Establishing Secret Mining Resulting in Huge Ground Subsidence Due to Conflicting Economic Interests and Repairing Damaged Structures - A Case Study

Abdul Jabbar Khan*, Syed Ali Rizwan, Muzna Anam**, Zafar Mahmood*****

* National University of Sciences and Technology (NUST), Islamabad, Pakistan.
** National University of Computer and Emerging Sciences, Lahore, Pakistan.
*** Imam Mohammad Ibn Saud Islamic University, Riyadh 11564, Saud Arabia.
Corresponding Author E-mail: abduljabbar@nice.nust.edu.pk,
Received: 24-04-2023, Received in revised form: 28-11-2023, Accepted: 01-12-2023, Published: 31-12-2023

Abstract:

An interesting study is reported on establishing secret mining activity resulting in severe ground subsidence which occurred and was corrected later in a village called Dhery Saydan located near the world famous salt range region of Pakistan and is located on a hill top with about 2000 inhabitants. After reviewing many cases of similar nature and on basis of geophysical techniques like resistivity survey, it was established that secret mining activity had taken place resulting in massive cracking of dwellings coupled with sinking of water table. Thereafter a suitable construction methodology was applied to correct the huge structural defects and make the dwellings functional.

Keywords: Ground subsidence, secret mining, Ground water depletion, electrical resistivity test and repair works

Introduction

Mining industry always plays an important role in development of any country and is considered as backbone of any economic growth. However, such vast mining operations also have some severe environmental impacts that cannot be neglected. So, there is a need to review existing policies and legal bindings to develop updated laws to mineral resource management and degradation of natural environment and habitats [1]. Active and even abandoned mines have potential of ground subsidence along with other environmental hazards. In populated areas such activities should be planned and executed carefully so as to minimize the mining related issues [2].

Pakistan has significant coal and salt mining activities and has world's second largest salt mine and fourth largest coal deposit [3,4,5].

This study of conflicting economic interests reports a secret mining activity and its consequences as both the beneficiaries and the affectees belonged to same larger family. In this article, a case study, related to coal mining in Dheri Saydan, a village of Pakistan has been presented and discussed and related remedial measures have been practiced to overcome ground and buildings damages. Dheri Saydan village lies at $32^0 44'35.61''$ N and $72^0 53'45.07''$ E, at elevation of 2456 feet. The site is located in world famous salt range at Dhery Saydan Village. The whole area is well known for its coal reserves and is subjected to extensive coal and salt mining. At the concerned village, secret coal mining activities were being carried out under simultaneous mask of heavy gun fire resulted in huge ground subsidence afterwards. This phenomenon of subsidence resulted in huge cracks in the village dwellings and sinkholes in nearby agricultural lands. The experts of both parties were giving grossly opposite opinions. The court appointed panel decided to use the technique of geophysical testing to detect underground mining activities. So after carrying out physical surveys and interviews, electrical resistivity tests were performed under police protection. Considering the opinions of geologists, geotechnical and structural experts the anomalous zones identified in resistivity profiles were possibly the cavities or tunnels made by secret mining activities which could be further confirmed by additional exploratory drilling at suspicious locations. From structural stand-point, the type of cracking, their location and sizes were not mainly due to seismic activity of the area considering single story dwellings made with stone and brick masonry using cement as binder. The unavailability of water in the concerned locality seemed to be the dewatering activity carried out by the mine operators and it could not be linked with the water withdrawal by the two distantly located cement factories. The water migration, either through pumping or seepage in the underlying rocks of dwellings seemed to have added to the subsidence phenomena resulting in huge fissures, cracks, sinkholes and differential settlement in existing civil structures. Even some cracks extended up to a depth of 5 meters. The villagers filed a petition in High Court against mining companies alleging that the mine owners were responsible for this damage.

Cracks in dwellings were found in various structural elements like ground floors, walls and roofs. The amount of cracking varied from cracks with small widths to cracks of several inches and sometime feet. The extent of cracking can be considered as heavy and difficult to treat. Skills in area of geotechnical engineering, structural engineering and concrete materials engineering were required and were applied to correct the problems. The possible causes of cracking are ground subsidence include secret mining, total seam extraction, initiation of cracks/fractures in rocks, penetration of water into calcite rock formation having embedded coal seam, earthquake related activity and other possible mechanisms. The causes were looked at from all possible angles and finally some conclusion was arrived at. The purpose of this paper is to briefly review the state of the art of subsidence engineering in Pakistan and to identify potential problem areas and to suggest possible remedial measures.

Geological framework of Study Area

The Salt Range and Potwar Plateau being active foreland fold-and-thrust belt of the Himalayan portion of Pakistan, [6, 7, 8] is about 175 kilometers long east-northeast-trending thrust front which emerges abruptly from the Jhelum River plains. This thrusting in the Potwar dates in Miocene and Pliocene Era of geological scale. [9, 10] In west, the Salt Range bends northward direction (Fig. 1) and bound by a prominent north-trending, strike-slip fault [9,11] while on eastern end, complex thrusts pass into northeast-trending anticlines [8]. To the north,

https://doi.org/10.24949/njes.v16i2.754

this Range merges with the low relief upland of Potwar Plateau, except where dissected by the Soan River and its tributaries [12].

