Karstified marble terrain – an engineering geologic challenge of urban development in Lusaka, Zambia

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Abstract: The presence of a cutter-and-pinnacled rock-head in the Lusaka marbles has caused a lot of foundation design and construction problems. Coupled with inadequate ground investigations, foundation design, construction practices and increased groundwater abstraction, there are a lot of performance-risks posed to completed engineering structures.

Key words: karst, foundation design, groundwater, failure, Lusaka, Zambia

INTRODUCTION

Construction in areas underlain by carbonate rocks has sometimes proved environmentally risky and economically infeasible unless the possible solutioning problems are identified in advance of project planning, design and construction (FISCHER ET AL., 1989). For Lusaka, inaugurated Zambia's (then Northern Rhodesia's) new capital in May 1935, the suitability of its location still remains a source of controversy today as it was during the early years of its founding in the early 1900s. This controversy originates from a number of factors, the major one being the nature of bedrock that underlies the city.

THE NATURE OF BEDROCK UNDERLYING THE CITY

A crystalline Basement Complex that comprises quartzites and schists underlies Lusaka. Strongly folded metasedimentary cover rocks that consist of thin horizons of schists and quartzites unconformably overlie the Basement rocks. These are dominated by thick and extensive sequences of dolomitic marbles (Fig. 1).

Differential solution of the marbles has led the development of a characteristic system of conduits and solution cavities, which have imprinted into these rocks a rugged cutter-and-pinnacled rock-head topography (Fig. 2). Borehole drilling has intersected some of these cavities at depths in excess of 60 metres below ground surface. On one hand, the presence of these features has transformed the Lusaka marbles into a favourable source of water supply to the city. On the other hand, the rugged cutter-and-pinnacled rock configurations have presented the geotechnical, structural and civil engineers with a range of unique planning, foundation design and construction problems.

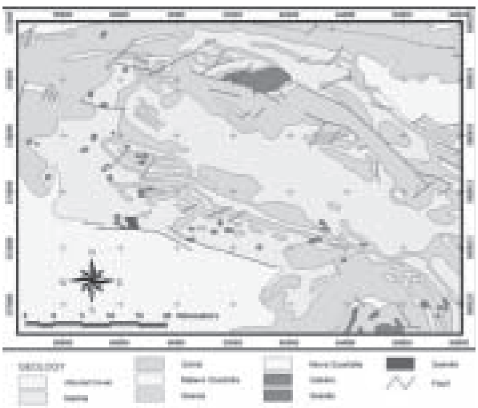

Figure 1. Geological map of the Lusaka area

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Figure 2. Disposition of the solution structures in the Lusaka marbles in different parts of the city.

FOUNDATION DESIGN AND CONSTRUCTION

Early civil and construction engineering work in Lusaka identified a number of problems associated with foundation design on/in the marble terrain. The most important among them was the occurrence of rock outcrops and solution hollows that provided variable pinnacled ground conditions.

Information available from trial pit excavations and test drill-hole logs from most construction sites reveals the intersection of rock on a pinnacle beneath a thin cover of soil. Within short distances away from such rock pinnacles, cutter or solution cavities have been intersected that extend a few to tens of metres deep (Figure 3).

The variation in thickness of mantling soils from a few centimetres over the pinnacles to some tens of metres in the fissures undoubtedly creates complications such that continuous/strip footings span across rock pinnacles (Fig. 4A), while spread/pad footings are cast on rock and soil (Fig. 4B) and in some cases, at different depths.

For the type of ground conditions depicted above, foundation design and the determination of *bearing capacity* (Q_b) must not be governed only by properties of the soil, but those of the

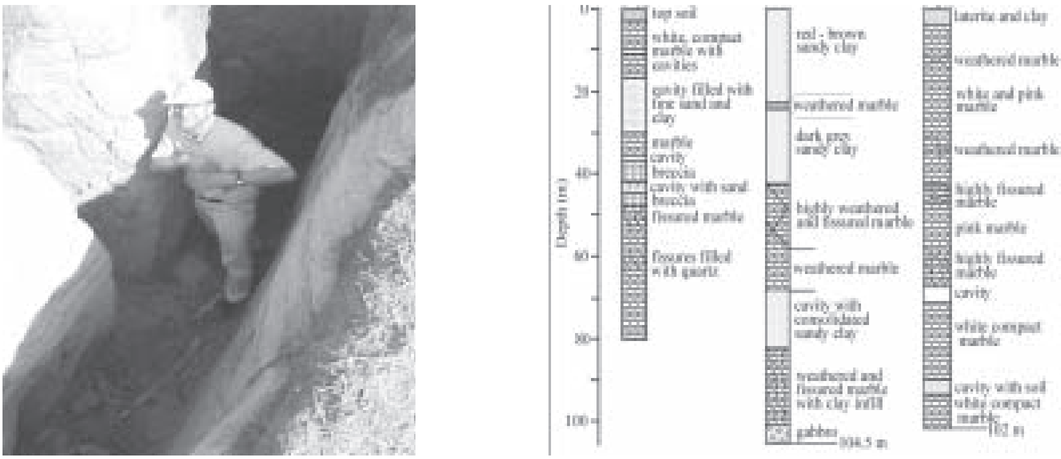

Figure 3. Occurrence of cavities at depths sometimes in excess of 60 m below ground surface

