International Journal of Mining Science (IJMS)
Volume 1, Issue 1, June 2015, PP 10-16
www.arcjournals.org

Pot-Hole Subsidence Potentiality in Nongtrai Limestone Mine of Lafarge Umium Mining Private Limited, Shillong, Meghalaya

Amar Prakash*, Ajay Kumar, Kalendra Bahadur Singh

Scientist, Central Institute of Mining & Fuel Research, Dhanbad, India
amar_cmri@yahoo.co.in

Abstract: *The Nongtrai limestone mine of Lafarge Umiam Mining Private Limited (LUMPL) is located in the East Khasi Hill district of Meghalaya. Limestone terrain is prone to solution features such as pot-holes. Potentiality of pot-hole subsidence occurrence is assessed based on site history, climatic condition in terms of rainfall, intact rock property and ground water of the area. There are past cases of two pot-holes around 20 m down the southern side of the mining lease boundary. The mine is close to Cherrapunjee Mawsynram belt and therefore the average annual rainfall ranged from 2000 to 5000 mm. The rock type is highly jointed and fracture in nature. The thickness of the top limestone varied from 100 to 200 m. The existence of void in the form of cavity or open fractures is studied in accordance with borehole data and Ground Penetrating Radar (GPR) survey. Pot-hole prediction is evaluated based on ratings of depth of cover, weak overburden, geological discontinuities and water seepage. Mitigative measures are also suggested for safety during mining operation.*

Keywords: *pot-hole, rainfall, limestone, groundwater, voids*

1. Introduction

Pot-hole, a naturally occurring geologic phenomenon, is common in areas underlain by limestone (Prakash and Singh, 2006). They are caused by various mechanisms, including water seepage, rainfall, earthquakes, limestone dissolution and underground excavations, among other factors (Yejin et al., 2015). The occurrence of subsidence events in various geological settings is an increasing hazard (Carminati and Martinelli, 2002). It does not give any indication before its occurrence. Coal mining particularly at shallow depth with saturated weak overburden and geological discontinuities poses serious threat of pot-hole subsidence (Lokhande, 2012; Whittaker and Reddish, 1989; Kerridge, 1952 and Singh, 2007). Similarly limestone terrain has also very much potential for the natural occurrence of pot-holes in saturated condition. The mechanism of pot-hole starts with dissolution of atmospheric water with some amount of carbon dioxide (CO_2) to form carbonic acid (H_2CO_3). This carbonic acid infiltrates into underground water which encounters carbonate rocks like limestone. This carbonic acid reacts with calcite ($CaCO_3$) and produces calcium ion (Ca^{+2}) and carbonate ion (HCO_3^{-2}). The dissolved limestone in the form of calcium and carbonate ions can travel away due to hydraulic gradient, thus underground void is formed. Many interconnected voids form cavern and a landscape many pot-holes formed by dissolution of limestone is called Karst topography. These underground voids can cause movement of overlying strata into it after attaining critical size and thus pot-hole appears on the surface.

The Nongtrai limestone mine of Lafarge Umiam Mining Pvt Ltd (LUMPL) lies in Nongtrai Durbar falling within Shella confederacy in the East Khasi Hill district of Meghalaya. The mine is located in a remote area at the western side of Umiam river on the foothills of Shillong Plateau, close to the border of India-Bangladesh. The mining lease area is 100 Ha ranging from latitude 25^{o}11'18"N-25^{o}11'55"N and longitude 91^{o}37'28"E-91^{o}37'57"E. Pot-hole probability is highly site-specific and cannot be accurately characterized on a statewide basis. The study encompasses outcome of investigations with respect to assessment of pot-holing in mining area.

