Journal of Engineering Geology *Volume XLIV, Nos. 1 & 2*
A bi-annual Journal of ISEG *June & December 2019*

Challenges in development of river valley and hydel projects in karst terrains - broad issues

Singh, Yamuna
Centre for Earth, Ocean and Atmospheric Sciences,
University of Hyderabad, Hyderabad – 500046, Telangana, India
E-mail: yamunasingh1957@gmail.com

Abstract

Calcareous rocks like limestones, dolomites, chalks and evaporites, are most susceptible for karstification, that is, process of solution action, by corrosive actions of meteoric, surface and subsurface waters. In fact, the corrosive action of the water is responsible for the development of various types of karstic features both on the surface and subsurface levels. Furthermore, pronounced solution action of water causes formation of dolines, which lead to development of caves passages and underground streams in karst terrains. The development of karst is intense around weak points such as intersections of joints, fractures, interstices, etc. Due to interconnected network of secondary pore systems, karst terrains pose diversified geotechnical challenges in development of river valley and hydel projects, including pressure tunnels, bridges and highways. Among others, the pronounced problems include leakages and discharges in distal places, which need to be properly identified and addressed adequately. Systematic and meticulous geotechnical assessments of karst terrains are thus imperative before development of such projects in them. Such investigations involve careful study of nature, depth, distribution and frequency of secondary pore systems and their interconnectivity by close-spaced drilling, geomorphological and geophysical surveys and geohydrological evaluations. Sealing of secondary pore systems through comprehensive pressure grouting by drilling closely-spaced bore holes is essential for checking distal leakages and discharges and degradations. Choice of depth and spacing of drilling and grouting is normally dependent up on the depth, nature and degree of karstification.

1. Introduction:

The term karst is used for geomorphic landscapes formed by solution and corrosive actions of water (Bogli, 1980; Ford, 1965; Ford and Williams, 2007; Sweeting, 1972; Singh, 1992). Carbon dioxide-rich and / or acidic water infiltrates along joints, fractures and bedding planes and forms secondary and tertiary porosities. Such corrosive action of water leads to development of surface and sub-surface solution openings including vertical and horizontal drainage. Surface karst landforms may include karren, solution basins, pavements, natural bridges and sinkholes, whereas, subsurface landforms include various types of caves, such as vadose and water table caves, phreatic caves, vertical caves and cave collapse and breakdown, and cave deposits (terra-rossa, rocks falls and stream deposits of external origin).Thus dissolution and attendant karstification results in various types of landscapes. Some of such landscapes in karst terrains are the sites of attractions and have been developed for World Geotourism (Hall and Day, 2011). Globally, karst topography forms at all latitudes and elevations. Best developed karst regions of the world are in tropical (South China, Vietnam, Jamaica) and temperate (Yugoslavia) regions. In this paper mode of development of pore systems and broad geotechnical challenges involved in development of river and hydel projects in karst terrains have been discussed.

2. Karstifiable Rocks:

The most common karstifiable rocks are biogenic, biochemical and chemical sedimentary rocks, namely, limestone, dolomite, chalk, anhydrite and evaporate. However, among others, quartzite and granite karsts are also known (Twidale, 1982; Dasgupta, 1993; Singh, 1995, 2005). In facts, pockets travertine deposits are reported from Adhaura plateau associated with Dhandhraul quartzite and sandstone, with very high Ca content and extremely low silica and Ma (Dasgupta, 1993). Karst may occur at all latitudes and elevations, and covers about 20-33% of the Earth's land surface (Milanovic, 1988; Jamali et al., 2015). Distribution of carbonate rocks in India is shown in Fig. 1. Solution-enlarged fractures and channels (Karren) and closed depressions of various dimensions (sinkholes, dolines, poljes), caves with speleothems (cave deposits, e.g., stalactites, stalagmites, dripstones and flowstones). In monsoonal tropics, speleothems form significant archives of past-monsoonal changes. In fact, recently, stalagmite from Meghalaya, North East India, helped define a geological age by the International Union of the Geological Sciences (IUGS). The karst form Earth's most diverse scenic and resource-rich terrains and repository for underground resources, like minerals, oil, natural gas, groundwater reservoirs (Singh and Dubey, 1997; Jeelani et al., 2018).