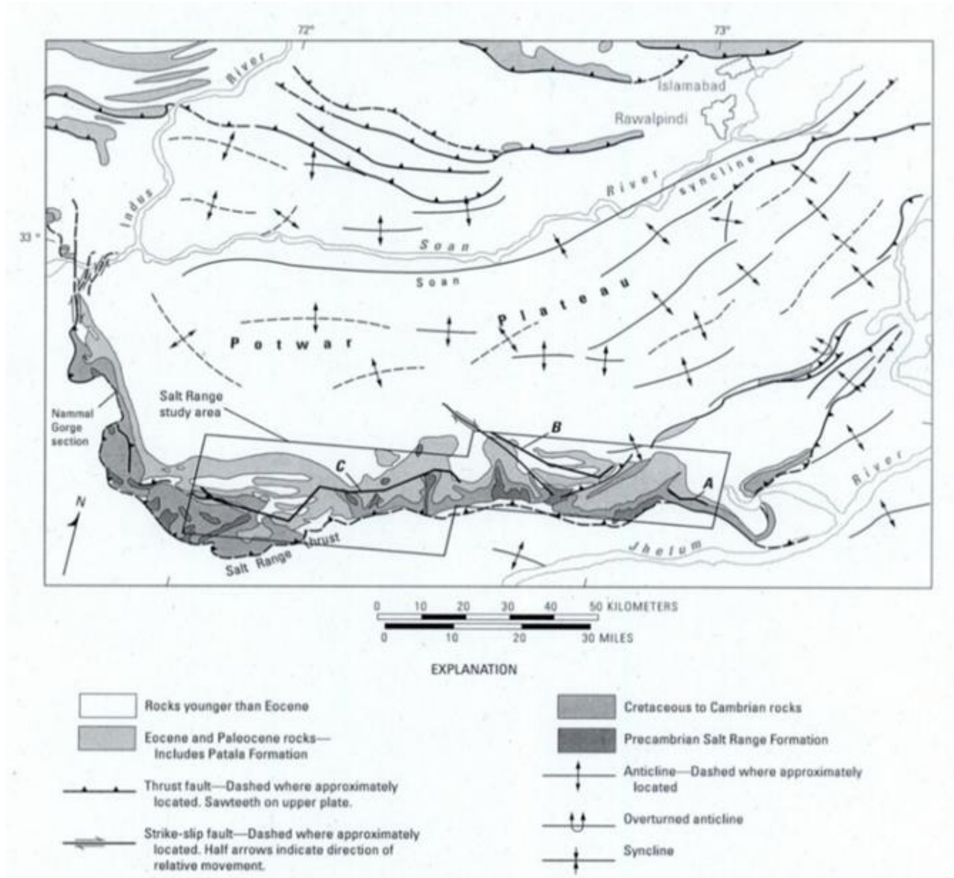


Fig 1: Map Showing Location and Generalized Geology of Salt Range Study Area [9]

The site area lies in Dandot and Waula portion of central Salt Range.In this part of the Salt Range, Paleocene coal-bearing rocks unconformably overlie Cambrian and Lower Permian rocks. The Cambrian rocks (Baghanwala Formation) consist of beds of pale-red to moderate-reddish-brown siltstone interbedded with mudstone and fine- to medium-grained sandstone. The Lower Permian rocks (Tobra Formation and Warchha Sandstone) consist of interbedded mudstone, siltstone, sandstone, and conglomerate that were deposited during the glaciations of Gondwana [8, 11, and 13]

The Patala Formation (5–90 m thick) consists of interbedded claystone, siltstone, mudstone, sandstone, marl, limestone, carbonaceous shale and coal. The formation conformably overlies the Lockhart and is conformably overlain by thick (>100 m) beds of limestone of Eocene age that consist of the (1) Nammal Formation (shaly, marly, nodular, skeletal mud-stone to wackestone) (2) Sakesar Limestone (nodular to massive bedded, cherty, skeletal wackestone to packstone), and (3) Chorgali Formation (interbedded marl and skeletal mudstone to wackestone) [14]. The Eocene limestones are unconformably overlain by the Miocene Murree and Kamlial Formations, which consist of beds of greenish-gray and brown, massive, coarse-grained to pebbly sandstone alternating with red and brown clay [7].

Material and Methods

Different case studies of similar natures were studied for better understanding of case under study [1, 6, 16, 2, 19, 20, and 18]. Different kind of knowledge was beneficial while dealing such case of interest. Based on different cases studied in the world, in areas of active mining, especially where total extraction is done, ground subsidence is contemporary with mining operations. In this case, ground deformations resulted from subsidence probably have caused structural damages starting with foundation settlement. Differential settlement, intensified pressure on subgrade walls, and other modes of soil-structure interaction are of equal significance. [16]. The detailed methodology of evaluation of reasons for subsidence and corrective actions applied later to rectify structural problems started with the site visits of authors has been explained in (Figure 2) . Information was gathered by asking questions from both the parties involved. Thereafter a strategy was adopted to confirm the secret mining activity. Electrical resistivity test was applied and its results are shown in Figure2, the most damaged residential building was selected and the following was steps were applied. All other building owners were asked to follow the same practice.

- Measurement of crack widths and their location
- Decision regarding the filling back of material back in cavities under/near crack

- Designing the composition and application of crack filler
- Curing
- Testing

In this case, the phenomena of subsidence caused irreparable cracks in residential buildings and sinkhole in nearby agricultural lands. During the visit, the mine operators were asked to give the alignments of the tunnels under operation and those which had already been abandoned. No report/drawing containing such alignments could be provided**.** It was decided later to carry out some study to ascertain the problem and do some actual tests to ascertain the alignments.