2. Geology of the Area

Geologically, the strata of the area form a part of the Cretaceous-Tertiary sedimentary sequence that occupies the southern fringe of Meghalaya Plateau. The calcareous and cal-carenaceous formations of the region belong to the Jaintia Group of Eocene period which are considered equivalents of Sylhet Limestone Formation of the Bengal Basin. The Jaintia Group is essentially a calcareous facies representing shelf sediments and has been divided into three formations, viz., the Langpar, the Shella and the Kopili Formations. The Langpar Formation, the basal member of Jaintia Group, consisting of calcareous shale, calcareous sandstones and impure limestone rests over a thick group of conglomeratic beds that overlie non-conformably the Sylhet Traps on the margin of the plateau. The Shella Formation of which the lithological units of the area form a part, consists of three sandstone and three limestone members beginning with a sandstone over the Langpar Formation. These lithological units have been designated successively as Therria Sandstone, Lakadong Limestone, Lakadong Sandstone, Umlatodoh Limestone, Nurpuh Sandstone and Prang Limestone, which together account for a total thickness of about 540 m. The limestone formation occurring over the area belongs to Prang Limestone unit. The thickness of the top limestone varies from 100 to 200 m according to variation in the ground relief. The base of this lime stone is not exposed in the present mining block.

3. Ground Condition

3.1. Backdrop

Site history is one of the guides to assess the hazard of pot-hole. The past record does not show any occurrence of pot-hole within mining area. But there are cases of pot-hole subsidence at two places around 20 m down the southern side of the mining lease boundary as shown in Fig. 1. Dimension of one pot-hole at the base was 50 m by 27 m whereas another pot-hole was 60 m by 24 m along major and minor axis respectively. Hence, the past history indicates the proneness of occurrence of pot-hole in this region.

3.2. Climatic Condition

Rainfall aggravates proneness of subsidence over old workings (Prakash et al., 2010). Rainfall absorbs carbon dioxide and reacts with decaying vegetation, creating slightly acidic water. When this water reaches the limestone aquifer, it moves through spaces and cracks slowly dissolving the limestone and creating a network of cavities and voids. A pot-hole is formed when the land surface above a cavity collapses or sinks into the cavity or when surface materials are carried downward into the voids (Anon., 2002).

Rainfall is generally heavy, average annual rainfall ranged from 2000 to 5000 mm. To the north on higher elevations, the Cherrapunjee Mawsynram belt of Khasi Hills has the distinction of having the World's heaviest rainfall with an average of 12000 mm per year. The rainfall data of last ten years in this region is given in Table 1.

3.3. Intact Rock Property

The competency of rock above void is important, and it is estimated from the compressive strength of overlying rock. The overall uniaxial compressive strength (UCS) of limestone in the mining area was 114.41 MPa (Anon., 2010) which assured higher strength of rock.

