PLANNING AND CONSTRUCTING MOTORWAYS AND RAILROADS CROSSING CLASSICAL KARST IN SLOVENIA

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Abstract

One of the major projects this time in Slovenia's karst area is concluding the construction of new motorways and begging of construction of new railroad. The karstologists of the Institute are involved in planning, in construction (through karstological control) and monitoring the use of the motorways and their environmental impact.
In planning roads and railroads we evaluate the terrain from a karstological perspective, both above and below ground, assess hydrological characteristics and consider any possible variants. Wherever roads are built in karst areas, we encounter numerous karst phenomena: dolinas, filled or empty caves and segments of old or recent drainage routes through the karst. Numerous karst caves have been exposed by denudation and are recognized on the surface of the karst as unroofed caves. We therefore evaluate the karst holistically, with an emphasis on types of karst and local characteristics, and avoid individual exceptional karst phenomena. One of the priority goals of planning is the conservation of the karst aquifer.
During construction we carry out karstological control and study karst phenomena as they are discovered. These are an important part of our natural heritage and a genuine treasury of knowledge about the development of the Classical Karst.
On the 75 kilometers of motorways being built in western Slovenia, 350 new caves have been opened. All have been geodetically measured. The research carried out has included geological research (stratigraphic, lithological, tectonic), speleological and morphological research (form and cave system, rocky relief), chronological field and laboratory research (dating of flowstone and sediments); plans of the caves have been drawn and their role in the development of karst aquifer determined. On the basis of newly collected data we have also determined the inaccessible cavernosity of the karst, which is of course essential if we wish to construct the best possible roads and railroads.

1 Introduction

Connecting regions in Slovenia with modern motorways is one of the big projects currently being implemented in Slovenia. Nearly half of Slovenia's territory is karstic and over half the water supply is drawn from karstic aquifers. These unique carbonate rock landscapes are named, in many languages, after the Classical Karst in Slovenia. The Classical Karst is also the origin of karstology. Good knowledge and effort are required to preserve the vulnerable karstic landscape, which is a significant part of Slovenia's natural and cultural heritage.
Karstologists have been collaborating in the planning and construction of the motorway across the Karst for a number of years.
The main factor in the selection of road and rail lay-outs is the preservation of the integrity of the karstic landscape and the application of guidelines for avoiding more important karstic surface landforms (dolinas, poljes, collapse dolinas, karstic walls) and the locations of known

caves. Special attention is given to the effect of motorway construction and use on karstic waters. Motorway roadbeds must be impermeable, and precipitation water from the road must be collected in oil catchers and cleaned before being returned.
We studied the effect of traffic infrastructure on karstic waters. Kogovšek [1] studied the composition of the daily runoff of polluted water from the roads. Small bodies of standing water discovered in caves alongside roads also contained traces of mineral oils [2].
Karstological monitoring is performed during motorway construction. We study newly exposed karstic phenomena, which represent an important part of Slovenia's natural heritage and, depending on the construction work taking place, propose methods for their preservation. At the same time our findings are useful to the road constructors. Our research has led to many new findings on the formation and development of karstic relief, the epikarst and aquifer hollowing. In recent years over 350 caves have been discovered [Figure 1] along the 75 km of newly constructed motorway across the Classical Karst.

1.1 Classical Karst

The Classical Karst is the landscape overlooking the boundaries of the north-western part of the Adriatic Sea. It is called the Classical Karst because it was in this area that speleology and karstology began. The 440 km2 karstic plateau is elongated in a north-west to south-west direction. The central part of the plateau is 200 to 500 m above sea level. To the north-east it borders on the Vipava valley and to the south-east on the vast flysch area, where it rises to over 600 m above sea level. Its north-western boundaries are the Friuli lowlands and the Soča river; to the south-west lies the Adriatic Sea.
The karstic plateau, which is part of the Adriatic-Dinaric carbonate plate, i.e. the area of the Outer Dinarides, is the result of compression tectonics and represents a tecto-morphological element of the highest order. The rock is generally monotonous: we find only Cretaceous and Paleogene limestones. Detailed inspection of the rock uncovers an extreme diversity of, primarily, limestone and dolomite, which have formed mostly in shallow sedimentation basins with abundant flora and fauna.
Our research did not discover any traces of surface flows, which in the past were thought to explain the surface formation of the plateau. Water was flowing and standing near the surface or at surface level minimized vertical water flow. Soil remained on the surface and, together with precipitation water, added substantially to the leveling of the relief to the present level by corroding limestone. The groundwater level later fell by an additional few hundred meters deep into the Karst.
Surface flows do not exist in the Karst. All karstic flows disappear underground in the area of contact between the flysch and the limestone bedrock. Of greater significance are the karstic aquifer and the sub-surface flows of water to the source of the Timavo river in Italy. The largest underground flow is the Reka river, which disappears underground in the Škocjan caves. From an environmental viewpoint the Karst is one of the most vulnerable natural systems in Slovenia.
This paper is an overview of experience gained in past years of research into this interesting karstic phenomenon. This includes current results, as motorway construction is ongoing and we are still performing karstological monitoring. We are of the opinion that more attention should be directed towards this karstic phenomenon even though it is not a new discovery. Our text focuses on cases in the Classical Karst, i.e. the Kras from which the name of all carbonate rock landscapes on which karstology has formed is derived [3].