Establishing Reasons of ground subsidence and structural cracking

Originally three possibilities regarding ground subsidence and consequential structural cracking were listed including secret mining along inadequate back filling, and total seam extraction, relative slipping of clay sandwiched in lime stone boulders and earthquake related effects. The seismic history of the area was consulted and considering shallow dwellings on hill top using stone masonry thick walls, the seismic effects were rejected as being the source of subsidence. The remaining two issues were then studied and it was thought that the ground subsidence may be due to secret mining activity coupled with seepage of water in boulders making them to undergo relative slip and giving rise to subsidence.

In first visit, some geological data regarding litho- logy, bedding and other structural geological data was gathered along with structural inspection of buildings. In the figures below the extent and crack pattern in the dwellings can be seen in figure 3.

Fig 2: Flow diagram, showing detailed methodology

.

(a) Cracks in solid stone masonary wall

(b) Cracks near the door opening in the stone masonary

(c) Cracks in floor system

Fig 3: Crack Pattern in Dwellings.

Rock bodies are often heterogeneous and discontinuous and may contain cracks, fissures, joint, faults and bedding planes with varying degree of strength. All these planes of weakness control the behavior of rock's strength. The frequency, orientation and strength along these joint with respect to loading direction are much important in context of stability, as shown in figure 4. Reliable information about joints and strength estimation of jointed rock bodies is needed to reliable and economical designs for tunnels, open pits, dam foundations and underground chambers. [17, 2].

Hydro-geological conditions are often complex in many coal mines and are flooded by water inrush, especially, when coal mines are under any aquifer body. If water inrush happens, it may lead to stress readjustment, strata failure and hydraulic conductivity enhancement, thereby flooding mines and causing lowering (in some cases, complete removal) of water table in the area. [18]. Same sort of phenomena happened in Dheri Sayadan village. Circle inventory method along with available literature on study area, was used to study fracture in rocks and rock classification parameters were established as shown in figure 5 and Table 1:

Fig4: Orientation of bedding and joints (Mostly joints are dip joint)

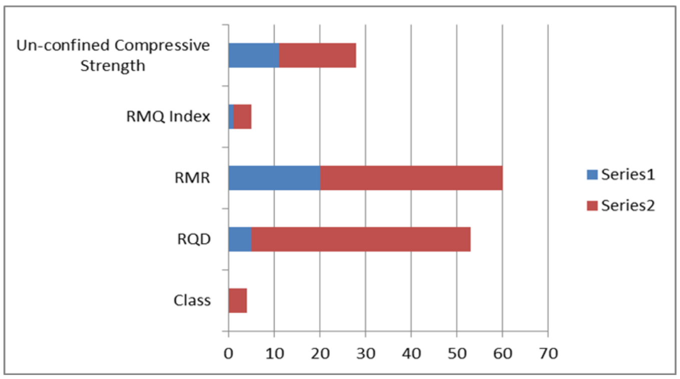


Fig 5: Showing properties of rocks in study area

Sr. No.	Circle No.	Density cm^{-1}	Porosity%	Permeability 10^{7} Darcy
1	5	0.144	13.2	6.9
2	6	0.16	12.6	7.5
3	8	0.08	10.4	10.1
4	4	0.104	9.9	6.08
5	15	0.109	7.2	4.4
6	9	0.07	7	6.7
7	10	0.063	6.4	3.5

Table 1: Fracture Density, Porosity and Permeability of Sakesar Limestone (Coal seam Overlying rock unit)

Structural Health Investigation

First of all, existing structures were examined and information about damages was collected by surveying these structures. Structures were divided into three groups; totally collapsed, partially collapsed and slightly damaged structures. Major cracks and mode of cracking was observed and some cracks were deeper than 2 ft, 1.5 ft wider and were interconnected with each other. Various reasons for cracking were listed and then short listed including; secret coal mining, differential settlements, water seepage within boulders and consequent dislocation of boulders and seismic effects. Sinkholes were also observed in the vicinity and existing ground water was not available as it diminished gradually over time possibly after consumption in mining activity or may due to sinking.

Geophysical methods have always been very helpful in detecting underground mine working. Some methods are rapid and are inexpensive and can be used for both shallow and deep targets. In addition, geophysicists may help to delineate the number and location of exploratory borehole for further confirmation [21]. In second visit, geophysical testing was planned to execute, but due to some financial and technical constraints, only Electrical Resistivity tests were done which provided clues to ascertain the basic cause of subsidence.

Electrical Resistivity test was conducted by using AGI Sting R1 IP instrument. Electrodes were laid at an interval of 6m to cover a wide area. The test was performed in sunny weather. The area of study was a small half ridge mountain with surface outcrop of Sakaser Limestone. Resistivity measurements were taken in the area to detect the cavities in order to alert city authorities. Resistivity data along most of the streets were collected with the array Dipole-dipole that consisted of 28 grounded electrodes. We performed 2-D inversions to the data in order to get a 2-D resistivity image of ground under study.

Geophysics might be effective when target of interest has a physical contrast with surrounding ground. Coal itself having high resistivity compared to other sedimentary rock types and this property formed the basis for detecting coal from borehole logs and DC resistivity surveying as early as 1934 [22]. Likewise, void also has high resistivity values so if the void is dry, it will be difficult to detect with electrical measurements. Hence, it becomes difficult to distinguish high-resistivity coal from a void.

The RES2DMOD program by Loke [23, 24, and 25] offers the possibility of calculating theoretical electrical measurements for different subsurface conditions that can then be used as input to the RES2DINV program based on finite element.