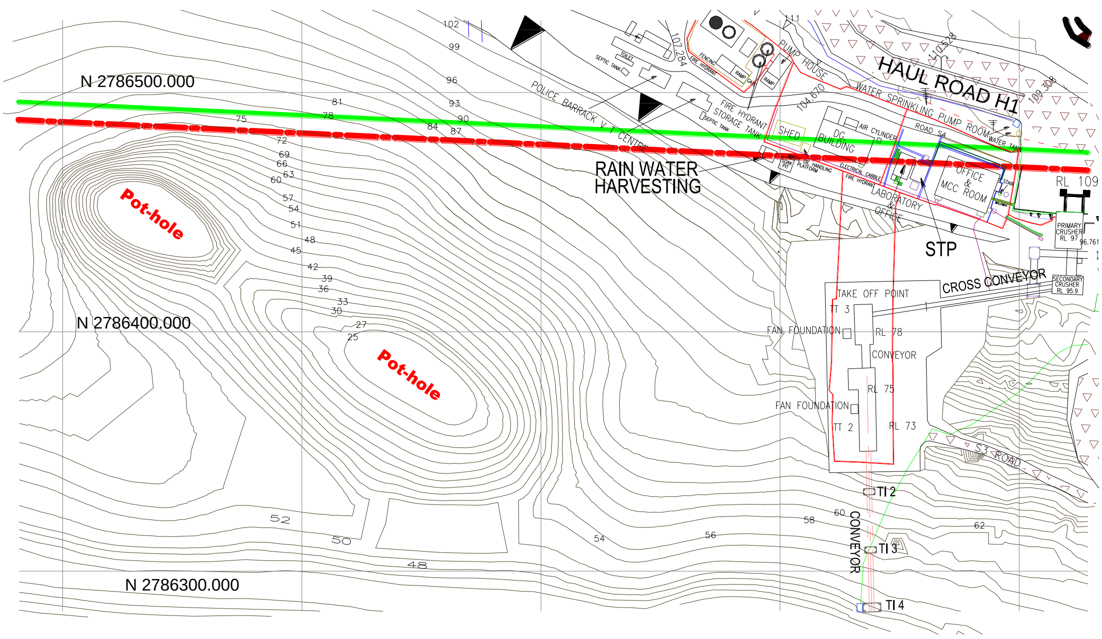

Fig1. *Pot-holes at the southern side of the Nongtrai limestone mine boundary*

Table1. *Rainfall data at Nongtrai limestone mining region*

Sl. No	Year	Rainfall Data (mm)
1	2005	8281.3
2	2006	9503.8
3	2007	11018.0
4	2008	10305.5
5	2009	10476.0
6	2010	10026.1
7	2011	6827.3
8	2012	7915.0
9	2013	5772.8
10	2014 till October	7859.3

3.4. Groundwater

Underground cavities are produced by dissolution of soluble rocks, make karst highly fragile and delicate environment, prone to subsidence (Lamont-Black et al., 2002). As the limestone dissolves, pores and cracks are enlarged and carry even more acidic water. Water not only contributes to the chemical dissolving of the limestone but it also affects the support or lack of support provided to a cavity when the water level changes. (www.watermatters.org/hydrology/sinkholes). Pot-hole development typically occurs over an extended period of time, but sudden and catastrophic failures occurs, especially during extreme fluctuations of groundwater levels from prolonged wet and dry periods (www.geology.ar.gov/geohazards/sinkholes).

Ground water level measured from January, 2013 to November, 2014 at three different locations namely blasting sign board (near border road), near mine entry gate and transit house premises, located at the periphery of the mine, showed a constant reading at around 50 m.

3.5. Existence of Voids

Cave locations within a limestone are unpredictable. They commonly have no surface indication (Waltham, 1994). The existence of voids was interpreted through borehole data. The borehole data showed existence of cavity/fractured void at different depth at different boreholes. The presence of voids nearest to surface in different boreholes is shown in Fig. 2 which ranged from 0.20 m to 22.20 m from the surface. But, these voids are not continuous. Had they been continuous, there would have been pot-hole in the surface.

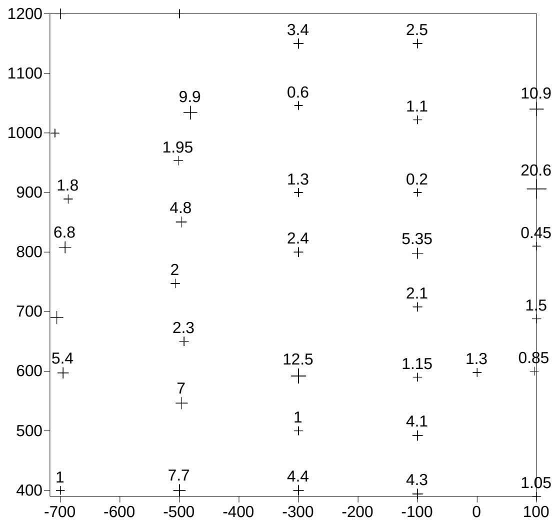

Fig2. *Depth (in m) of void from the surface at different borehole positions*

3.6. Geo-Mining Status

Mechanized opencast method of mining by drilling and blasting was in progress. Five benches were developed in the mine. The status of rock mass along each bench was physically investigated. It was found from the exposed benches that the rock was weathered to a depth of 3 to 4 m with wide cracks especially in the top bench. National Geophysical Research Institute (NGRI), Hyderabad conducted mapping of underground voids/cavities by Ground Penetrating Radar Surveys upto a depth of 15 m (Anon., 2013). The outcome of the study revealed that the rock of the study area was highly weathered having vertical fractures and at most of the places filled with clayey material (Fig. 3).

