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Shallow Mine Subsidence – A Case Study

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ABSTRACT: This paper documents a site on which multiple nonsystematic, shallow mine subsidence events affected a residential structure in a heavily developed area in the Newcastle Region of NSW. The mine workings beneath the property were mined prior to 1887 in the Borehole Coal Seam (BH Seam) at shallow depth and under very limited rock cover. The mine workings beneath the property were only partially mapped. In the mid-1930's, a timber framed, weatherboard clad residential structure was constructed over the now abandoned mine workings. Over its lifetime, this residential structure suffered damage due to extensive pothole/sinkhole formation as well as experiencing significant movement due to goaf consolidation which resulted in a loss of serviceability and damage to the residence.

1 INTRODUCTION

1.1 *Shallow Subsidence in Newcastle*

Subsidence of shallow abandoned mine workings is a common cause of damage to housing in Newcastle, New South Wales due to extensive areas that are underlain by shallow abandoned mines (Johnston et. al. 2017).

Shallow mine subsidence, as opposed to subsidence impacts from deep mining, is generally defined as surface movement due to the collapse or ongoing settlement of mine workings under 30m depth (e.g. Piggott and Eynon (1978)). Subsidence occurring over shallow abandoned mine workings is typically controlled by a roof collapse mechanism in which a progressive roof failure continues through the superincumbent strata and progresses to surface level. However, in areas that have been subject to secondary workings or pillar extraction, ongoing consolidation of the shallow mine goaf may present a significantly higher risk to built infrastructure than traditional pothole type subsidence events.

Estimation and prediction of shallow subsidence over mines in the BH Seam is challenging in Newcastle, given the unreliability of available record tracings, the typically dispersive, highly weathered, low strength claystones and siltstones contained in the makeup of the immediate overburden, and the historically poor filling practices that occurred post mining as a part of residential subdivision works.

2 MINING HISTORY AND INVESTIGATION OF THE STUDY SITE

2.1 *Geology and Mining History*

The site of the residential structure studied in this paper lies within the Upper Permian Newcastle Coal Measures. Mine workings beneath the subject site were completed during the mid 19th century in the BH Seam, which was recorded as being 7ft 10.5in (approximately 2.35m) thick beneath the site, with an unrecorded working section. A seam section taken from mine record tracing No. 469 (RT469) is shown in Figure 1.

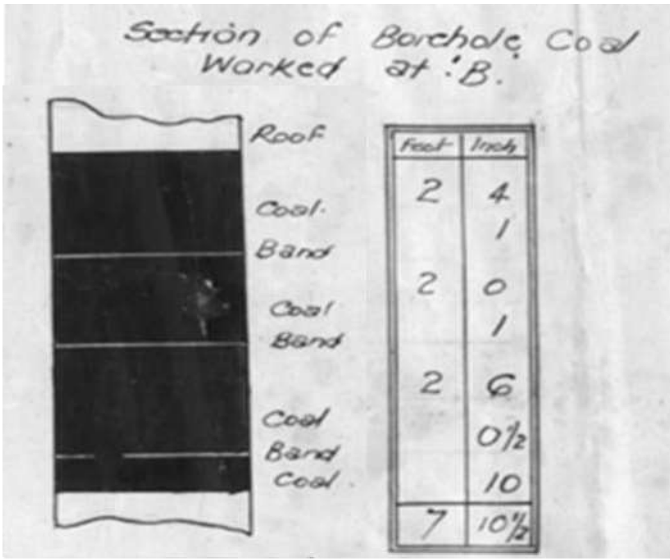

Figure 1. Section of coal worked beneath this site (from RT 469)

The mine located beneath the site is a regularly laid out Welsh bord style mine, typical of the mid-1800s mines found in Newcastle. The early stages of the mine are relatively well documented, with regular bords connecting to a set of roadways that are shown running directly under the site itself. Based on the record tracing available for the site, once first workings were complete, a smaller operation re-worked parts of the original mine, driving further towards the outcrop of the seam. This second phase of mining does not record any additional workings immediately beneath the subject site.

2.2 *History of Subsidence and Damage*

The study site hosts a single-storey timber-framed weatherboard cottage on shallow-founded isolated piers, spaced at between 1.5 and 2m. It was constructed around 100 years ago, probably post mining. No records prior to 1961 are available. In 1963 a subsidence event severely damaged the residence, resulting in re-laying of strip footings, re-piering and the demolition and reinstatement of front verandah brickwork and dwarf walls. Further subsidence events occurred in the 1980s, 1990s and 2000s resulting in further re-piering/re-levelling, replacement of concrete pathways and the replacement of a sewer impacted by potholing.

