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ON MINING-INDUCED HORIZONTAL SHEAR DEFORMATIONS OF THE GROUND SURFACE

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ABSTRACT: Horizontal shear deformations have not been commonly considered in subsidence engineering and risk management practices. This situation is quite different from many other engineering disciplines. This article presents the authors' initial findings of case studies from a number of collieries across all NSW Coalfields. The objective of this article is to highlight the significance of a ground deformation mode, that is, horizontal shear, and its implications to subsidence engineering and risk management. A Shear Index is suggested to facilitate studies of mining-induced shear deformations of the ground surface.

INTRODUCTION

This article presents an argument that conventional subsidence parameters specifying horizontal deformations, in particular, horizontal strains (i.e. change in length), are inadequate for subsidence engineering and risk management. The above-mentioned inadequacy can become practically important in areas where only low magnitude of conventionally defined horizontal strains is detectable due to deep cover depths (or relatively low "extraction width-to-cover depth" ratios).

There is clear evidence to suggest that the above-mentioned inadequacy is related to a lack of understanding of mining-induced horizontal deformations of the ground surface, in particular, horizontal shear deformations.

Despite theoretical definitions found in limited literature on mine subsidence (e.g. Peng, 1992), horizontal shear deformations have not been commonly considered in subsidence engineering and risk management practices. This situation is quite different from many other engineering disciplines.

HORIZONTAL SHEAR DEFORMATIONS

Indicators of horizontal shear deformations, as identified by this study, comprise:

1. Observed subsidence effects on civil structures indicating influence of shear deformations and significance of this deformation mode in terms of its impacts and frequency of occurrences. The shear effects at a particular site are demonstrated in Figure 1;

Figure 1 - Structures Affected by Horizontal Shear Deformations

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2. Statistical information suggesting a strong correlation between the shear-affected structures and strip footings, which have less capacity to resist or accommodate horizontal shear deformations as compared with that for other types of footings considered in this study;

3. Observed patterns of mining-induced surface fractures and deformations (in plan view) suggesting influence of shear, for example, i) en-echelon fractures near chain pillars where shear deformations were active or ii) occurrences of surface wrinkles where the effects of horizontal shear were clearly visible, and

4. Importantly, horizontal shear deformations of ground surface as indicated in 3D survey data obtained from a number of collieries across all NSW Coalfields (to be further discussed).

However, rigorous definition, in accordance with the principles of continuum mechanics (e.g. Jaeger, 1969), of horizontal shear strains is not possible using 3D survey data from a straight line of survey points.

It follows that if warranted considering the significance of the surface features and their capacity to resist or accommodate shear deformations, the current surveying practices may need to be changed to obtain properly defined horizontal shear strains (or principal strains).

To utilise the large amount of subsidence data in existence in the mining industry, an alternative (and approximate) Shear Index is suggested in order to gain an understanding of the general characteristics of mining-induced horizontal shear deformations. This Shear Index is derived based on the component of horizontal movements perpendicular to a survey line or a line of interest. The formula for deriving this index is the same as that for the conventionally defined tilt. Physically, this index reflects angular changes in the horizontal plane but it is not possible to tell what causes such changes, being either shear or rigid body rotation or both. However, the distribution pattern of this index can help to understand the development of shear deformations and to find "trouble spots" (refer to further discussions presented in the Section below).

FURTHER DISCUSSIONS ON HORIZONTAL SHEAR DEFORMATIONS

Figure 2 shows the distribution pattern of horizontal movements perpendicular to a survey line across a longwall panel and the corresponding Shear Index as discussed above.

Although the site is located in the Hunter Coalfield with shallow cover depths, this case is selected as it provides a clear demonstration of the following observations common to the studied cases from all NSW Coalfields:

- A complex history of the horizontal movements perpendicular to the cross line (Figure 2a) involving a reversal of movement direction after the extraction face passed the survey site by a certain distance. This distance varied from site to site. Similar findings were reported by Holla and Thompson (1992) and Mills (2001);