It was decided to conduct electrical resistivity tests which resulted in graphs capable of showing anamolous regions, their location and size. The test was run by giving the impression of carrying out a survey for the supplying telephone and water lines. Had the people of area known that it was being carried out for establishing secret mining, it would have been impossible to carry out this test due to armed villagers having conflicting economic interests. Though the support of Police was also requested, it was found that it had also been financially influenced. Towards the end of tests, some of the villagers got suspicious and the work had to be completed hurriedly using the help of group of villagers in favor of unearthing the crime. Figure 4 shows the electrical resistivity test in progress.

Results and Discussions

As already explained, electrical resistivity test using AGI Sting equipment was performed along
the axes shown in Fig. 4, which has revealed points given below:

- Anomalous zones have been marked in resistivity profiles indicated by pointed arrows (Figs. 15, 16, and 17)

- These anomalous zones may have been created possibly due to some underground mining activity by mining contractors
- Ground subsidence (sink holes) and floor cracks (few) extending up to depth of 5m.
- Some expected cavities show refilling by low resistivity soft material

The overburden thickness plays a very important role in subsidence. Generally, subsidence decreases with increasing overburden thickness. Shallow mining faces more subsidence relative to mine having more overburden thickness with less discontinuities [19]. After establishing secret mining and reasons of structural damages, the following results have been drawn and discussed as follows

Fig 6: Electrical Resistivity test in progress at Dhery Syedan with AGI Sting Equipment.

.

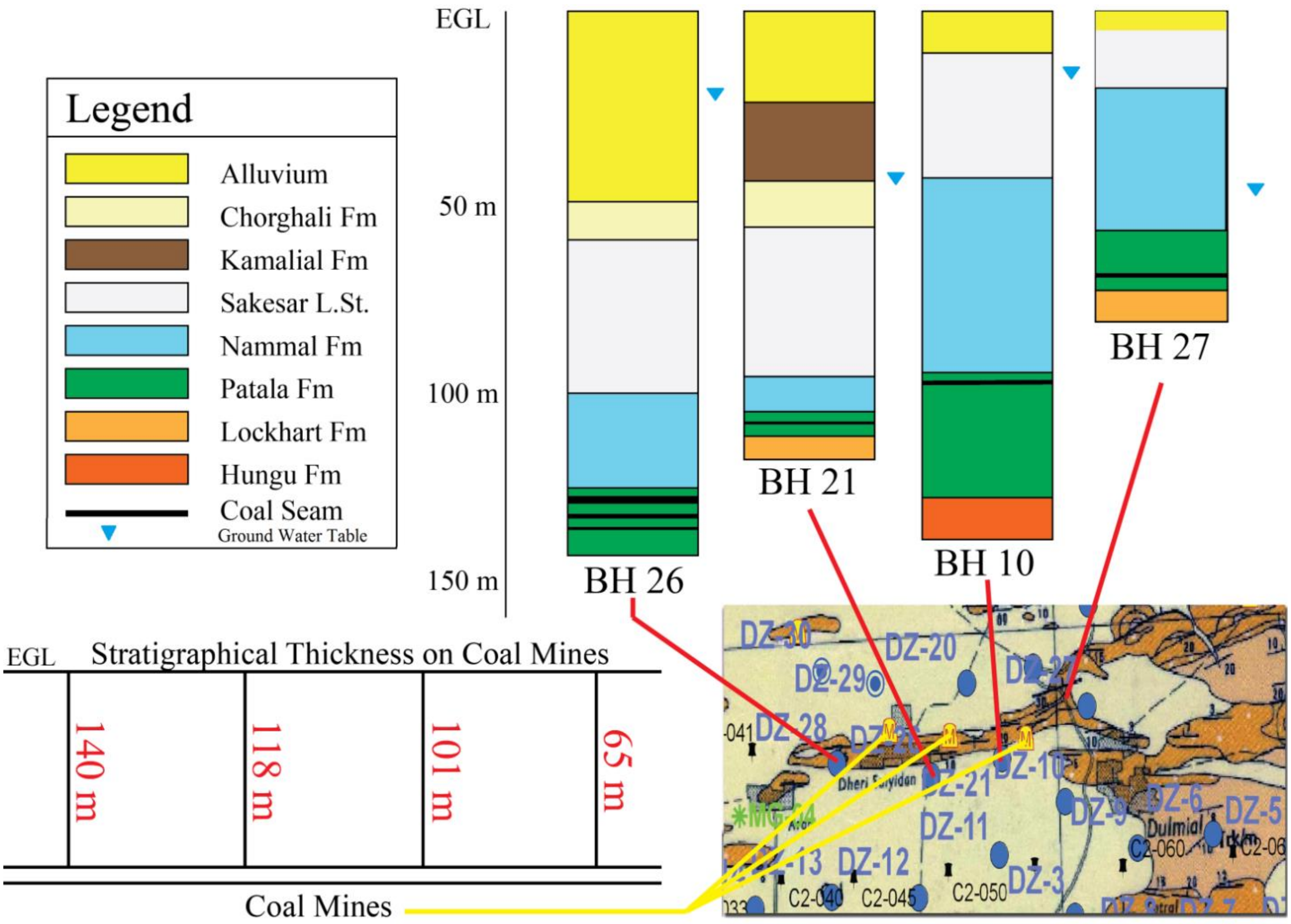


Fig 7: Result of drilling and overburden thickness over mines in study area.