In 2016, SA NSW received an additional claim for mine subsidence damage. The damage to the residence was consistent with previous damage at the site and consisted of out-of-level floors and walls, together with minor cracking of internal finishes, the dropping of piers, and the tilting of a detached garage structure. SA NSW contracted a consultant to carry out a subsoil geotechnical investigation to establish the ground conditions and investigate the mine workings beneath the property. The house was purchased by SA NSW in 2018.

Figure 2 shows the studied site, indicating the position of the residence, and relative ground surface contours of the back yard at the time of purchase. Notwithstanding a general fall from front to back (top to bottom of figure), the yard surface displays pronounced hummocks and swales in what is otherwise an empty yard comprising only mown lawn. The structural conditions are detailed below.

2.3 *Geotechnical Conditions*

Three boreholes (see Figure 2) drilled at the property indicated significantly disturbed geological profiles. Up to 1m of fill had been placed at the site, over the natural alluvial and residual silt and clay soils which extended to between 7 and 9m deep. Extremely weathered siltstone rock was encountered in the im-

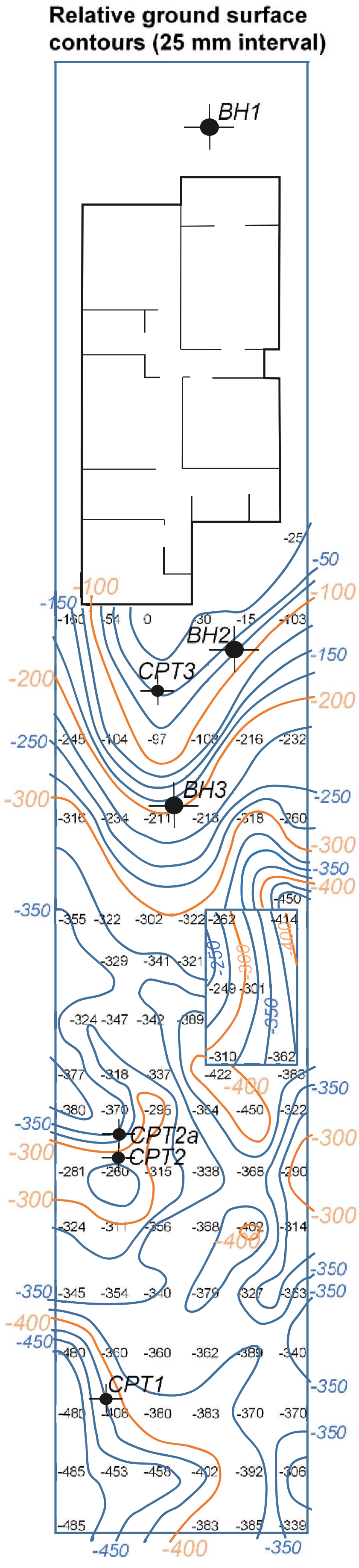

Figure 2. Ground surface contours in the yard. The numbers in black are ground surface spot levels. Locations of subsurface investigation are also shown.

mediate roof of the mine, and the floor was moderately to highly weathered siltstone rock at between 12.5 and 13.6m. The interval of the seam and workings comprised erratic intervals of clay, coal and voids (interpreted to be mine goaf), which coincided with total water loss during drilling.

Camera inspection was unsuccessfully attempted in the boreholes, with BH01 collapsing at 10.4m and PVC casing in BH3 found to be crushed at 4.6m, indicating ongoing movement at mine level. CPT testing and sampling by NEWSYD Geotechnical Testing at the University of Newcastle was completed following the purchase of the property and generally confirmed the profile indicated by the boreholes.

3 EFFECTS OF SUBSIDENCE ON THE STRUCTURE

Subsidence beneath the structure has resulted in severe differential foundation movements, with subsequent significant tilts in floors and walls.

Figure 4a shows the levels of the pier tops beneath the house, (figures in black) relative to a value of zero assigned to the highest pier, as indicated. The maximum differential movement between piers is 226mm. The pier-top levels have been contoured at a 10mm interval to represent the surface upon which the overlying structure is supported (and not the surface shape of the subsided ground). Also shown in Figure 4a (shaded in grey) are regions where potholes have formed, with some having been filled with concrete, and some not.

An inevitable consequence of the severe foundation settlements is the separation of the house structure from the piers in many locations, resulting in 14 piers and approximately half of the front and side support walls no longer being in contact with the bearers or floor plates. The values in red in Figure 4 represent the magnitude of the gaps (in mm) between subsided piers and the floor bearers.

Figure 3 shows examples of some of the severe structure-foundation separations that have occurred. It is important to note that the piers and footing walls in these photographs are clearly younger than the house itself, and it is believed that all of the footings have at some stage been replaced (presumably with the house being re-levelled) which means that the presently observed settlements are only a portion of those that have occurred on the site since the house was constructed.

