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Geotechnical Risks of Foundation in Karst: A Case Study of Wind Power Plant Podveležje, BiH

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Abstract

The foundation of structures in rock massifseems to be less problematic than foundation in soil, given that rock massif is characterized by significantly better physical and mechanical properties compared to soil. However, cases of foundations in karst alsocarry certain difficulties that we face during the construction of various infrastructural and energy objects. The karstified limestone massif abounds in numerous underground karst formations such as pits, caves and caverns that can remain hidden and unexplored in the process of geological-geotechnical investigation work and as such represent a significant geotechnical risk.

This paper will analyze the case of the foundationing in the karst of the wind turbine poles at the Wind Power Plant Podveležje, Bosnia and Herzegovina. On this project, during the execution of investigations, but also during the excavation of the foundation-rock interface, caverns were identified on the foundation-rock interface and in the rock below the foundation.

The paper describes the procedures for detecting such karst formations on and below foundation-rock interface, both during the investigation phase and during the excavation phase, procedures for defining cavern contours, and methods for remediating caverns.

Keywords

Geotechnical risk, Foundation, Karst, Caverns.

1 General

1.1 Foundation in karst

During the foundation of constructions in karst areas, usually built from carbonate rocks, due to karstification, problems often arise. Although these rocks such as limestone and dolomite have good bearing capacity for foundations, problems are caused by karst phenomena that sometimes remain undiscovered as part of research work and are recorded during the implementation of projects. It is not uncommon for karst phenomena to be of large dimensions or difficult to define, so the scope of the problem is greater and remediation is not an adequate solution.

The most common karst phenomena that can appear in limestone or dolomite carbonate rock massifs are pits, caves and caverns. These karst phenomena can be periodically or permanently filled with water, filled with geologically diverse types and accumulations of material with usually poor or, due to inhomogeneity, difficult to define physical and mechanical characteristics, and often empty with large contour dimensions.

When conducting geological and geotechnical investigation works in preparation for the design of constructions, exploratory boreholes are usually performed as well as geophysical methods of recording the terrain between the boreholes. In accordance with the current legal regulations that define the scope of geotechnical investigations for certain types of objects, these investigations are not performed on the entire surface of the affected area of the future object, and these research methods cannot be completely reliable.

1.2 Roads

In the construction of line objects, which are characterized by long stretches of terrain, and due to the limited scope of geoinvestigation works, major problems caused by the geomorphological phenomena of the terrain often occur. Roads in karst terrain are usually accompanied by the occurrence of underground and surface fracture systems and karst phenomena. In limestone and dolomite rocks, these karst formations are often formed due to the action of flowing surface and groundwater. Caverns in road structures are a fairly common occurrence in the Dinaric karst zone. The most dangerous caverns are those located just below the surface along road sections with embankments, because in that case there are no engineering works on the ground and such caverns are impossible to detect (Roje-Bonacci et al. 1993). When caverns are discovered during construction, the project implementation is usually suspended and the financial framework is increased, both due to the delay and the need to conduct detailed research and, if possible, find an effective solution for remediation.

1.3 Tunnels

For the construction of tunnels, extensive research work is usually carried out during the preparation of the design and selection of the route, and based on the research results, the route is adopted and the design is carried out according to the most favorable routes in technological and financial terms. Considering that these are underground works, there is a high probability that on the routes being carried out in karst areas, despite the limited testing carried out, karst formations will appear that may at the very least delay or slow down the implementation. Karst phenomena in the underground of carbonate massifs can be of such dimensions and hydrogeological conditions that it is very difficult to find a technologically adequate and favorable solution for rehabilitation if it coincides with the tunnel route. Tunnels, as well as the works on them, are objects that are exposed to significant risk during construction and exploitation. Carrying out tunneling work using tunnel boring machine technology in karst areas with caverns and fracture systems is very risky because serious delays are possible, for which it is sometimes very difficult to find a solution to eliminate the problem.