Anomalous Zones

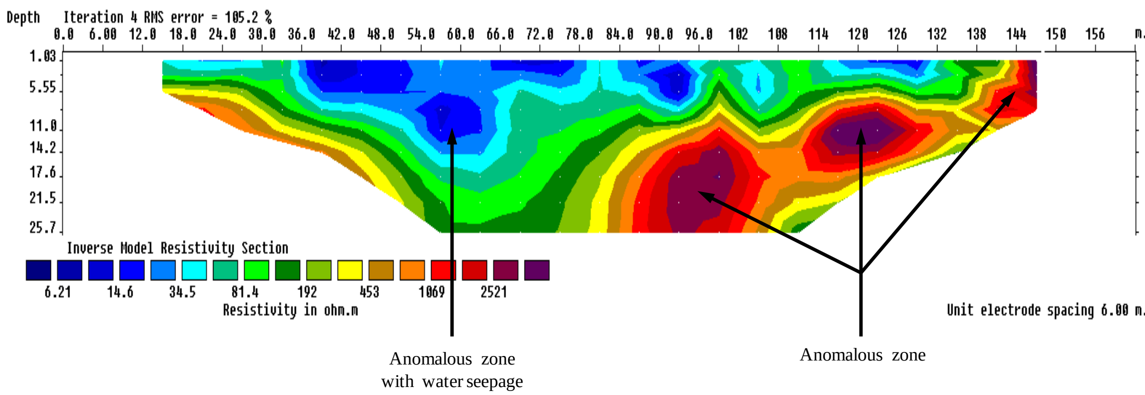
Anomalous zones identified in resistivity profiles (Figs. 15, 16, and 17) may possibly be cavities or tunnels made by mining activities. Location of these anomalous zones is marked on Fig 18, and their coordinates are given in Table 2. These cavities were confirmed by further confirmatory/exploratory drilling at suspicious locations, as shown in Figure 7. Moreover, geophysical exploration techniques like resistivity survey, Ground Penetration Radar(GPR) and Multispectral Analysis of Surface Waves(MASW) can be helpful in marking more accurate points for confirmatory drilling. Although a buffer zone has been marked by the Department of Mines and Minerals (DMM), but these mines are very close to Dheri Sayidyan village. Moreover, these operations involve shallow mining, so any collapse in these mines may lead to ground subsidence.

(a) Locations for Electrical Resistivity Test (b) Possible Location of Anomalous zones

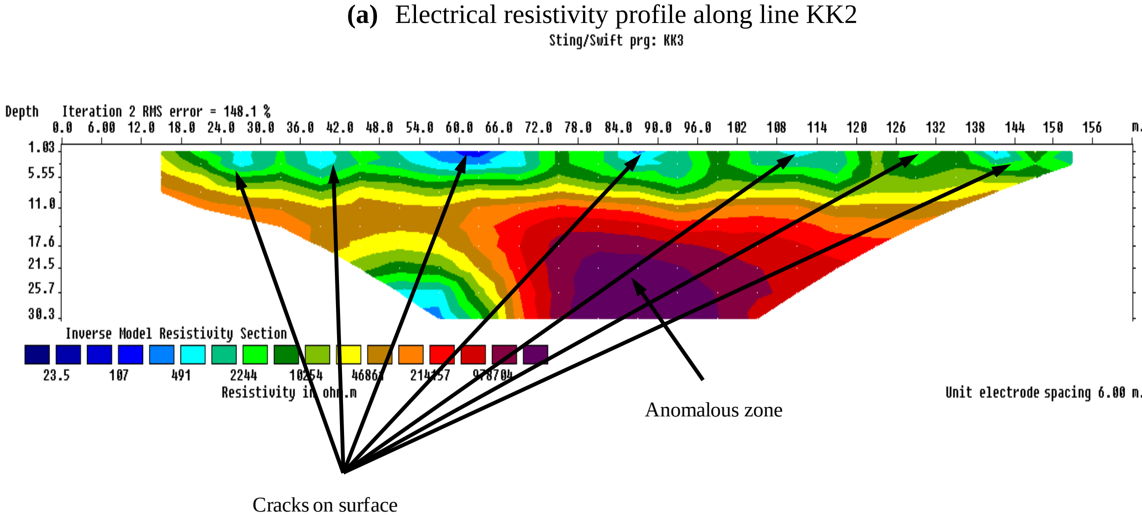
Fig 8: Locations for Electrical resistivity Tests and Anomalous zones.

Table 2: Coordinates of Anomalous Zones.