3. Agents of Karstification:

Various factors are responsible for the development of karst. The most common ones are the presence of soluble rocks close or near the surface, high density of joints, fractures, bedding planes, differential solubility of constituent minerals, relief, rainfall, vegetation cover, climatic conditions and anthropogenic activity (Singh, 1992; Bonacci, 2004; Narayana et al., 2014; Jeelani et al., 2018). These factors work differently in combination with each other in variable magnitude. In Meghalaya, North East India, the density of cave system appears to be the highest, and several factors are responsible for their formation, namely, high grade of limestone, high precipitation, elevation and a humid climate (Brooks and Smart, 1995). In each region, some factors play a dominant role relative to others.

4. Mode of Development of Secondary Pore Systems:

Calcareous rocks like limestones, dolomites, chalks and evaporites, are most susceptible for karstification, that is, process of solution action, by corrosive actions of meteoric, surface and subsurface waters. Most of the carbonate rocks are chemical precipitates, and possess insignificant primary (intergranular) porosity (Fig. 2). Dissolution of constituent minerals of carbonate rocks causes formation of small-scale moldic porosity in them (Fig. 3). The corrosive action of the water is responsible for the development of various types of karstic features on variable scales both on the surface and subsurface levels (Figs. 4 to 11). Furthermore, pronounced solution action of water causes formation of dolines, which lead to development of cave passages and underground streams in karst terrains. The development of karst is intense around weak points such as bedding planes, intersections of joints, fractures and interstices (Figs. 4, 5, 6, 7 and 8). Apart from network of fracture systems and other factors, differential dissolution of constituent minerals play significant role in variable karstification in granites and quartzites. At times, quartzites display pronounced karstification, with development of secondary and tertiary porosities including conspicuous pinnacles (Figs. 10 and 11). Interconnectivity of such secondary and tertiary pore systems exercises significant role in geotechnical issues in development of river valley and hydel projects in karst terrains.

5. Discussion:

5.1 Geotechnical Aspects:

Due to interconnected network of secondary and tertiary pore systems, karst terrains pose diversified geotechnical challenges in development of river valley and hydel projects including pressure tunnels, bridges and highways. Among others, the pronounced problems include leakages and discharges in distal places, which need to be addressed adequately (Singh, 2007). Systematic and meticulous geotechnical assessments of karst terrains are thus imperative before development of such projects in them. Such investigations obviously involve careful study of nature, depth, distribution and frequency of secondary and tertiary pore systems and their interconnectivity by close-spaced drilling, geomorphological, geophysical surveys and geohydrological evaluations. Sealing of secondary pore systems through comprehensive pressure grouting by drilling closely-spaced bore holes is essential for checking distal leakages and discharges and structural degradations. Choice of depth and spacing of drilling and grouting is normally dependent up on the depth, nature and degree of karstification.

5.2 Challenges in Karst Terrains:

The karst terrains are unique in many ways with mysterious surprises throughout their lengths and breadths. At places, they show pronounced karstification and excellent interconnectivity of pore systems, whereas elsewhere opposite is the true. Regional, local and lateral variabilities are erratic and profound. Likewise, depth variabilities are also equally variable and uncertain. On surface manifestations of karstification may be minimal, whereas in depth it may be intense (Singh, 1989). These variabilities and uncertainties compound problems. In certain cases, in sedimentary sequences, interbedded limestone units have also been found to be intensely karstified at depths (Singh and Dubey, 1997). Identification of such zones is equally significant for proper assessments. Accordingly, the most notable challenges in karst terrains are as follows:

- Mapping of karstified and associated rocks
- Structural mapping
- Agents of karstification
- Depth of karstification
- Degree of karstification
- Mode of developments of (secondary/tertiary) pore systems
- Degree of interconnectivity of pore systems
- Identification of recharge and discharge sites
- Delineation of catchments and actual source areas

- Aquifer mapping
- Geohydrological studies
- Geophysical studies
- Environmental issues

6. Conclusions:

Based on the studies likes field traverses, karst geomorphic landscapes, mode of developments of pore systems, agents of karstification and geohydrological parameters, the following conclusions may be drawn with respect to geotechnical issues and remedial measures to be taken for planning and development of river valley and hydel projects in karst terrains.

