Victoria Boyne

Subject: FW: Response to Action Item GS-11

From: Matthew Pierce <matt@pierce-engineering.com>
Sent: Friday, March 13, 2020 11:43 AM
To: Peacey, Victoria (RC) <Victoria.Peacey@riotinto.com>
Subject: [External] Response to Action Item GS-11

Vicky,

See my response to GS-11 below.

Matt

Action Item GS-11. Provide additional information or insights on how subsidence model output (displacement, tilt, differential movement) can be translated into real-world effects. One suggestion raised in the meeting is to focus on analog natural processes, such as freeze-thaw damage, in order to supplement the quantitative analysis.

Surface displacements from mining-induced subsidence have five major components:

- vertical displacement (settlement, sinking, or lowering);
- horizontal displacement (lateral movement);
- slope (or tilt) — i.e., the derivative of the vertical displacement with respect to the horizontal;
- horizontal strain — i.e., the derivative of the horizontal displacement with respect to the horizontal; and
- angular distortion, approximated by the second derivative of the vertical displacement with respect to the horizontal.

It is important to note that that vertical displacements alone cause little damage to surface infrastructure. For example, Singh (2003) provides examples of an observation tower that sank 30 ft (9.2 m) in a coalfield, mining structures that subsided a similar amount around the sulfur mining areas off the coast of Louisiana and a church in a potash-mining district that settled 20 ft (6.2 m), all without significant damage. Subsidence-induced damage associated with cave mining is normally related to strain rather than displacement. Strains can be horizontal (stretching of the ground surface) or angular distortion (differential settlement). In addition to strain, tilt is of interest at Resolution in terms of its potential impact on the tall slender rock formations (hoodoos) of the Apache Leap formation.

The strain values used to define the limits of subsidence are normally based on the damage they could cause to buildings. Even when no buildings are present on site, building damage is still a convenient means to convert strain values into real-world effects and appreciate the effects of different strain levels. It also represents a conservative approach since buildings with concrete/masonry foundations are stiffer and hence more susceptible to damage than the rock mass itself. A building founded within the zone of continuous subsidence at Resolution (see model-predicted limits in Itasca, 2017 report) is forecast to experience combinations of strains above the purple dashed line in the plot below and be subject to moderate to severe damage as a result. The nature of this damage is defined in the accompanying table below. With severe damage, windows and door frames are distorted, floors slope noticeably, walls lean or bulge noticeably and there is some loss of bearing in beams. Extensive work involving removal and replacement of sections of walls would be required, especially over doors and windows and crack widths would be on the order of 15–25mm, depending on the number of cracks. Apache Leap, US Hwy 60 and Devil's Canyon are all forecast to lie well beyond this limit at Resolution, within the zone of negligible damage (white zone in plot below). A building founded at those locations would only experience hairline cracks less than 0.1mm in width. As noted, buildings are much more sensitive to strains than a rock mass

and so the rock mass at these locations would not exhibit any visible cracking or be subject to any damage. The mining-induced tilt is also forecast to be very small at these locations, far less than what could cause toppling of the rock pillars or could be visible to the naked eye.