Some common cases that can occur in karst with applicable remediation solutions are free cavernous spaces that are resolved by filling in material, bridging or bypassing. When caverns are filled with deposit material, it is necessary to conduct research into its geotechnical properties, as well as the shape of the cavern's distribution and contour dimensions, on the basis of which a rehabilitation solution is adopted. Caverns filled with groundwater are usually approached by evacuating the water and preventing further flow and contact, or by controlled conduction to the recipient in order to prevent possible collapse of materials and delays in the work. Water in karst fracture systems can be under high pressure, with destructive force and turbulent flows through narrow, irregular fracture spaces, making tunneling work in such an environment very risky. Drainage is being installed in and

around the tunnel tube, making the work much more complicated and slower. A very dangerous case are unexplored caverns in the tunnel cap, which can cause sudden falling of blocks from the cavern into the tunnel pipe and problems during excavation and use of the tunnel. Recording undiscovered caverns affects changes to project documentation, organization, technology and methodology of work execution, with long delays and high costs.

In order to conduct the most detailed explorations, define the necessary hydro-geological and geotechnical characteristics of the terrain, and adopt the most favorable route, the exploration methods that are being carried out are detailed geological mapping, geophysical methods, vertical and horizontal drilling, TV borehole recording, observation of the level and direction of groundwater, geotechnical testing, and speleological research (Milanović 1999; Selimović 2014; Špago 2021).

1.4 Hydrotechnical facility

The construction of hydrotechnical objects in karst areas poses certain specific problems. Due to the presence of karst phenomena and fracturesystems in the carbonate massifs, underground water flows and works are being carried out to cut underground water, in order to protect works and buildings.

A common problem is the loss of water from hydrotechnical water supply facilities and artificial reservoirs, and works are being carried out to prevent water from flowing away, causing a change in the direction, level, and quantity of underground water flow towards other potential outflow zones (Špago 2021).

2 Case Study: Wind Power Plant Podveležje, Bosnia and Herzegovina

A characteristic case is the foundation of wind turbine pillars in limestone rock in the power project for the construction of the Wind Power Plant Podveležje, Bosnia and Herzegovina. The wide excavation for the foundations was carried out by blasting, with digging and cleaning of the lower layer of the excavation by mechanization, after which the foundation-rock interface was cleaned with water. The foundation-rock interface is inspected by a geotechnician and a geologist to gain insight into the actual condition of the rock massif and compare that condition with the results from the G21 mission (investigation work at the main design level). Special attention was paid to the presence of cracks and caverns (see Fig. 1).



Fig.1 Cleaned substrate for the foundation.

According to the recommendations from the G21 mission, in places where caverns have been observed by drilling or geophysical tests, it is planned to carry out core drilling during the execution, with the core being placed in boxes (see Fig. 2). In addition, drilling with the ejection of stone dust is also planned, where the result of drilling is stone powder and not core. These drillings are planned at the locations of all wind turbines in order to check the geotechnical model established during the G21 mission in a large number of places on one foundation, quickly and cheaply, and based on the appearance and color of the stone powder. Deterioration of tools and rapid drilling shows the existence of cracks, cavities and caverns.



Fig. 2 Investigation works: a) Boxes with drilled core, b) Limestone dust exhaust (Interprojekt Mostar 2020).

In order to more precisely locate the contours of the cavern, the recording of boreholes with a video camera was also used (see Fig. 3).