(1) Systematic and meticulous geotechnical assessments of karst terrains are imperative before development of river and hydel projects in them.
(2) Such investigations should include careful study of nature, depth, distribution and frequency of pore systems and their interconnectivity by close-spaced drilling, geomorphological and geophysical surveys and geohydrological evaluation.
(3) Sealing of secondary pore systems through comprehensive pressure grouting by drilling closely-spaced bore holes is essential for checking distal leakages and discharges and attendant degradations.
(4) Hales Gar Dam in Tennessee (USA) failed as cavities in the limestone at the foundation were not adequately treated. Therefore, to ensure projected life time functioning of river and hydel projects, geotechnical assessments during prefeasibility, feasibility and detailed feasibility stages must be critically done and adequately addressed.

Acknowledgements:

I am grateful to Prof. D.P. Dubey, Govt. Science College, Rewa, M.P. for guidance and to Dr. P.S. Mishra and Dr. I.B. Chhibbar, Geological Survey of India for stimulating discussion and useful suggestions. I am also grateful to Shri M. Raju, Retired DG, GSI and Chairman, Organizing Committee, EGCON-2018, for encouraging and supporting me to contribute, without which I would not have been able to participate and present this paper in Conference.

References:

1. Bogli, A. (1980) Karst Hydrogeology and Physical Speleology (Translated by J.C. Schmid). Springer-Verlag, 284p.
2. Bonacci, O. (2004) Hazards caused by natural and anthropogenic changes of catchment area in karst. Nat. Hazards Earth Syst. Sci., v. 4, pp. 655-656.
3. Brooks, S. and Smart, S. (1995) Caving in the abode of the clouds: caves and karst of Meghalaya. NE India. Meghalaya 94, Bradford on Avon, UK, 68p.
4. Dasgupta, S. (1993) Occurrence of travertine from Vindhyan Supergroup in Rohtas district, Bihar, India. Indian Minerals, v. 47, No. 2, pp. 169-170.