Figure 4b shows relative levels of the internal floors (values in black) of the house. Also shown (again) on this figure are the pier-bearer separation values (values in red), with the areas of the structure that have lifted off the piers shaded in red. The highest point on the floor coincides with the highest pier top, and the floor levels fall away from this point in all directions. The house bears on piers around the highest point, and piers and walls at the opposite corners, but it spans across the intervening distance, in several places without touching 2 adjacent piers.

a) packing of gaps between house and support walls

b) severe settlement of support walls

c) drop and/or rotation of piers

Figure 3. Examples of foundation movements

Figure 5a is a profile along the side of the house which includes the highest pier, about half way along. The reversal of tilt either side of the highest point is readily apparent, however no appreciable splits or separations of the weatherboards was noted.

Figure 5b shows the severe deformations in the garage in the yard. Contours of deformation in the garage slab are shown in Figure 2, indicating that the slab deformation is consistent with that of the house.

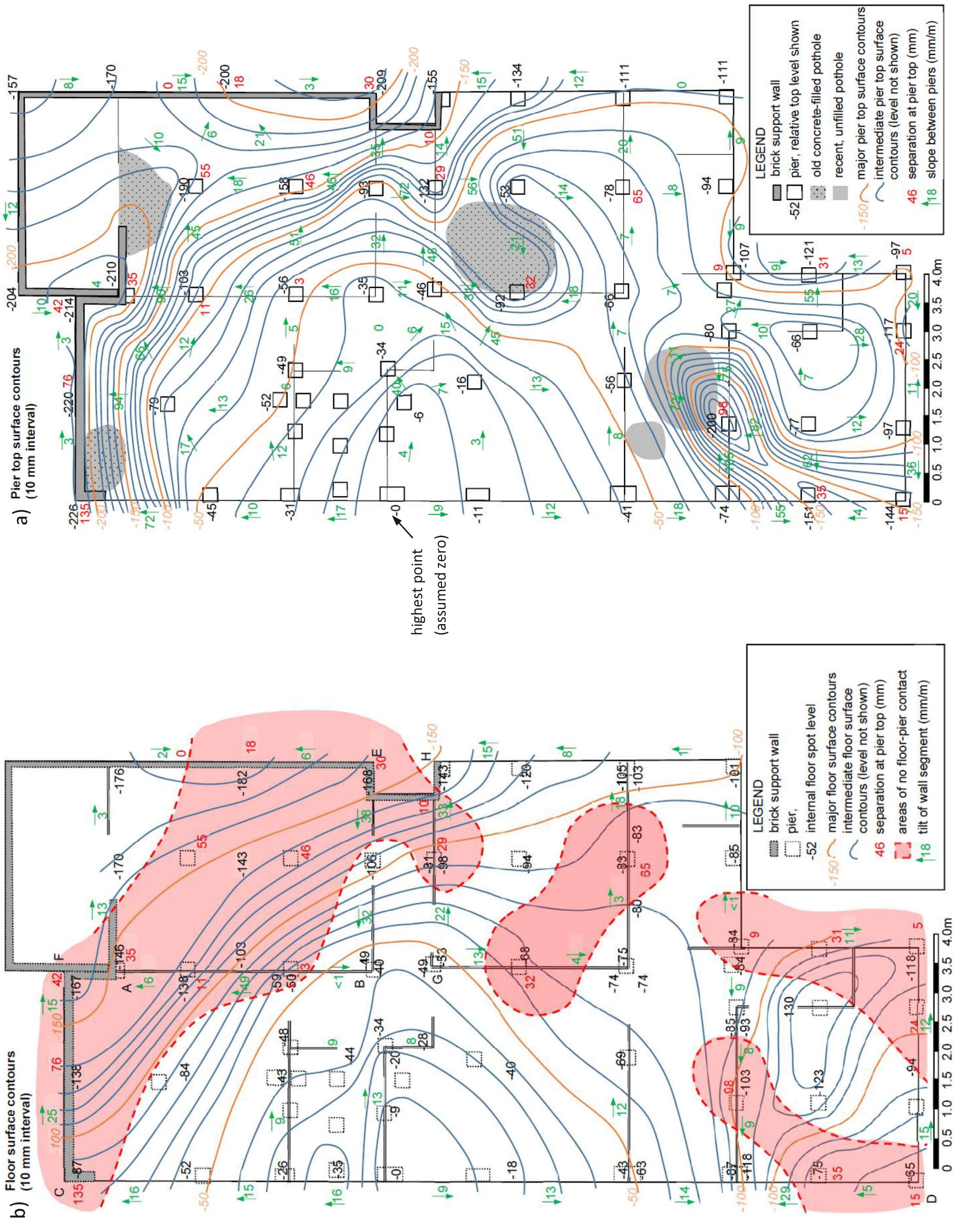

Figure 4. Contoured surface of the relative pier top levels (a) and internal floor surface contours (b) showing areas of no pier-floor contact. Note that the pier top levels contain only information from the pier tops and do not reflect the ground levels between piers.

a) curvature of weatherboards along the side of the house. (wall C-D in Figure 4b)

b) tilts in the garage (see slab contours in Figure 2).