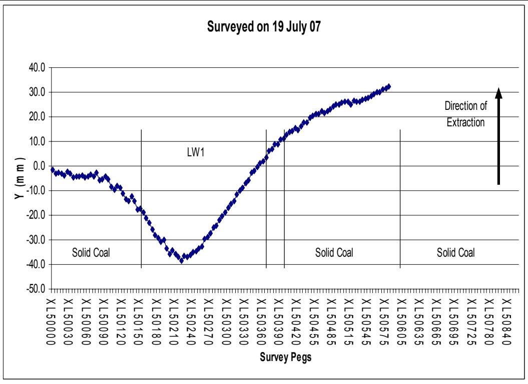
- Indications of horizontal shear deformations (near both solid ribs in this case, as shown by the Shear Index plotted in Figure 2b), noting the reversal in the sense of shearing after the extraction face has passed the survey site. The reversal in the sense of shearing has a potential to enhance the effects of shear deformations, and

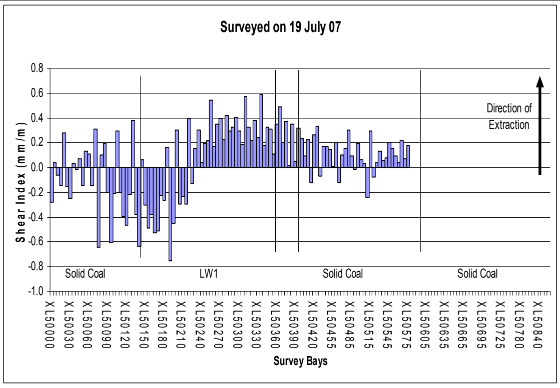
- The occurrences of permanent horizontal deformations.

IMPLICATIONS

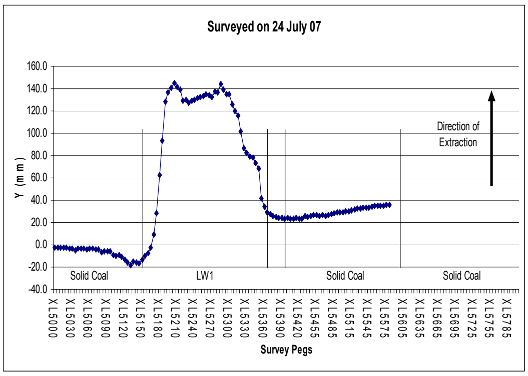
From the 3D survey data collected from a number of collieries across all NSW Coalfields, the characteristics (i.e. the magnitude, nature, distribution and timing of occurrences) of the conventionally defined subsidence parameters are compared with those of the following horizontal deformational parameters:

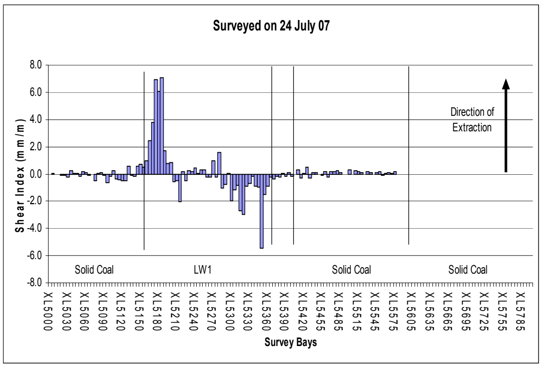
(i) Mining-induced horizontal movements perpendicular to survey grid lines, and
(ii) The corresponding Shear Index as discussed above.



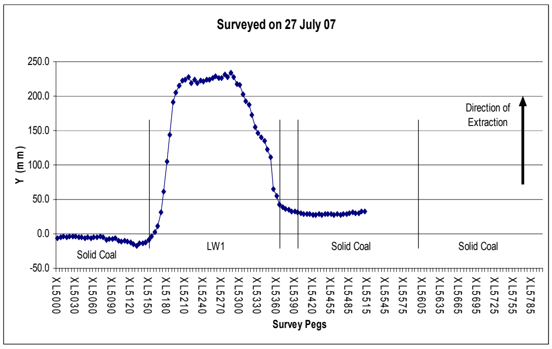


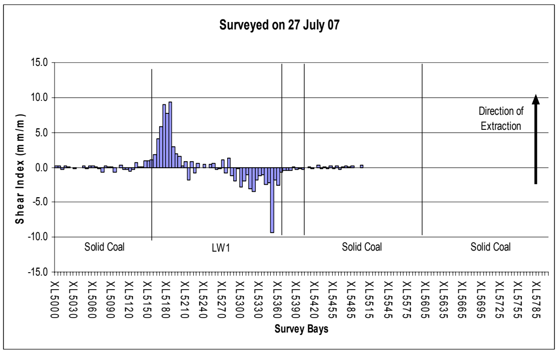
Longwall face 5m past survey line





Longwall face 88m past survey line
note: reversal in direction of horizontal movement