5. Ford, D.C. (1965) The origin of limestone caverns: a model from the central Mendip Hills, England. Nat. Speleol. Soc. Bull., v. 27, pp. 109-132.
6. Ford, D. and Williams, P. (2007) Karst hydrogeology and geomorphology. Wiley, New Jersey, 554p.
7. Jamali, M., Moghimi, E. and Zafarpour, Z.A. (2015) Geomorphology of karst features of Shiraz city and Arjan Plain and development limitations. Int. J. Environ. Chem. Ecol. Geophys. Eng., v. 9, 1.doi:scholar.waset.org/1999.6/10000362
8. Jeelani, G., R.H. Shah and R.D. Deshpande (2018) Assessment of groundwater in karst system of Kashmir Himalayas, India. In: A. Mukherjee (ed.), Groundwater of South Asia, Springer Hydrogeology, pp. 85-100. http://doi.org/10.1007/978-981-10-3889-1_6
9. Hall, A.B. and Day, M.J. (2011) Water as a focus of ecotourism in the karst of Puerto Rico. Tourism Karst Area, v. 4, No. 1, pp. 17-25.
10. Milanovic, P.T. (1988) Artificial underground reservoirs in the karst experimental and project examples. In: Karst hydrogeology and environment protection, v. 1, Proc. 21st Congress of IAH, Guilinj, China, IAHS Publ. No.176, pp. 76-87.
11. Narayana, A.C., Yadava, M.G., Dar, F.A. and Ramesh, R. (2014) The spectacular Belum and Borra caves of eastern India. In: V.S. Kale (ed.), Landscapes and Landforms of India, World Geomorphological Landscapes, Springer, pp. 189-194. DOI: 10.1007/978-94-017-8029-2_19
12. Singh, Y. (1989) Sinkholes (dolines) in Bhander limestones around Rewa, central India and their environmental significance. In: Beck, B.F. (Ed.), Engineering and Environmental Impacts of Sinkholes and Karst. A.A. Balkema Publisher, Rotterdam, pp. 47-52.
13. Singh, Y. (1992) Study on the cave passages in Precambrian Bhander Limestone of the Vindhyan Supergroup, India. Z. Geomorph. N.F., Suppl.-Bd. 85, pp. 115-126.
14. Singh, Y. (1995) Morphology of pseudosinkholes in granitic rocks of the Bastar craton, central India. In: Beck, B.F. (Ed.), Karst Geohazards: Engineering and Environmental Problems in Karst Terrane. A.A. Balkema Publisher, Rotterdam, pp. 67-72.
15. Singh, Y. and Dubey, D.P. (1997) Deep zone karst aquifers as a boon in central India. In: Beck, B.F. & Stephenson, J.B. (Eds.), The Engineering Geology and Hydrogeology of Karst Terranes. A.A. Balkema Pub., Rotterdam, pp. 245-249.
16. Singh, Y. (2005) Pseudoexokarst landforms associated with granitic terrain of the Bastar craton, central India. In: Chandrasekar, N. (Ed.), Quaternary Climatic Changes and Landforms. Manonmaniam Sundaranar University, Tirunelveli, Tamil Nadu, pp. 261-271.
17. Singh, Y. (2007) Some geotechnical aspects of construction of hydroelectric dam including environmental considerations in karst terrains. In: Sarolkar, P.B. & Shiv Kumar, K. (Eds.), Energy Scenario 2020: Challenges, Perspective and Exploration Strategies. Gond. Geol. Mag., Spl. Vol. 9, pp. 179-184.
18. Sweeting, M.M. (1972) Karst Landforms. Macmillan Press, London, 362p.
19. Twidale, C.R. (1982) Granite Landforms. Elsevier, 372p.

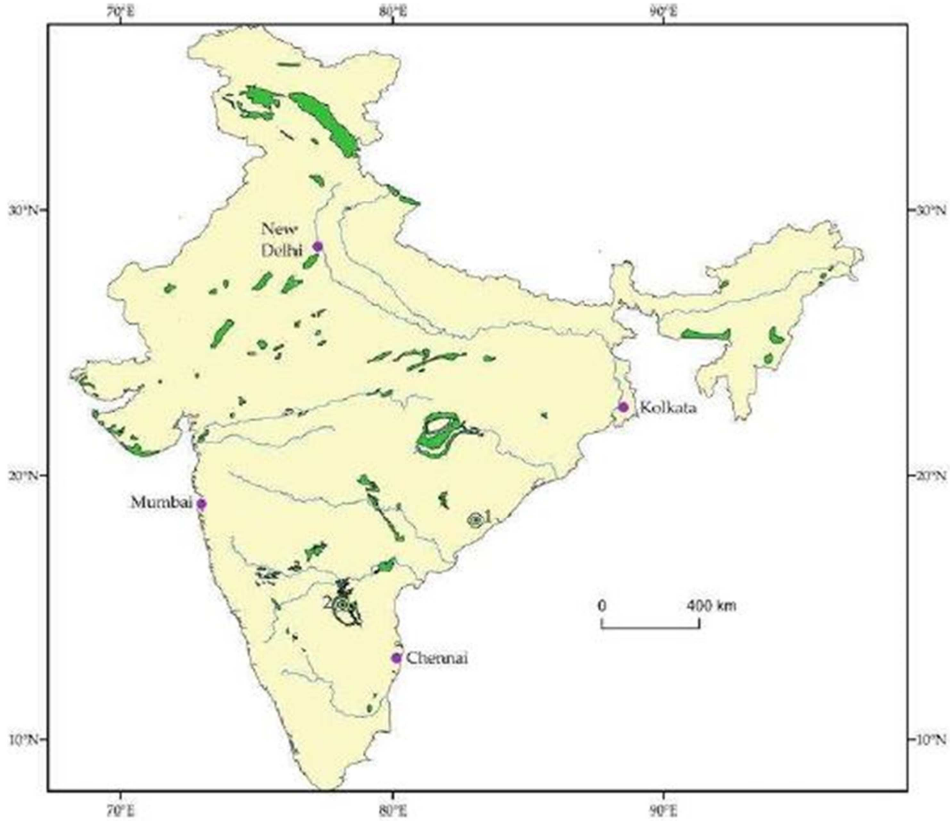

Figure 1 Map showing distribution of carbonate rocks in India (Narayana et al., 2014)