Figure 5. Structural distress in the exterior of the house (a) and garage (b).

In contrast to the severe deformations evident in the exterior and floors of the structure, internal distress predominantly consisted of minor cracking of plasterwork ceilings, minor cracking and separation of cornices and some straining of horse-hair plaster sheet linings, where joins are concealed beneath moldings and battens. Despite being finished with a decorative plaster ceiling and cornice, damage to the living room was moderate, with the most severe damage shown in Figure 6.

Surprisingly, the majority of doors throughout the house not only opened and closed freely, they looked reasonably square, with little suggestion they had been subject to significant adjustment.

Deformations in the garage structure were sufficiently great to cause rigid sheet cladding to detach and the roller door to jam.

a) relatively minor damage to decorative plaster ceiling

b) most severe damage observed in internal linings.

Figure 6. Examples of damage to internal linings

4 DISCUSSION

Overall, the internal damage was classified as Damage Category 1 – 2 in accordance with AS2870 - 2011, with minor areas of Damage Category 3 – 4 limited to that shown in Figure 6. However, the significant differential movement in the floor of the residence is well above any suggested limit values derived from AS 2870-2011 or those summarized in Appleyard (2011). It was concluded that despite the mild damage to internal and external walls, the house was rendered unserviceable by the significant differential settlements of the floor plate.

The green values in Figure 4 represent slopes and tilts for different segments of the structure. Figure 4a shows slopes between pairs of adjacent piers in mm/m, which are as great as 105mm/m, with about 20% of all adjacent piers having a slope greater than 50mm/m. Figure 4b shows tilts along wall segments throughout the house. Localized tilts at floor level along walls of up to 50mm/m were recorded, with around 15% of wall segments tilted by more than 20mm/m.

A histogram plotting the relative frequency of both slopes between adjacent pier tops and tilts along wall segments is presented in Figure 7. As expected, tilts along walls are less severe than slopes between piers, due to the stiffness of the timber-framed house-structure allowing it to rest upon the highest of the piers, and to span across more seriously subsided piers. The stiffness of the house is able to moderate foundation slopes of up to 105mm/m, down to wall tilts consistently less than 50mm/m. It is apparent that significant mitigation of subsidence impact is achieved by this construction type.

Perhaps most significant are the curvatures that result from changes in tilt along particular wall segments. The segments denoted C-F and G-H in Figure 4b) each experience a change in slope of around 10mm/m along their length. Even more severe are the tilt reversals in the wall from C-D, and the double tilt change in segment A-B, which is greater than 40mm/m in each case. Despite this, the most severe damage in wall A-B is that shown in Figure 6.

Table 1 compares maximum measured tilts and slopes with those of Subsidence Advisory Guideline 4, for areas likely to be affected by active mining with high predicted impact.

Table 1. Comparison of measured values vs. prescribed design limit values

	Tilt (mm/m)		Max Deflection (mm)
	Max	Mean	
Measured (walls)	49	14	182
Measured (pier)	105	26	226
Limit (AS2870)	3.3	-	40
SA Guideline 4	7	-	-

Measured values are well in excess of the maximum values to be accommodated by design for either reactive soils or longwall mining subsidence. For properties affected by such severe movements, SA Guideline 1 guides acceptable site development practice, and requires footings that are able to span a 5m pothole anywhere on the site.

The values reported in this paper are useful for speculating what sort of foundation deformations might affect a structure on a site with a likelihood of high impact from pothole subsidence.

5 CONCLUSIONS

Unlike modern longwall operations, mine subsidence from shallow mining is challenging to both predict and mitigate in the design of structures. In this case study, a residential house was subjected to multiple subsidence events over its lifetime. From the parameters derived in Section 4, it is apparent that mine subsidence from shallow goaf consolidation gives significantly higher design parameters than those predicted for modern longwall mining in the Northern or Southern NSW Coalfields.

The actual structural design parameters given by the top of pier head measurements is significantly higher than any known longwall subsidence design parameters and is likely undesignable.

The flexible nature of the house has significantly mitigated against the damage due to subsidence.

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