increase around a panel, such as that shown in Figure 4. Ideally, a model should be calculated for each case, but the equivalency factors will be similar if a model of a typical situation is used. The equivalency factor is determined as the ratio of two distances:

1) from the gob to the 138 kPa (20 psi) stress increase contour in the direction of the instrument or observation when abutment stress was first detected
2) from the gob to the 138 kPa (20 psi) contour at the side of the panel at mid-length of what is excavated

The input file generator for LaModel, LamPre 3.0 [Heasley 2010] uses a calibration algorithm for load distribution between the abutment and the gob that neglects load on the abutment that is within a yield zone, where vertical stress on the coal has reached maximum strength. LamPre estimates the depth of that yield zone. In an attempt to be consistet with Heasley's approach, an assumed yield distance of 6.1 m (20 ft) was subtracted from both of these distances before the conversion ratio was calculated.This yield distance resulted from a best fit MulsimNL/Large model to Mine A results. Figure 5 shows a plot of those conversion factors used at Mine B with direction to the instrument from the gob corner, represented by an angle from along the length of the panel (i.e., the angle shown in Figure 4 that passes from the gob corner through the instrument). Since all measurements of distance at the initial abutment stress made at Mine A and Mine B were made ahead of the face, equivalency factors were made using models of each site in the LTDs determined in the results section of this report. In summary, for adjustments to LTDs reported in the literature, the following equation was used:

$$\text{Adjusted LTD} = \frac{\text{Reported LTD}}{(\text{Sensitivity factor})(\text{Equivalency factor})} \qquad (2)$$

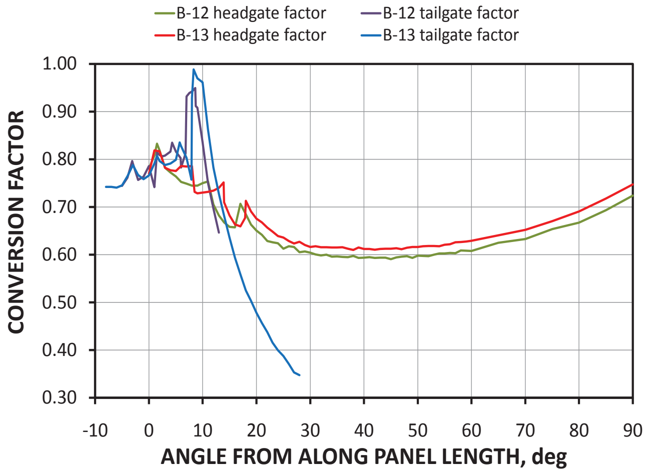


Figure 5. Piecewise linear conversion factor functions derived from Mulsim model for determining equivalent LTD at Mine B.

At Mine A, the detected LTD using instrumented support Cans was 0.938 of the average obtained using BPCs, indicating that instrumented support Cans are nearly as sensitive as using BPCs. Lowering of the detection threshold for support Cans to match the LTD for the BPCs is not advisable. The loading of support Cans depends heavily upon the structure in the roof and floor. Loading of the pillar is likely to be more consistent, and, therefore, the BPC would likely be more consistent, if installed properly, without compromising the cell.

From the data at Mine A, the average equivalent LTD determined from closures was about 0.712 of the average distance determined with BPCs.

Not enough ground condition surveys were conducted at Mine A to evaluate this method well. However, if frequent surveys were conducted and a correlation were made with respect to the BPC-determined equivalent LTD, then frequent ground condition surveys might be used to determine whether structure changes have taken place that would warrant further examination and study. At Mine A, the equivalent LTD determined from ground surveys could not be ascertained but was most likely about 0.6 of that determined with BPCs, as calculated from the average of the tailgate minimum range and the headgate maximum range with respect to the average.