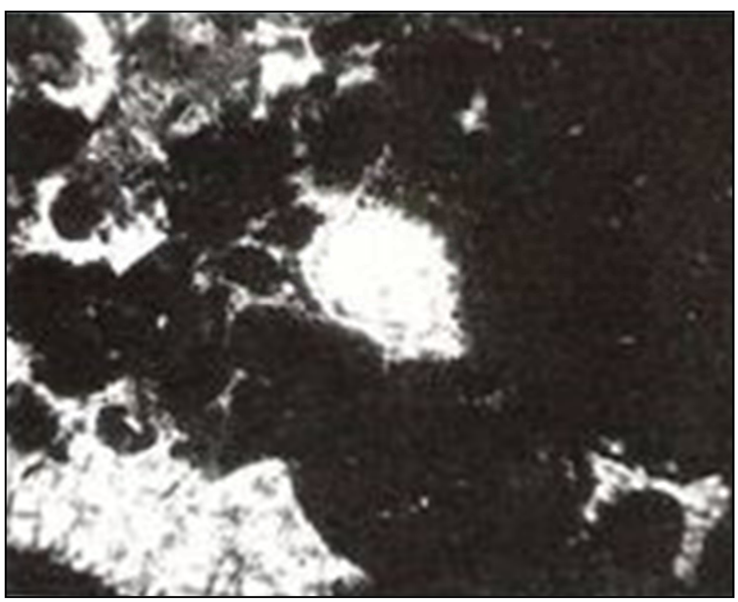

Figure 2 Primary Porosity (intergranular pores and vugs) in limestone. X33.

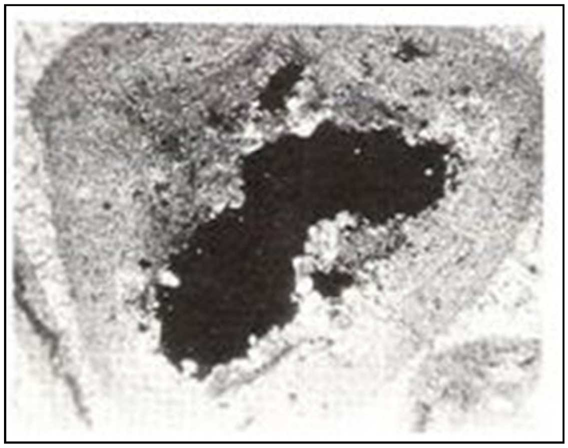

Figure 3 Moldic porosity formed due to dissolution of aragonite in limestone. X33.

Figure 4 Development of grikes along joint planes in stromatolitic limestone.

Figure 5 Well-developed sinkholes, pot holes and grikes in the river bed. Note solution enlarged joints leading to development of vertical caves in horizontal bedded limestone.

Figure 6 Two sets of solution enlarged joints leading to development of vertical caves in limestone.

Figure 7 Grand statuary of karst in horizontally stratified limestone showing compartmented karst

Figure 8 Three benches of karstification in the limestone in the river bed, with river flowing after monsoon over the last bench. Horizontal grooves are exposed in second bench, whereas the vertical grooves in vertical section of the cave.

Figure 8 Underground caves showing well-developed (a) Tunnels with solution channels and conduits & (b) Stalactites and stalagmites (After Narayana et al., 2014).

Figure 10 Quartzite showing pronounced karstification due to corrosive action of water with well-developed pinnacles.

Figure 11 Road Construction in intensely karstified quartzite terrain.