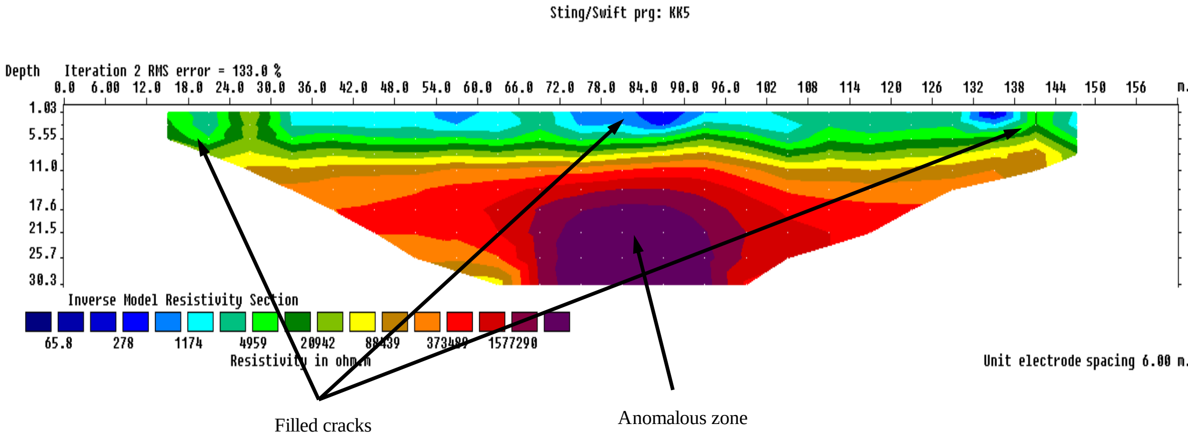
Serial No.	Northing	Easting	Serial No.	Northing	Easting
01	32”44’31.97N	72”53’42.05E	**05**	32”44’32.41N	72”53’49.23E
02	32”44’32.86N	72”53’42.69E	**06**	32”44’34.30N	72”53’49.32E
03	32”44’35.12N	72”53’43.02E	**07**	32”44’34.90N	72”53’49.16E
04	32”44’32.12N	72”53’45.90E			



(a) Electrical resistivity profile along line KK2



(b) Electrical resistivity profile along line KK3



(c) Electrical resistivity profile along line KK5

Fig 9: Profiles from Resistivity test with possible Anomalous Zones.

The presence of anomalous zones was confirmed due the maps print out of electrical resistivity tests showing the existence of anomalous zones and thus establishing secret mining activity. After having confirmed secret mining activity coupled with water seepage resulting, the slippage of boulders due to draining out of sandwiched clay, the repair work was carried out.

Repair Work

In self-compacting cementitious systems, special ingredients are usually used considering the types of placements and site constraints [26 ,27]. The packing concepts are also useful in reducing the mixing water content for a typical application self-compacting cementitious systems [29]. Locally available SRMs were also considered but due to site requirement these were not used. The literature reports that even shelf-life expired super-plasticizers can also be used though with marginally reduced efficiency [29]. Sulphate modifications are also helpful in making repairs in short open times [30] and especially in cold weather repairs [31].It is imperative to consider the shrinkage of cementitious systems and temperature accumulation while making repairs[32].It is suggested that a combinations of pozzolanic and inert locally available SRMs of a small particle size (less than that of cement) of average particle sizes D_{50} , compared with D_{50} of cement grains can also be used at typical repairs [33]. Volume changes which were possible to occur were considered in the light of literature [34] to avoid cracking. Such mineral admixtures should be used which help in placements and reducing water demand like fly-ash [35]

For the sake of brevity, the methodology adopted at the worst hill top location is discussed. Similar technique was used throughout the work by the inhabitants on self-help basis thereafter. There was a Cantilever retaining wall, consisting of rock stone pieces joined with cement mortar, of about 15-22 feet height having infill on inside and nothing on outside to generate passive soil pressure. The cracked area was replaced after removing the inside soil up to a depth of about 10 feet. Stone blocks were used with carefully suggested multi-component cement binder system including bonding agents. The other side (toe side) was provided with over-riding soil depth of about 7-10 feet before refilling on inner (heel) side of wall. Thereafter, the water supply and waste water lines were located, in the absence of drawings by using metal detectors and digging, and were relayed. It was felt that there existed boulders and stones of varying sizes and the sandwiching material soil might have migrated allowing these boulders and stones to have time dependent movements independently. So it was decided to design a suitable self-compacting grout system and apply it with a view to bind these stones and boulders together so that they act as a unit. It has been a difficult phase and only experienced engineers could do it. Applying the expertise and considering all the factors, multi-binder systems based on ordinary Portland cement (OPC) and calcium aluminate cement (CAC) along with fly-ash was used with corresponding calcium formate and lithium carbonate accelerators used in the proportions of OPC and CAC as determined in the laboratory flow tests satisfying open times, grout being able to make a kind of pre-placed aggregate concrete and strength requirements. The repairs were done in winters where night time temperature was near freezing during month of February. As a precautionary measure, the practices used for cold-weather concerting were observed. Laboratory designed Self-compacting and self-leveling grout system containing OPC-CAC-fly-ash ternary binders with accelerators was pumped because the depth and path of infiltration was not known though the crack widths ranging between three to eighteen inches. After about one week, the replacement work of floor systems was undertaken. Then the damaged portions of wall systems were reconstructed with cement sand mortar after applying SBR latex bonding agent. The cracks in columns and slab systems were repaired as suggested by the Second author. During repairs, lots of villagers used to see this kind of unusual re-construction. They were asked to select the repair teams and the recipes for the repairs were handed out, which were used in the sample severely cracked structure. The structural repairs were inspected and some were tested thereafter before allowing the owners to start using their dwellings. After rehabilitation, the snake bites in summer were eliminated and the reports are that ground water table is rising and it is hoped that water hand pumps would possibly be reinstalled. For the time being, the water supply is being made from the overhead water tank provided by the Government.