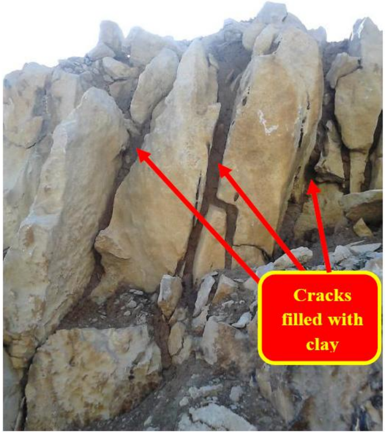

Fig3. *Vertical fractures filled with clayey material*

Crevices with an opening of 0.40 to 0.50 were also observed at the surface as shown in Fig. 4. At places, in the lower bench fractures were closely spaced (Fig. 5).

Fig4. *Developed cracks at the surface*

Fig5. *Closed fractures at bottom bench*

4. Pot-Hole Potential Assessment

The main causative factors of pot-hole subsidence are presence of voids at shallow depth of cover, weak overburden, geological discontinuities and water seepage (Singh and Dhar, 1997; Singh, 2007). These four factors have been assigned certain ratings (Table 2). The individual ratings of each causative factor are summed up to know the pot-hole potential ratings for the evaluation of risk of pot-hole subsidence as given in Table 3. The risk of pot-hole subsidence is divided into four classes. These classes are high, medium, low and very low with 80-100, 60-80, 40-60 and 0-40 pot-hole potential ratings respectively.

Table2. *Ratings based on parameters (Singh, 2007)*

Parameter	Rating
Shallow depth	30
Uniaxial compressive strength	30
Geological discontinuities	20
Water seepage	20

Table3. *Classification for risk of pot-hole subsidence (Singh, 2007)*

Sl. No.	Class	Pot-hole potential rating	Risk of pot-hole subsidence
1	I	80-100	High
2	II	60-80	Medium
3	III	40-60	Low
4	IV	0-40	Very low

The rating for each causative factor, i.e., depth, overburden strength, geological discontinuities and water seepage is summed up to know the risk of pot-hole at Nongtrai limestone mine. The depth of void is less than 30 m and hence rated as 30. The strength of overburden is high in this area and therefore rated as 0. The geological discontinuity has been rated as 20 due to presence of joints at 0.2 to 0.3 m spacing. Water seepage is taken as 20 due to presence of closely spaced joints and crevices with openings. The pot-hole potential ratings of pot-holes at Nongtrai limestone mine is 70. Thus, the risk of pot-hole in this type of rock formation is medium. However, there is no case of any pot-hole during mining. The other causative factors of pot-hole are lowering of ground water and rainfall. Heavy rainfall, in this region, is further likely to enhance the potentiality of pot-hole occurrence.

5. Mitigative Measures

The following mitigative measures were proposed be adopted to avoid such occurrence of pot-holing at Nongtrai limestone mine:

5.1. Filling of Cracks

Open surface cracks in limestone terrain should be filled in to avoid downward movement of water which can cause dissolution of calcite particularly in rainy season.

5.2. Drainage

Proper drainage should be maintained to drain surface water outside the mining lease area to avoid infiltration of surface water into groundwater. This will also prevent to some extent the formation of underground void in the limestone.

5.3. Void Detection

Geophysical technique like GPR can be used to know the extent, depth and size of void prior to occurrence of pot-hole on the surface. This will help to shift the manpower as well as machines at the safer place.