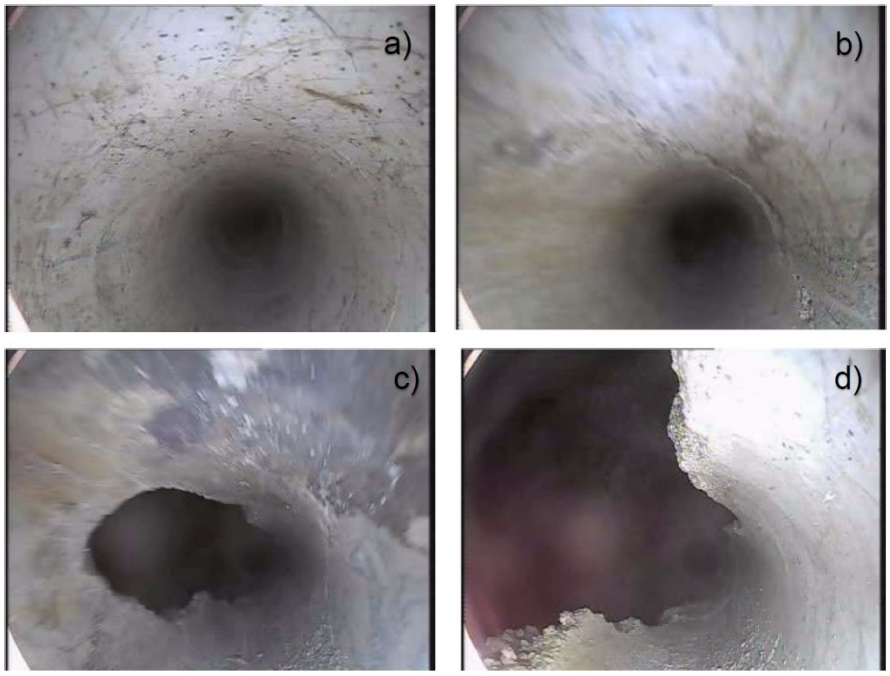


Fig. 3 Recording the borehole with a video camera - a)The upper part of the borehole – compact, b)Visible fissures in the upper interval of the borehole, c) Entering the cavern at a depth of 9.8 m, d) Cavern, (IGH Mostar 2020).

At the site of the T15 wind turbine, a cavern was found under the foundation site, and it was repaired by filling it with concrete (see Fig. 4).

The process of rehabilitating the cavern was carried out following the steps that consist of inserting the concreting pump hose through borehole B3 for a minimum of 2m and gradually filling the borehole while monitoring the flow of concrete from borehole B1, and if no concrete appears, continue filling borehole B1. Concrete C30/37 with a minimum amount of cement of 400 kg, maximum aggregate grain D16, consistency grade F5 was used for the rehabilitation of the cavern. (see Fig. 5)

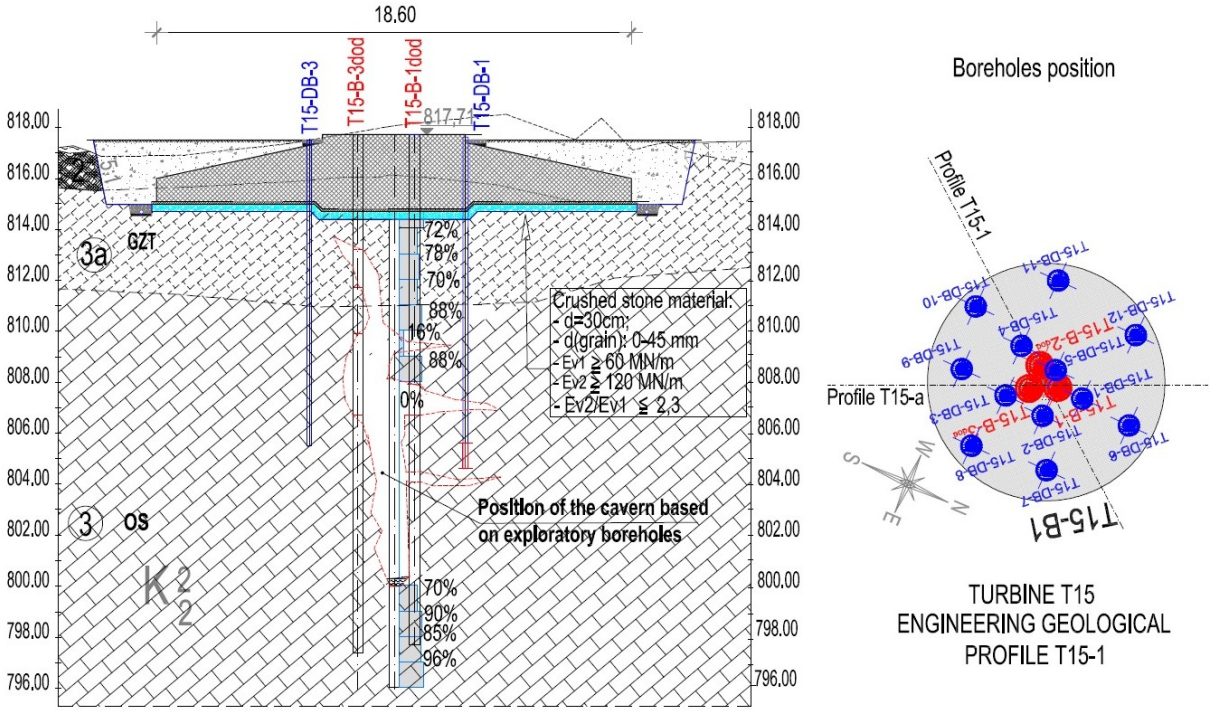


Fig. 4 Engineeringgeological profile, location of boreholes with coring (red) and dust exhaust (blue) at the site of turbine T15 (IGH Mostar 2020).