Conclusions

Mining induced ground subsidence are greatly influenced by onsite geological conditions, discontinuities, joints set and their orientation, Dip and Strike of beds, the depth of mining, overburden thickness, thickness of extracted coal seam, mining techniques in practice and support techniques used. It also, matters, the type of buildings, other civil structures, types of foundation under these structures and others construction techniques. During our literature review it is seen, similar structures response in similar manner during subsidence, so studies made in other areas even in other countries are helpful and comparable to some extent. It was observed, absolute ground displacement does not make severe damages to surface structure, while vertical displacements, even slight or uniform may cause un-repairable damages to land structures. These displacements may result in tensional cracks, buckling surface structures, dependent on magnitude of horizontal strain – tensile or compressive. The phenomenon of displacement is caused due to in practice shallow mining in Dheri Sayadan. Displacement is accelerated due to total seam extraction. Because, when total seam is extracted, the mining span is increased until a point is reached, where beams under roof starts to fail due exceeding capacity of roof load and larger span. As this practice continues, more roof strata participate in caving process. Mining acts have been developed like mining act 1923, 1935 and 1995 and National Mineral Policy have also been made. National Mineral Policy (1935) ‘s section 7.3 and National Mineral Policy (1995) ‘s section 8.7 state clear concerns about conservation of environment in mining areas. But, this has not been bothered in this case. Punjab Mining Concession 2002 also provide clear guidance for mining operations, especially Para 213(relates about buffer zone), 218(relates about un-authorized mining) and 227(relates about safe workings) are more relevant in this case. Like Para 213 states a 100 m buffer zone for any kind of civil structures like railway tracks, oil and gas lines, water reservoirs and buildings etc., which has been neglected, merely and mining has been carried out below the dheri sayadan village. Such negligence should be noticed seriously and mining laws should govern over the subject.

- There is need to review existing policies and legal bindings to develop updated laws to mineral resource management and degradation of natural environment and habitats
- Geophysics proved an excellent tool, while dealing this exotic project and is encouraged in such explorations

Acknowledgements

The authors extend their heartfelt thanks to the Geologists of Geological Engineering Department, Mining Engineering Departments of the University of Engineering and Technology Lahore. Thanks are due to experts of the Geotechnical Division of NESPAK, Faisal Town Lahore for the valuable informal inputs which made the work easy. Thanks are also due to the Laboratory staff of Structural engineering department and geotechnical engineering department of NUST Institute of Civil Engineering, National University of Sciences and Technology (NUST), Islamabad, Pakistan for their work under supervision of authors.

References

1. Ajit Kumar, Mayukh Sarkar 2012, Watershed Management: Focus On Mining Impacts National Conference on Sustainable Development of Groundwater Resources in Industrial Regions (SDGRIR 2012).
2. Mondal, D., Roy, P. N. S., & Kumar, M. (2020). Monitoring the strata behavior in the Destressed Zone of a shallow Indian longwall panel with hard sandstone cover using Mine-Microseismicity and Borehole Televiewer data. *Engineering Geology, 271*, 105593.
3. Malkani, M. S., & Mahmood, Z. (2017). Mineral Resources of Pakistan: provinces and basins wise. *Geological Survey of Pakistan, Memoir*, *25*, 1-179.
4. Khan, I. H. (2006). *Paleoenvironmental and tectonic reconstruction of the lower Eocene Ghazij Formation and related units, Balochistan, Pakistan: Implication for India-Asia collision*. University of New Hampshire.
5. Hughes, N. C., Myrow, P. M., Ghazi, S., McKenzie, N. R., Stockli, D. F., & DiPietro, J. A. (2019). Cambrian geology of the Salt Range of Pakistan: Linking the Himalayan margin to the Indian craton. *Bulletin*, *131*(7-8), 1095-1114.
6. Donnelly, L. J., Pirrie, D., Harrison, M., Ruffell, A., & Dawson, L. A. (Eds.). (2021, August). *A guide to forensic geology*. Geological Society of London.
7. Craig, J., Hakhoo, N., Bhat, G. M., Hafiz, M., Khan, M. R., Misra, R., ... & Khullar, S. (2018). Petroleum systems and hydrocarbon potential of the North-West Himalaya of India and Pakistan. *Earth-science reviews*, *187*, 109-185.
8. Mashhadi, S.T.A., Javed, S., Anwar, M., Hussain, H., and Alam, G.S., 1990, Coal deposits of Ara-Basharat Plateau, District Chakwal, eastern Salt Range, Punjab, Pakistan: Lahore, Geological Survey of Pakistan Information Release 456, 32 p.
9. Wang, C., Dai, J., Zhao, X., Li, Y., Graham, S. A., He, D., & Meng, J. (2014). Outward-growth of the Tibetan Plateau during the Cenozoic: A review. *Tectonophysics*, *621*, 1-43.
10. McDougall, J.W., and Hussain, Ahmad, 1991, Fold and thrust propagation in the western Himalaya based on a balanced cross section of the Surghar Range and Kohat Plateau, Pakistan: American Association of Petroleum Geologists Bulletin, v. 75, no. 3, p. 463–478.
11. McDougall, J.W., and Khan, S.H., 1990, Strike-slip faulting in a foreland fold-thrust belt: the Kalabagh Fault and western Salt Range, Pakistan: Tectonics, v. 9, no. 5, p. 1061–1075.
12. Reed, F.R.C., Cotter, G. de P., and Lahiri, H.M., 1930, The Permo-Carboniferous secession in the Warchha valley, western Salt Range, Punjab: Records of the Geological Survey of India, v. 62, pt. 4, p. 412–443.
13. Medlicott, H.B., 1886, Memorandum on the discussion regarding the boulder-beds of the Salt-range: Records of the Geological Survey of India, v. 19, pt. 2, p. 131–133.