Longwall face 157m past survey line

Figure 2a - Horizontal movements (Y) perpendicular to survey line (mm)	Figure 2b - Shear index as defined in the article (mm/m)

Implications from the findings of the current study so far are summarised as follows.

1. Horizontal Shear Deformations – There is a need to recognise horizontal shear deformation as a significant mode of mining-induced deformations at the ground surface. Specific attention should be paid to surface features with inadequate shear resistance and to areas with deep cover depths (or relatively low "extraction width-to-cover depth" ratios) where the conventionally defined horizontal strains predicted may suggest low risks.

2. Assessment of Subsidence Impacts on Civil Structures – Further to Point (1) above, there is a need to recognise the limitations of subsidence models based on conventionally defined horizontal strains and AS 2870-1996 (Standards Australia, 1996) when predicting subsidence impacts on civil structures. Consequently, there is a need to identify areas where changes and improvements to these models are required.

3. Civil Structures on Sloping Ground – Further to Point (1) above, specific attention should be paid to civil structures on the sloping ground. In this case, there is a potential for enhanced shear deformations due to the participation of down-slope movements. In addition, the performance of any footings to resist or accommodate shear deformations in this environment needs to be investigated and understood.

4. Capacity of Surface Features to Resist or Accommodate Shear Deformations – This is an area where knowledge has not been clearly established for subsidence engineering and management. The situation here, again, is different from many other engineering disciplines when shear deformations are concerned. There is a need to undertake necessary research into this area.

5. Mining-induced Surface Wrinkles – Mining-induced surface wrinkles (Figure 3), or compression humps, are one of the significant factors for subsidence impacts on civil structures. Where these deformational features occurred in areas with low predicted horizontal strains according to conventional subsidence models, geological structures were often blamed for their occurrences resulting in unpredicted or higher-than-predicted impacts on civil structures. However, recently conducted field investigations have not been able to provide a clear link between geological structures and such surface wrinkles, while there is a continuing need for an improved understanding of these features to develop effective early warning and risk management systems. The identification of horizontal shear deformations can offer an explanation (Figure 4), additional to geological structures and the conventionally defined compressive horizontal strains, for the occurrences of these deformational features.

6.

Figure 3 - Mining-induced surface wrinkles

6. Management of Subsidence-related Risks to Linear Infrastructure Items – The results of this study suggest a need to review the adequacy of risk management systems for important linear infrastructure items such as roads, rails, canals or pipelines, if these management systems have been developed based primarily on conventional subsidence models taking into consideration parameters predicted or measured along the lengths of such infrastructure items and/or if the features in questions do not have sufficient capacity to resist or accommodate lateral movements or shear deformations.

7. Survey Practices - As discussed above, to obtain properly defined shear strains or principal strains, the survey practices need to be changed. The suggested change is related primarily to the layout of survey grids, for example, 3D surveys of two (or multiple) parallel grid lines separated by an appropriately defined distance.

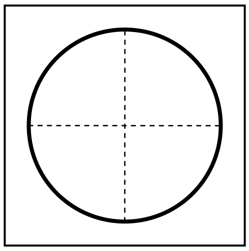


Figure 4a - Strain circle prior to shear deformation

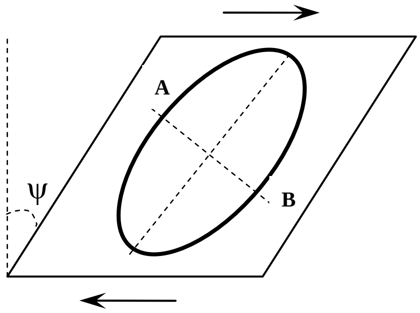


Figure 4b - Strain ellipse after shear deformation (After Ramsay, 1980). Surface wrinkles may occur due to shortening along the AB axis

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