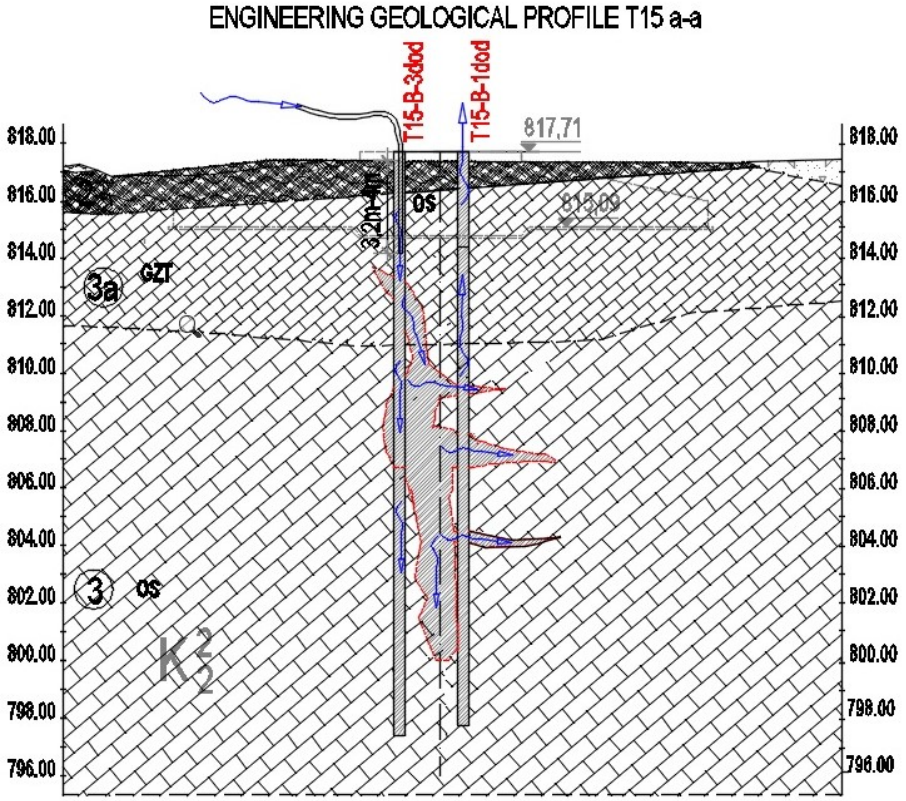


Fig. 5 Cavern remediation procedure at the site of the T15 wind turbine (IGH Mostar 2020).

At the location of the foundation of the wind turbine T16, a surface cavern was found with vertical narrow shallow cracks in the bottom of the cavern. Due to the possibility of easy access, the remediation of this cavern was carried out by cleaning and blowing out the cavern and filling it with concrete. Concrete of strength class C16/20 was used as filling (see Fig. 6 and 7).

An expanded scope of exploratory boreholes with exhaust, coring and TV logging on location of T3 wind turbine identified a cavern at a depth of 7m to 18m centrally below the foundation with a volume of approximately 15 m^3 (see Fig. 8). The cavern was remediated by filling it with concrete according to the procedure described for T15.