6. Discussions

It is well known that limestone is dissolved in acidic water. And dissolved water moves along open joints/fault causing further widening of joints. Such widening of jointed limestone creates void in it. And when void reaches to critical size, the overburden tends to collapse into it and thus pot-hole appears on the surface. Pot-hole potential assessment was also done to know the possibility of pot-holes. The overall rating of pot-hole potential at Nongtrai limestone mine of the LUMPL was 70. This comes under medium risk of pot-hole. But, heavy rainfall further enhances the possibility of pot-holing phenomenon. Thus, possibility of pot-hole cannot be ruled out and it may occur in future. The following precautionary measures can be taken to reduce the possibility of pot-hole:

a) Open surface cracks in mining leasehold area should be filled in to avoid downward movement of water which can cause formation of cavity following the dissolution of calcite particularly in rainy season.

b) Proper surface drainage should be maintained to drain water outside the mining lease area to avoid infiltration of water into groundwater. This will also prevent to some extent in the formation of underground void in the limestone.

c) Geophysical technique like Ground Penetrating Radar (GPR) should be used to detect the existence of voids after development of each bench for the safety of manpower as well as machines.

7. Conclusion

The main causative factors of pot-hole subsidence are shallow depth of void open geological discontinuities in the form of crevices and fractures, water seepage and heavy rainfall. The potential risk of pot-hole occurrence in this limestone formation was medium which may further aggravated by heavy rainfall. Open surface cracks should be filled in to avoid downward movement of water particularly in rainy season. Proper surface drainage should be maintained to drain water outside the mining lease area to avoid infiltration of water into groundwater. Geophysical technique like GPR can be used to know the extent, depth and size of void before the formation of pot-hole on the surface to shift the manpower as well as machines at the safer place in time.

Acknowledgements

The authors are thankful to the Director, Central Institute of Mining and Fuel Research, Dhanbad, for permitting to publish the paper. The views expressed in this paper are those of authors and not necessarily of the organizations they represent. The support received from mining industry for facilitating data collection and field studies is thankfully acknowledged.

References

Anon. (2002). Understanding subsidence, The Hartford Loss Control Department, p 6.

Anon. (2010). Report on applicability of surface miner in Nongtrai limestone mine of Lafarge Umium Mining Pvt Ltd in Meghalaya, India, July, p 66.

Anon. (2013). Report on Ground Penetrating Radar Scanning at Lafarge Umium Mining Pvt Ltd., Shillong, Meghalaya, NGRI, Hyderabad, August, p 56.

Carminati, E. and Martinelli, G. (2002). Subsidence rates in the Po Plain, northern Italy: the relative impact of natural and anthropogenic causation, Engineering Geology, 66, pp. 241-255.

Kerridge, F. W. (1952). Contribution to discussions on North-South Wales Institute of Engineers, Vol. 67, p 155.

Lamont-Black, J., Younger, P. L., Forth, R. A., Cooper, A. H. and Bonniface, J. P. (2002). A decision-logic framework for investigating subsidence problems potentially attributable to gypsum karstifi8cation, Engineering Geology, 65 (2-3), pp. 205-215.

Lokhande, R. D. (2012). An investigation into the causes of pot-hole subsidence and its prediction in underground coal mining. Ph. D. Thesis, Indian School of Mines, Dhanbad, p 219.

Prakash, A. and Singh, G. (2006). Land degradation due to pot-hole subsidence, Minenvis, No. 50, September, pp. 1-14.

Prakash, A., Lokhande, R. D. and Singh, K. B. (2010). Impact of rainfall on residual subsidence in old coal mine workings, Journal of Environmental Science & Engineering, Vol. 52, No. 1, January, pp. 75-80.

Singh, K. B. (2007). Pot-hole subsidence in Son-Mahanadi master coal basin, International Journal of Engineering Geology, Vol. 87, pp. 88-97.

Singh, K. B. and Dhar, B. B. (1997). Sinkhole subsidence due to mining, International Journal of Geotechnical and Geological Engineering, Vol. 15, pp. 327-341.

Waltham, A. C. (1994). Foundations of engineering geology, published by E&FN Spon, pp. 54-59.

Whittaker, B. N. and Reddish, D. J. (1989). Subsidence—Occurrence, Prediction and Control: Elsevier, p 528.

Yejin, Y., Jin, K. and Ji-whan, A. (2015). Causes and prevention for sinkhole in limestone mine, International Journal of Emerging Technology and Advanced Engineering, Vol. 5, No. 3, March, pp. 382-390.

www.geology.ar.gov/geohazards/sinkholes

www.watermatters.org/hydrology/sinkholes