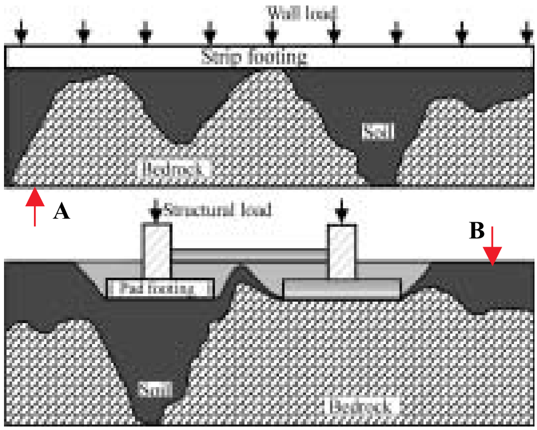

Figure 4. Shallow foundations over pinnacled rock-head; (A) Strip footing spanning across rock pinnacles, and (B) Spread footings cast on soil and rock

rock as well. Consequently, this complicates the application of simplified bearing capacity equations, such as those given in the DIN 4017 and all its modifications. This is because the placement of either strip or pad footings on soil and rock for the same superstructure makes it difficult to determine the allowable bearing capacity that avails the structure an adequate factor of safety against shear failure. This has been particularly so because, where rock has been intersected in a foundation excavation, no testing has been done and no further investigations have been made to ascertain that the intersected rock is continuous in the subsurface. In some instances, where cavities underlie rock intersections (Fig. 5A), these solution features are envisaged to pose serious complications to foundation design and the eventual performance of completed civil engineering structures.

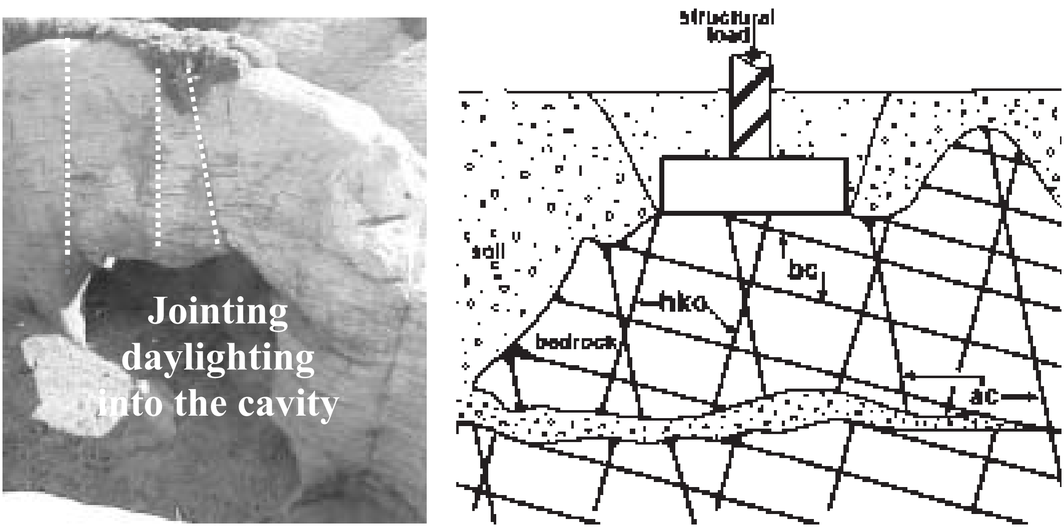

Figure 5. (A) Solution cavity intersection at depth. (B) Model depicting jointing *daylighting* into a solution channel, creating a potential to initiate slip failure.

Compounded by the presence of solution channels into which discontinuities daylight, the inherent liability of loading such a rock mass is the possible provocation of excessive rock deformations and/or the initiation of slip. This is exacerbated by the presence of. Fig. 5B gives a visual impression of the general type of problems that may arise from loading processes emanating from such construction activities.

Since current foundation design practice in Lusaka utilises basic parameters of cohesion (c) and the angle of shearing resistance (j) usually determined for the soils, and while the concept that *design is always safe as long as it is based upon the weaker/weakest mass properties,* such construction practices avail no guarantee whatsoever that rock may not cause foundation problems because its properties and the extents of cavities ramifying it are usually not determined. Under such circumstances, determination of admissible displacements on individual foundation elements resting on rock-head from those on soil has been difficult. This has resulted, among others, to the unavoidable and inevitable differential settlement accruing from differential compaction-properties between rock and soil. Such instabilities have been responsible for failure of engineering structures experienced in some parts of the city (Fig. 6).

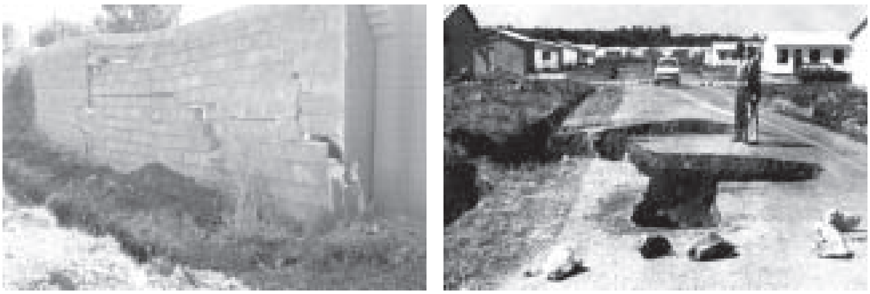

Figure 6. Failure of engineering structures arising from either loss of support and/or differential settlement in the substructure

Conclusion

Engineering geological and foundation design challenges over karstified marbles in Lusaka are real and deserve immediate attention. As major hazards in the terrain are posed by subsidence and the formation of collapse sinks, zones of high permeability in construction sites should be isolated by use of tests such as borehole recharge or Lugeon. Subsequently, appropriate ground treatment procedures (e.g. grouting) must be undertaken to seal the principal conduits (fissures, cracks, solution caverns, and many other openings in the rock mass) by which water is conveyed underground to weaken ground masses underlying substructures.

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