14. Middlemiss, C.S., 1892, Petrological notes on the boulder-bed of the Salt Range, Punjab: Records of the Geological Survey of India, v. 25, p. 29–35.
15. Ghaznavi, M.I., 1988, The petrographic properties of the coals of Pakistan: Carbondale, Southern Illinois University, M.S. thesis, 175 p.
16. Gray, Richard E., and Robert W. Bruhn. "Coal mine subsidence—eastern United States." *Reviews in Engineering Geology* 6 (1984): 123-150.
17. Arora, V.K., 1987: Strength and Deformation Behavior of Jointed Rocks. Ph. D. Thesis,IIT Delhi, India.
18. Zhang, Jincai, and Baohong Shen. "Coal mining under aquifers in China: a case study." *International Journal of Rock Mechanics and Mining Sciences* 41.4 (2004): 629-639.
19. Singh, Ramesh P., and Ram N. Yadav. "Prediction of subsidence due to coal mining in Raniganj coalfield, West Bengal, India." *Engineering Geology* 39.1 (1995): 103-111.
20. Wagner, H., and E. H. R. Schümann. *Surface effects of total coal-seam extraction by underground mining methods*. na, 1991.
21. Johnson, W. J., R. E. Snow, and J. C. Clark, 2002, *Surface Geophysical Methods forthe Detection of Underground Mine* Workings, Symposium on Geotechnical Methods forMine Mapping Verifications, Charleston, WV, October 29.
22. Ewing, M. A., A. P. Crary, J. W. Peoples and J. A. Peoples, 1936, *Prospecting for Anthraciteby the Earth Resistivity Method*, Transactions of the American of Mining andMetallurgical Engineers, Coal Division, Vol. 119, pp 43-483.
23. Loke, M. H. and Barker, R. D.: Rapid least-squares inversion of apparentresistivity pseudosections using a quasi-Newton method,Geophysical Prospecting, 44, 131–152, 1996.
24. Loke, M. H., 2002, *RES2DMOD, Rapid 2D Resistivity Forward Modeling Using Finite-Difference and Finite-Element Methods*, published at www.geoelectrical.com
25. Loke, M. H., 2000, *A Practical Guide to 2D & 3D Electrical Imaging Surveys*, publishedat,www.geoelectrical.com.
26. Rizwan,S.A and Bier, T.A.,"Self-Compacting Mortars using Various Secondary Raw Materials"- paper Published in *ACI Materials Journal, USA, Vol. 106, No. 1, January-February 2009, pp 25-32.*
27. Rizwan,S.A and Bier,T.A., "Blends of limestone powder and fly ash enhance the response of self-compacting mortars", Paper published in the Journal of "Construction& Building Materials",Elsevier , USA.:27(2012)398-403,
28. Rizwan,S.A; Ahmad,S and Bier, T.A., "*Application of Packing Concepts to High Performance self-Consolidating Mortar (SCM) Systems", ACI SP 289.22, USA, pp 299-315, September 2012.*
29. Rizwan. S.A, Khalid, A.R and Bier, T.A.," Self-compacting mortars using locally available secondary raw Materials-A comparative study towards making SCC in Pakistan, Proc. International Seminar Sponsored by ACI, DAAD, HEC, PEC and NUST on" Advanced Concrete Technology and its Applications", (ACTA-2014), Islamabad-Pakistan September 30, 2014. ISBN 978-969-8535-27-8, pp 74-83.
30. Rizwan, S.A, Khalid, A.R and Bier T.A.," Effectiveness of high-performance super-plasticizers in self-compacting paste systems(SCPs) varies with time", III-All Russian International Conference on Concrete and Reinforced Concrete, Moscow, 12-16 May, 2014-05-20.Vol.6,pp 115-123
31. Rizwan, S.A, Bier, T.A, Akbar, R.A.A and Iqbal, H.M.I.," Influence of $CaSO_4$ Modifications on Self-Compacting High Early Strength Grout Systems", The Third International Symposium on Design, Performance and use of self-consolidating Concrete(SCC 2014-China), Xiaman, China, June 5-8, 2014.pp 403-409
32. Rizwan,S.A and Bier, T.A., "Shrinkage and Temperature Development of Self-Compacting Concrete in Underground Tunnel"."-.Paper presented at ACI/RILEM,CSCE,ACBM(USA) International Conference on Advanced Cement Based Materials , Lahore, December, 12-14, 2007. pp 733-742.vol 2 ISBN 978-969-546-016-0 (Co-author)
33. Rizwan,S.A and Bier, T.A., "High Performance Self-Compacting Mortars Containing Pozzolanic Powders", The Eight International Symposium on Brittle Matrix Composites (BMC-8) Proceedings, 23-25 October 2006, Warsaw, Poland, pp 175-186.ISBN 1-84569-031-1 & 83-89687-09-7
34. Rizwan,S.A and Bier, T.A.,"Early Volume Changes of High-Performance Self-Compacting Cementitious Systems Containing Pozzolanic Powders", Proceedings of International RIELM conference on Volume Changes of Hardening Concrete: Testing and Mitigation, 20-23 August 2006, Technical University of Denmark, Lyngby, Denmark, pp 283-292.(PRO 52), ISBN 2-35158-004-4 & e-ISBN 2-35158-005-2.
35. Rizwan,S.A and Bier, T.A., "Role of Mineral Admixtures in High Performance Cementitious Systems ", International Conference on "Concrete and Reinforced concrete",2nd All Russian International Conference on "Concrete and reinforced Concrete-Development trends", Vol. 3,"Concrete Technology",5-9 September 2005,Moscow, Russia. pp 727-732. ISBN 5-98580-013-x.