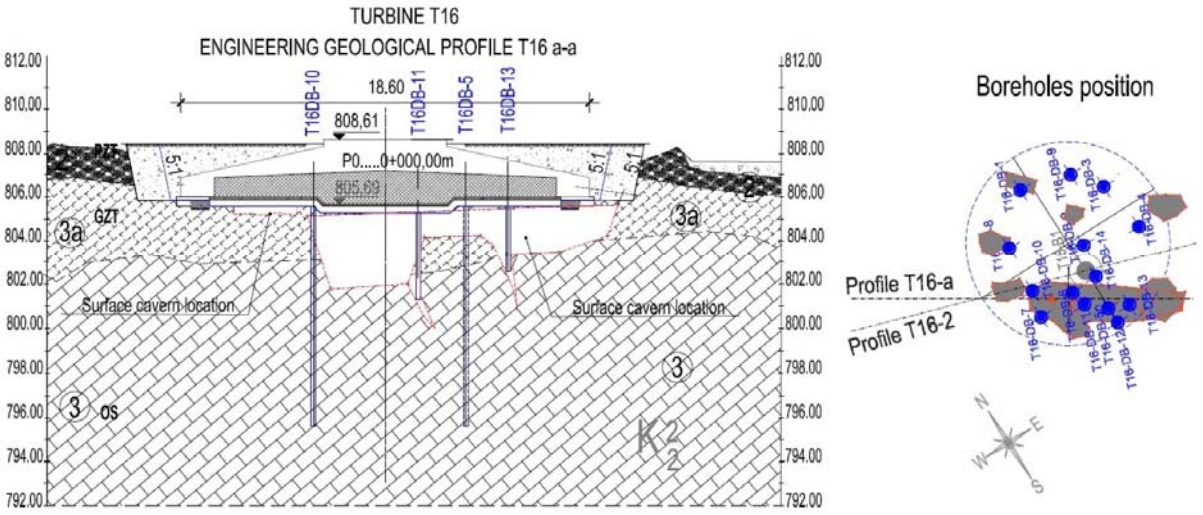


Fig.6 Engineering geological profile, location of boreholes at the site of the T16 wind turbine (IGH Mostar 2020).

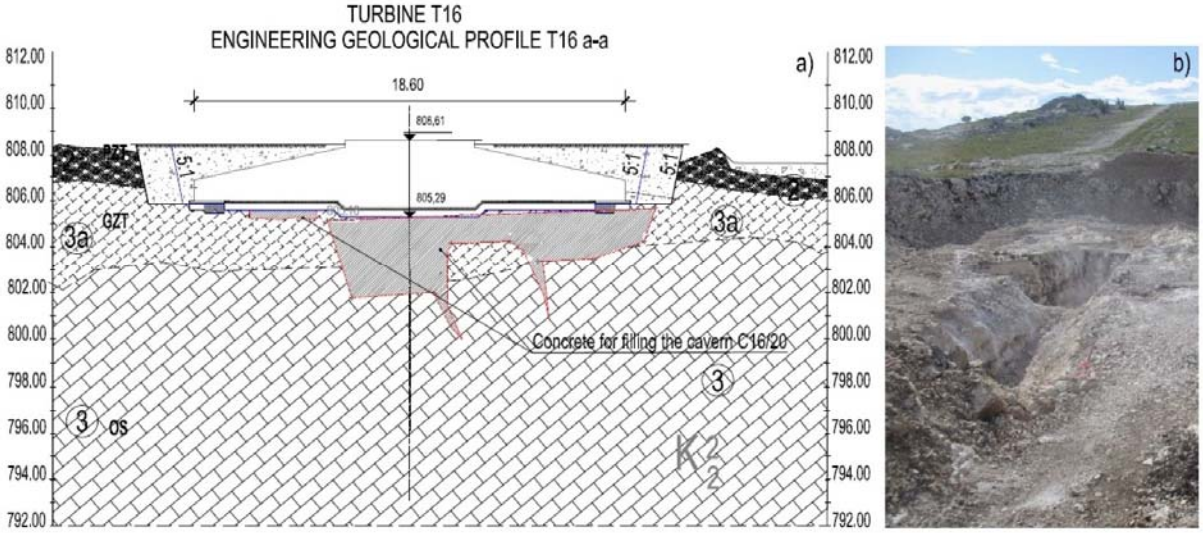


Fig.7 Wind turbineT16,a) Cavern remediation, b)View of the caverns (IGH Mostar 2020).