Even with the uncertainties of the measurements at Mine B, the data supports that LTD at this mine is at least 2.7 times that calculated by Equation 1. This lower ratio compared to that at Mine A is consistent with overburden depth. The longer LTDs of this region seem to be associated with strong, massive geologic units in the overburden. Since Larson, et al. (NIOSH, forthcoming-a) reports a change in roof structure (including observations of the immediate roof, but changes are unknown above that in the overburden) that was observed over the course of mining Panel 1 at Mine A, it is likely that the presence of a massive unit increased the ability to transfer load farther away from the area of the mined panel

The LTDs described in the introduction of this report are shown as reported in Figure 6 along with those measured with BPCs at Mines A and B. However, this graph is not meaningful because different definitions of LTD and threshold sensitivities were used. Here, an attempt is made to compare the reported LTDs on an equal basis. With the knowledge that most or all of the sources of Abel (1988) made measurements or observations ahead of the face instead of at the side and made no equivalency adjustment for such, much of the LTDs that he reports should be adjusted higher. A compensating adjustment is necessary when using various methods that have differing sensitivities. The relative sensitivities of the methods described above at Mine A are used for this purpose.

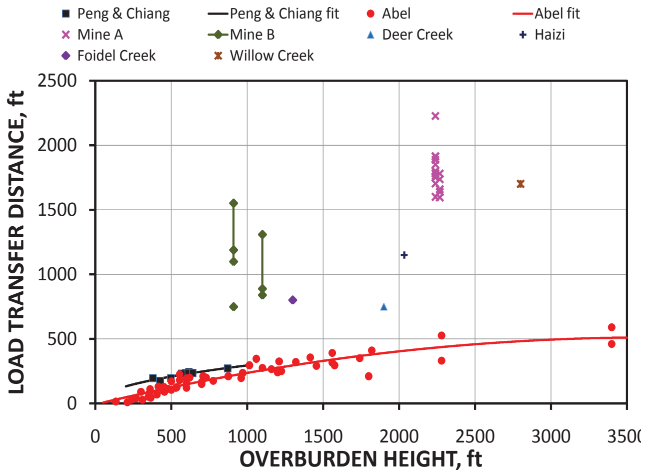


Figure 6. Load transfer distances found in the literature and those measured with BPCs by the author and collegues and presented in this paper from Mine A and Mine B. Mine B measurement ranges are indicated, except one upper range that was considered an outlier.

It is impossible to make adjustments with a high degree of accuracy to the Abel, Deer Creek, Haizi, Foidel Creek, and Willow Creek data to make them equivalent to the BPC method using a 138 kPa (20-psi) increase in cell pressure. To do so accurately would require more knowledge in most cases of the location of the instruments and the face positions. Moreover, models for each case would need to be constructed and run to determine relevant equivalency factors. However, it is illuminating to use the average sensitivity factors above and some assumptions about locations of instruments (if they are not known), so equivalency can be estimated based on the factors used at Mine A and Mine B. Using equivalency adjustments from the headgate area of Mine A, the entry next to the panel being mined had an equivalency factor of 0.879, but the factor varied little through the first pillar. An average equivalency factor of 0.840 was used for anything located elsewhere. Biaxial stressmeter data were assumed to have the same sensitivity as the BPC. An adjustment factor for the Foidel Creek case was derived from numerical models of Mine B, where panel width and overburden were similar.

For the Deer Creek Mine and Haizi Mine data, which were estimates of LTD at the side of the panel, the equivalency factor was 1. The sensitivity factor was estimated with the data shown in Figure 7. This figure demonstrates a vast difference in distance from the gate road side of the panel to the location of the initial mining-induced abutment stress, depending on the cell pressure-increase threshold chosen. Sensitivity factors for Deer Creek and Haizi Mine data were estimated by doing the following under the assumption that a proportional stress increase existed at these mines that was similar to that at Mine A:

1) Normalizing the increase of cell pressure from the minimum in Figure 7 with respect to the estimated pre-panel stress
2) Determining the distance from the panel to the location of the increases in stress of 13% (Deer Creek Mine) and 5% (Haizi Mine)
3) Dividing this distance by the distance at the BPC 138-kPa (20-psi) threshold

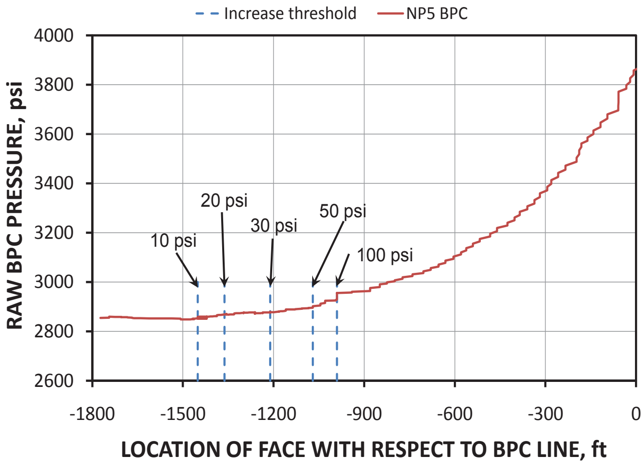


Figure 7. Example BPC pressure rise with approach of face, showing how various thresholds would affect determination of first arrival of mining-induced abutment stress.