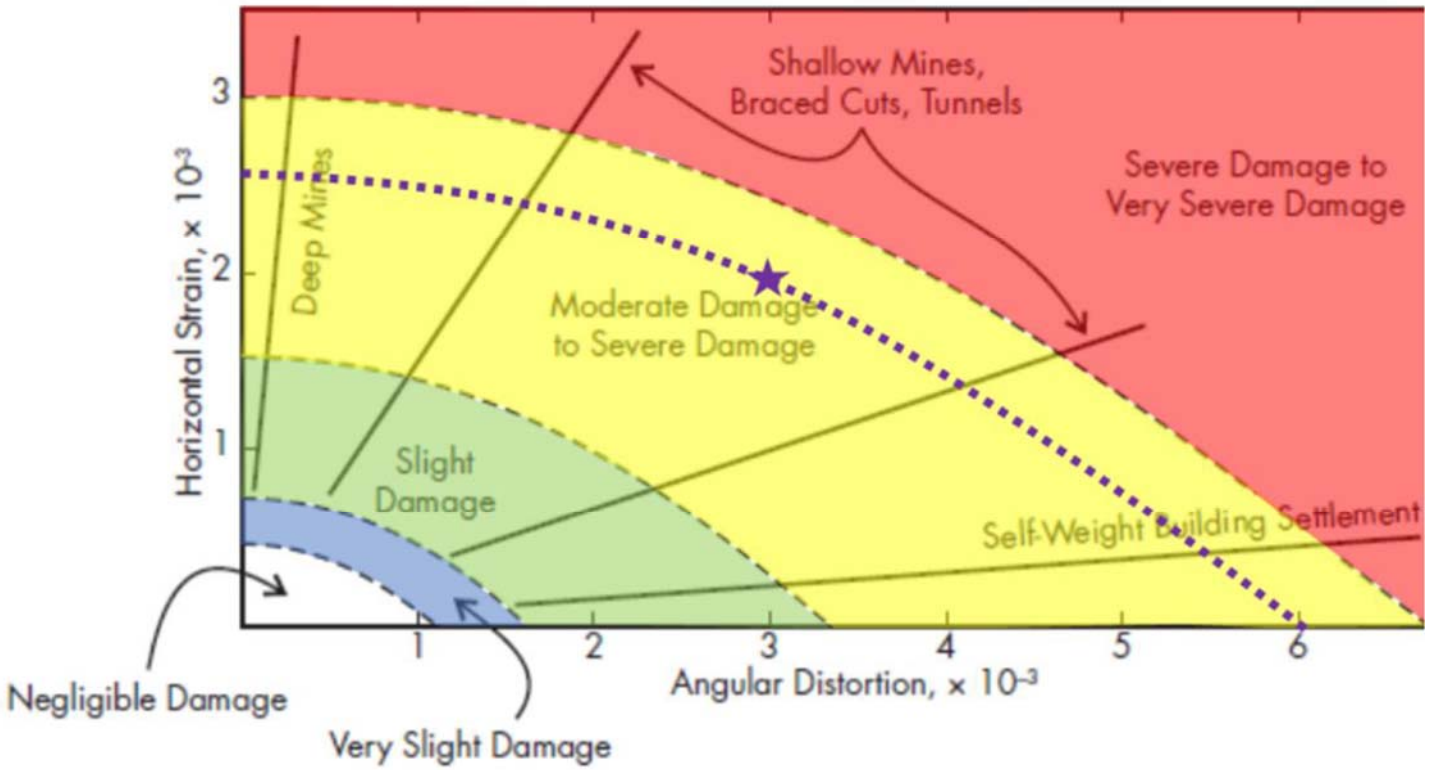

Table 8.9-4 Classification of building damage

Class of Damage	Description of Damage*	Repair	Approximate Width of C
Negligible	Hairline cracks	None	<0.1
Very slight	Cracks in exterior brickwork visible upon close inspection; possible isolated slight fracture in building	Fine cracks easily treated during normal redecoration	<1
Slight	Several slight fractures inside building; visible external cracks; doors and windows may stick slightly	Cracks easily filled; redecoration probably required; some repointing may be required for weather tightness	<5
Moderate	Doors and windows sticking; weather tightness often impaired; utility service may be interrupted	Cracks may require cutting out and patching; recurrent cracks can be masked by suitable linings; repointing and possibly replacement of a small amount of exterior brickwork may be required.	5–15, or several cracks :
Severe	Windows and door frames distorted; floor slopes noticeably; walls lean or bulge noticeably; some loss of bearing in beams; utility service disrupted	Extensive work involving removal and replacement of sections of walls, especially over doors and windows	15–25, also depends on cracks
Very severe	Beams lose bearing, walls lean badly and require shoring; windows broken by distortion; danger of instability	Major work involving partial or complete reconstruction	Usually >25, depends or cracks

Source: Adapted from Wahls 1994.
*Location of damage in the building or structure affects assessment of degree of damage.
†Crack width is only one aspect of damage and should not be used solely as a measure of it.

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Matthew E. Pierce, Ph.D., P.Eng.
Mining/Geological Engineer
1501 West 28th St.
Minneapolis, MN, USA 55408
Mobile: +1-612-201-7560
www.pierce-engineering.com