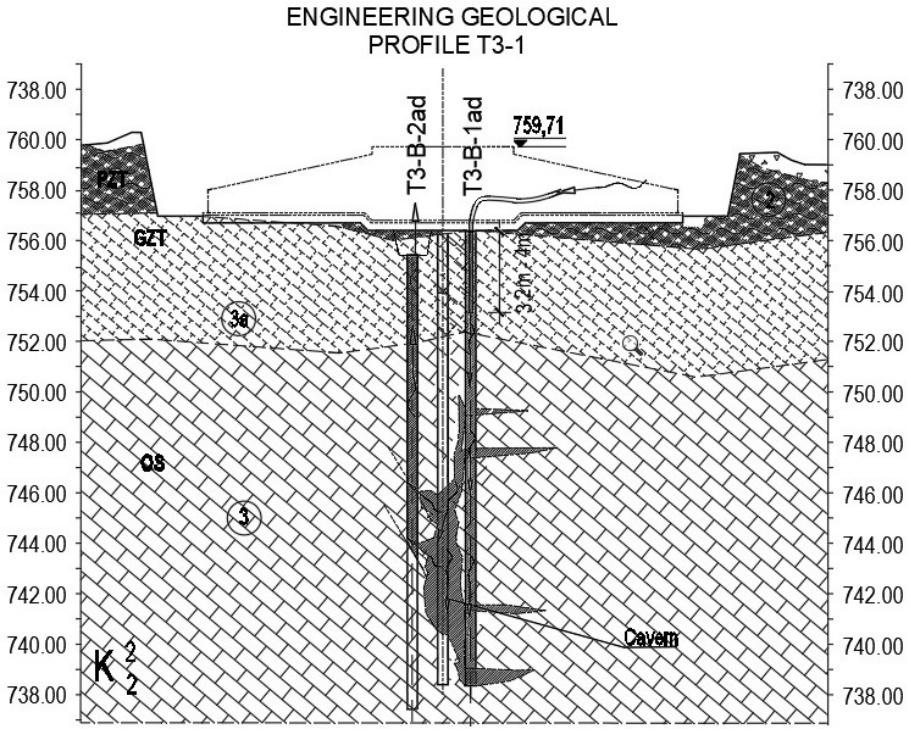


Fig. 8 Cavern at the site of the T3 wind turbine (IGH Mostar 2020).

On one part of the foundation of the wind turbine T4, a pronounced vertical mostly closed and less crushed system of fissure was observed (see Fig. 9), the extent of which was contoured by additional prospecting drilling, and the remediation was carried out by grouting.



Fig. 9 TV logging of the prospecting borehole on the turbine T4– a laterally open fisure at a depth of 9–10 m.(IGH Mostar 2020).

Many cases of karst formations during foundation construction in karst can be solved by remediation methods, however, in some cases, even the remediation methods are not technologically reliable enough. A wide fault zone passes through the location of wind turbine T12 with clays of different colors, with broken and crumbling limestones, limestone relics, limestone blocks and sandstone lens (see Fig. 10).



Fig. 10 Location of turbine T12, a) View of the fault zone, b)Layered yellow sandstone, c) Drilling additional boreholes on location of fault zone, d) Box with core from additional borehole B-3, depth 6-11m (IGH Mostar 2020).

Additional exploratory works and core-sampling boreholes were carried out. During drilling, numerous collapses and core loss were mainly recorded. The borehole channel on the fault zone completely collapsed below a depth of 4 m (see Figure 11). Further work focused on relocating the T12 foundation to a new location within the auxiliary plateau.



Fig. 11 TV logging of the borehole in the fault zone, a) borehole entry, b) depth 2–3 m, c) depth 3–4 m, d) collapsed section of the borehole below 4 m (IGH Mostar 2020).

3 Conclusion

In accordance with the applicable legal regulations, exploratory works are carried out only on a limited portion of the area affected by the construction of the structures, and they cannot be fully relied upon. We can say that the design documentation is as comprehensive and precisely defined as the extensive previous investigations and the reliable data obtained allowed. In practice, there is an increasing need for a multidisciplinary approach to monitoring project implementation and recording significant signals that indicate the occurrence of karstic phenomena. This approach entails mutual cooperation between engineers and specialists from various fields related to this issue, such as geotechnical engineering, geology, hydraulic engineering, speleology, and ecology, in order to find the most thorough and specific solutions to problems arising from the potential occurrence of karst phenomena.

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