Table 1 lists the sensitivity and equivalency factors assumed for each type of instrument in this report. The adjusted LTDs were determined using these factors in Equation 2. Table 2a and Table 2b show all of the data points, their adjustment factors, and a classification of the overburden. Overburden geology was determined in most domestic cases from the National Coal Resources Data System (NCRDS) Database (U.S. Geological Survey, 2015). Other cases were determined, where possible, from the report source. Figure 8 shows all of the adjusted LTD data according to the adjustment factors listed in Table 2a and Table 2b. Figure 9 shows the same adjusted data according to their geologic classification listed in Table 2a and Table 2b. The results indicate that the trend of those data where overburden had strong semi-massive to massive structure(s) was different from the trend of data without that structure. Fitted curves indicate that difference. The equation fitted in both cases is as follows:

$$LTD = a + b\left(1 - e^{-cH}\right) \tag{3}$$

where a, b, and c are fitted constants

H is the height of overburden in ft.

Table 1. List of assumed factors to adjust LTDs.

Determination method	Sensitivity factor	Equivalency factor
BPCs	1.000	0.840
VWS	1.000*	0.840
Crib flatjacks	0.938†	0.840
Packwall dynatometer	0.938†	0.840
Entry closure	0.712	0.879‡
Observations	0.600	0.879‡
Biaxial stressmeter-Foidel Creek	1.000	0.978
Biaxial stressmeter-Willow Creek	1.000	0.840
Deer Creek	0.374	1.000
Haizi	0.646	1.000

*VWS were assumed to have the same sensitivity factor as BPCs, since Peng and Chiang (1984) used measurements from both to fit Equation 1. Both were assumed to be placed in pillars.

†Crib flatjacks and packwall dynatometers were assumed to have the same sensitivity factor as the instrumented support Cans. Both were assumed to be in an entry that was not adjacent to the mined panel.

‡Entry closures and observations were assumed to be made in the entry next to the panel to be mined, so that their equivalency factor was higher than an instrument in the pillar.

LTD is the load transfer distance in ft.

The massive curve was fitted to data in categories 1, 3, 4, and 5, except one outlier point. The non-massive curve was fitted to data in categories 2 and 6. These fitted equations are

$$LTD_{massive} = -347.00 + 3890.0\left(1 - e^{-0.0035329H}\right) \tag{4}$$

$$LTD_{nonmassive} = -210.86 + 830.39\left(1 - e^{-0.0012300}\right) \tag{5}$$

The correlation coefficients, r^2, for these fitted equations, are 0.855 and 0.857, respectively. A square root equation, the same form as Equation 1, was fitted to the nonmassive data. Although the correlation coefficient is only 0.539, it is interesting that the fitted equation

$$LTD = 9.0554\sqrt{H} \tag{6}$$

is similar to Equation 1, suggesting that the addition of several cases like those of Peng and Chiang (1984) did not change the fitted curve in a significant way.

Table 2. a. List of load transfer distance data from the literature, their sensitivity, and side-LTD equivalency adjustment factors used in this report, adjusted load transfer distance, and classification of overburden.

Data source	Method	H, m	H, ft	Reported first arrival, m	Reported first arrival, ft	Sensi-tivity factor	Equiva-lence factor	Adjusted or measured LTD, m	Adjusted or measured LTD, ft	Over-burden geology
1	BPC or VWS	265.5	871.2	NU	NU	NU	NU	82.4	270.5	2
1	BPC or VWS	129.9	426.3	NU	NU	NU	NU	53.2	174.6	2
1	BPC or VWS	115.3	378.2	NU	NU	NU	NU	59.5	195.2	2
1	BPC or VWS	151.6	497.4	NU	NU	NU	NU	59.5	195.2	2
1	BPC or VWS	187.5	615.2	NU	NU	NU	NU	74	242.8	2
1	BPC or VWS	195.2	640.5	NU	NU	NU	NU	71.7	235.2	2
1	BPC or VWS	181.7	596.2	NU	NU	NU	NU	71.9	235.8	2
1	BPC or VWS	172.8	566.8	NU	NU	NU	NU	70.2	230.4	2
2,3	Observation	106.7	350	15.2	50	0.6	0.879	28.9	94.8	7
2,3	Observation	138.7	455	27.4	90	0.6	0.879	52	170.6	7
2,3	Observation	109.7	360	33.5	110	0.6	0.879	63.6	208.6	7
2,3	Observation	182.9	600	36.6	120	0.6	0.879	69.3	227.5	7
2,3	Observation	126.5	415	39.6	130	0.6	0.879	75.1	246.5	7
2,3	Observation	182.9	600	47.2	155	0.6	0.879	89.6	293.9	7
2,3	Observation	152.4	500	51.8	170	0.6	0.879	98.2	322.3	7
2,3	Observation	169.2	555	54.9	180	0.6	0.879	104	341.3	7
2,3	Observation	222.5	730	61	200	0.6	0.879	115.6	379.2	7
2,3	Observation	266.7	875	64	210	0.6	0.879	121.4	398.2	7
2,3	Observation	292.6	960	59.4	195	0.6	0.879	112.7	369.7	7
2,3	Observation	169.2	555	68.6	225	0.6	0.879	130	426.6	7
2,3	Observation	216.4	710	64	210	0.6	0.879	121.4	398.2	7
2,3	Observation	295.7	970	71.6	235	0.6	0.879	135.8	445.6	7
2,3	Observation	161.5	530	36.6	120	0.6	0.879	69.3	227.5	7
2,3	Observation	373.4	1225	76.2	250	0.6	0.879	144.5	474	7
2,3	Observation	365.8	1200	77.7	255	0.6	0.879	147.4	483.5	7
2,3	Observation	353.6	1160	80.8	265	0.6	0.879	153.2	502.5	7
2,3	Observation	309.4	1015	89.9	295	0.6	0.879	170.5	559.3	7
2,3	Observation	443.5	1455	88.4	290	0.6	0.879	167.6	549.9	7
2,3	Observation	480.1	1575	89.9	295	0.6	0.879	170.5	559.3	7
2,3	Observation	402.3	1320	97.5	320	0.6	0.879	185	606.8	7
2,3	Observation	368.8	1210	99.1	325	0.6	0.879	187.8	616.2	7
2,3	Observation	431.3	1415	108.2	355	0.6	0.879	205.2	673.1	7
2,3	Observation	554.7	1820	125	410	0.6	0.879	237	777.4	7
2,4	BPC and conv	94.5	310	8.5	28	1	0.840	10.1	33.3	2
2,4	BPC and conv	64	210	2.7	9	1	0.840	3.3	10.7	2
2,4	BPC and conv	82.3	270	12.2	40	1	0.840	14.5	47.6	2
2,4	BPC and conv	73.2	240	9.1	30	1	0.840	10.9	35.7	2
2,4	BPC and conv	111.3	365	13	42.5	1	0.840	15.4	50.6	2
2,4	BPC and conv	123.4	405	20.7	68	1	0.840	24.7	81	2
2,5	BPC	109.1	358	26.8	88	1	0.840	31.9	104.8	2

Table 2b. List of load transfer distance data from the literature continued.

Data source	Method	H, m	H, ft	Reported first arrival, m	Reported first arrival, ft	Sensi-tivity factor	Equiva-lence factor	Adjusted or measured LTD, m	Adjusted or measured LTD, ft	Over-burden geology
2,9	unknown	182.9	600	59.1	194	1	0.840	70.4	231	7
2,10	VWS	189	620	61	200	1	0.840	72.6	238.1	2
2,11	VWS	548.6	1800	64	210	1	0.840	76.2	250	3
2,12	Pack dyn.	694.9	2280	100.6	330	0.938	0.840	127.7	418.8	7
2,12	Pack dyn.	694.9	2280	160	525	0.938	0.840	203.1	666.3	7
2,13	crib flatjacks	530.4	1740	106.7	350	0.938	0.840	135.4	444.2	2
2,9	convergence	323.1	1060	105.2	345	0.712	0.840	175.8	576.8	6
2,14	convergence	1036	3400	140.2	460	0.712	0.840	234.4	769.1	2
2,14	VWS	1036	3400	179.8	590	1	0.840	214.1	702.4	2
2,15	VWS	213.4	700	45.7	150	1	0.840	54.4	178.6	2
2,16	convergence	475.5	1560	96	315	0.712	0.840	160.5	526.7	discard
2,16	VWS	475.5	1560	118.9	390	1	0.840	141.5	464.3	discard
2,17	VWS	236.5	776	53	174	1	0.840	63.1	207.1	4
18	Obs, mod 13%	579.1	1900	228.6	750	0.374	1	611.2	2005.3	1
19	Evnt, mod 5%	620	2034.1	350	1148.3	0.646	1	541.8	1777.6	5
20	BSM	396.2	1300	243.8	800	1	0.978	249.3	818	4
21	BSM	853.4	2800	518.2	1700	1	0.840	616.9	2023.8	1
22,23	BPC	682.4	2239	NU	NU	NU	NU	583.1	1913	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	678.7	2226.7	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	487.6	1599.6	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	519.1	1703.1	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	536.7	1760.9	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	583.4	1914	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	564.1	1850.6	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	548.5	1799.7	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	574.7	1885.5	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	543.8	1784.1	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	533.4	1750.1	3
22,23	BPC	682.4	2239	NU	NU	NU	NU	542.8	1780.8	3
22,23	BPC	691.3	2268	NU	NU	NU	NU	542.5	1779.7	3

NU = Not used
BPC = Borehole pressure cell
VWS = Vibrating wire stressmeter
Conv or convergence = entry convergence
Obs or observation = observation of ground deterioration
Mod 13% = determined with numerical model using 13% threshold stress increase
Evnt = Event such as outburst
BSM = Biaxial stressmeter
Discard = data point discarded because measurements were taken too close to the start-up room
Overburden geology classification:
1. Dominant sandstone with strong, massive unit(s) 2. Dominant shale, with no massive unit
3. Alternation sandstone and shale, with semi-massive unit(s) [> 15.2 m (50 ft) and < 30.5 m (100 ft)]
4. Dominant shale, with semi-massive to massive unit(s) 5. Alternating sandstone and shale, with massive igneous sill
6. Dominant halite, 7. Unknown

Even considering the imprecise adjustments used to get side LTD equivalency, Figure 9 highlights that overburden height is not the only dependent variable. The figure also shows a wide range of data, even at one site, suggesting both measurement scatter and possible dependence on other variables having to do with the massive strata (e.g., these variables could be thickness of massive member(s) and proximity to the seam). Even so, the two trends, represented by fitted massive and non-massive curves highlight the effect of presence of massive stratigraphic units. Based on experience with modeling Mines A and B (Larson and Whyatt, 2013; Larson, 2015), it is likely that MulsimNL/Large will provide a better model of stress redistribution at sites incorporated into the massive overburden LTD curve. A laminated overburden model, such as LaModel (Heasley, 1997 and 2010), will likely provide a better model of stress redistribution at sites incorporated into the nonmassive overburden LTD curve because it more easily follows bending of less massive strata.

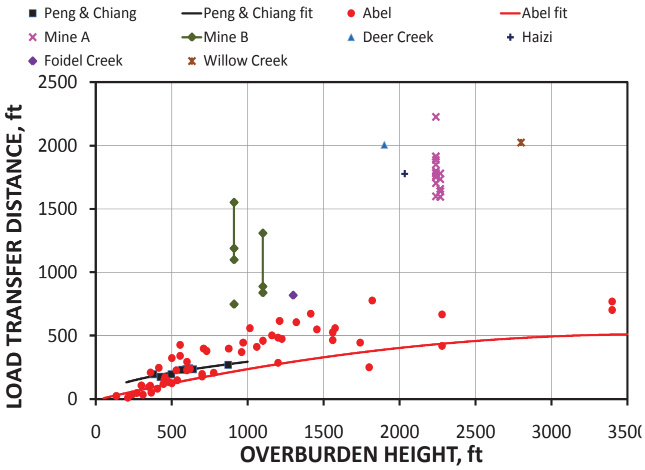


Figure 8. LTD data from Figure 6 with estimated sensitivity and side equivalency adjustments made to the Abel, Deer Creek, Haizi, Foidel Creek, and Willow Creek data.

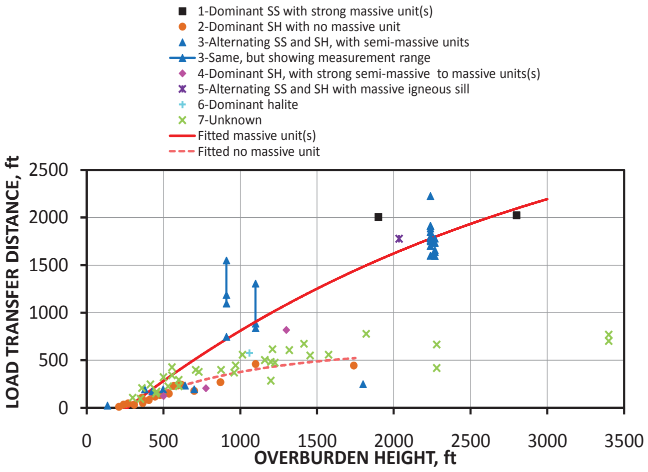


Figure 9. Load transfer distance with overburden height according to overburden geology classification. Fitted lines show the difference in trends according to presence of strong, massive units in the overburden.

This work to compare LTDs on approximately the same basis is preliminary. A better understanding of LTD will be possible as methods to measure LTD are improved and more detailed information about the geology is recorded so that the effects of various aspects, such as composition, strengths, thickness, and proximity to seam might be examined.

CONCLUSIONS AND RECOMMENDATIONS

As a result of this study, the following conclusions and recommendations can be made concerning measuring LTD:

INSTRUMENTATION

- Support Cans with load bladders and pressure transducers calibrated to applied load, entry closures, and support Can closures appear to be sensitive to local structural conditions. The result is a wide range from site to site of initial trends and subsequent change that reflects the initial mining-induced abutment stress.
- Tightness of cap and wedge pieces above support Cans affect initial load trends, which may mask indications of initial abutment stress.
- The spring-loaded take-up wheel of the string potentiometers can be problematic. In this study, their typical behavior was characterized by a delay in displaying trend while initial friction was overcome, followed by smaller stick-slip behavior. Such characteristics made determination of the initial abutment stress to be difficult, and sometimes impossible.
- Borehole pressure cell (BPC) installation must be in a smooth, clean hole to increase quality of the installation.

LOAD TRANSFER DISTANCE DETERMINATION

- The measured LTDs in the area of Mine A and Mine B are much greater than those calculated with Equation 1. The range of LTD at Mine B, determined with BPCs, is consistent with the LTD determined with BPCs at Mine A considering the difference in overburden depth.
- Advancement of an updated empirical curve should only proceed using common criteria to determine LTD.
- Future reporting of measured LTDs should include as much detail as possible of the overburden geology so that the influence of various geologic factors on LTD might be determined and empirical equations are refined.
- LTD measurements taken with various methods and at various locations can be adjusted to a common standard, based on evidence from sites where multiple methods and locations have been reported. Adjustments may be partially site-specific, so more work is needed. However, results reported here provide a framework for comparing measurements taken by a variety of means and using them for model calibration.

LOAD TRANSFER DISTANCE ESTIMATION

- Overburden height is not sufficient as an independent variable to describe LTD. The data shown here clearly shows that strong, semi-massive to massive strata increases LTD.
- LTD estimates should be based on both the depth of mining and geology of overburden.

ACKNOWLEDGEMENTS

The authors are greatly indebted to the mining companies that operate Mine A and Mine B for allowing NIOSH personnel to come on site and install instruments. Engineers and personnel at these mines participated in installation of the instruments and subsequent monitoring. They made this project possible. Agapito and Associates installed the BPCs at Mine A. Their drilling expertise, careful notes, subsequent discussion of measurements, and the information they provided are very appreciated. NIOSH OMSHR co-workers, Brad Seymour, Craig Compton, David Oyler, Tristan Jones, and Dennis Dolinar participated in various parts of the field installations. Their efforts are also very appreciated. Co-worker Eric Zahl was on site at the mines numerous times to lead installation efforts, troubleshoot problems, make equipment moves, and extract datalogger readings. His efforts and dedication made possible the results of this project.

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