Figure 1 Caves opened during the construction in the area from Razdrto, Fernetiči and Črni kal. Legend: 1. old caves: a. caves filled with sediment and flowstone, b. unfilled, empty caves; 2. shafts. Motorway on sketch is 15 times enlarged.

2 Planning

From the karstological viewpoint, the planning of roads requires an evaluation of the karstic relief, karstic underground and hydrological singularities, and an evaluation of the road layout alternatives presented. Numerous karstic phenomena are exposed in any construction location in the Karst: dolinas, filled or empty caves, and segments of old or recent drainage paths through the Karst. Many deep karst phenomena (caves) have already been exposed by denudation and can be recognised from the surface. At the present time, unroofed caves discovered during road construction are the focus of special attention. We are aware that a good karstological study of the area across which the road is planned allows a good choice of road lay-out and is one of the basic starting points for planning construction in this unique and vulnerable landscape.
The first step is to collect data on surface karstic phenomena, especially in dolinas, collapse dolinas, blind valleys and other morphological landforms, using published literature, archives and various collections. Later, fieldwork enables us to define criteria for the mapping of the area for the selected road lay-out. In the field we evaluate the important rock segments from a karstological aspect. We mark the known entrances into underground chambers on a map and, if necessary, supplement them with new ones. On the basis of surface mapping and the genetic interpretation of morphologically clear and denuded caves that are visible in

the relief, we make a preliminary projection of the underground caves. If necessary, we plan for surplus material deposition on the basis of surface mapping.
Experience has taught us that every road lay-out across the Karst strikes underground caves and sections of cave systems. The shapes and types of cave can be partly predicted by interpolating surface and underground phenomena. We then define and present on appropriate maps the cave's type, position and role in the aquifer, and its shape, rock relief, sediment and flowstone near the road lay-out. Fieldwork confirms the validity of existing data by supplementing any new measurements and genetic interpretations (i.e. filling with allochthonous clastic sediments). For a better understanding, present knowledge of the hollowed aquifer is presented and prognostic sub-surface maps emphasising anticipated litho-tectonic rock alterations are produced.
Karstic waterflows disappear underground in the area under examination and are easily drawn to the direct route to the underground karstic aquifer because of the specific characteristics of carbonate rock. Water can penetrate 100 m of rock in a little over an hour. Even though flysch rock, which is in constant contact with carbonates in the Karst, is generally thought to be composed only of impermeable beds, it must be stressed that the flysch (in some locations it is less thick) are isolated pockets in the permeable carbonate rock. It is also important to note that underground channels do develop in the flysch, although to a lesser degree, and that precipitation over the flysch is drawn into the Karst. This is why we perform field hydrogeological mapping. To do this we delineate and define the basic characteristics of the hydrogeological units in the wider area of the road lay-out, catalogue hydrological bodies and facilities (springs and withdrawn springs, surface waterflows, water caves, wells, gauges and others), and establish the physiochemical attributes of the springs. If the need arises we also carry out tracing experiments during low and high water table levels mainly in order to define the direction and speed of the underground flow in the wider area of the road lay-out. We produce hydrological maps and upgrade existing ones with the results of fieldwork and tracing experiments, and produce a register on the state of the environment and an evaluation of the impact of construction on karstic water.

3 Karstological monitoring during construction

The removal of soil and plant cover from the karstic relief and extensive groundwork during the digging of the road bed and tunnels exposed surface, epikarstic and underground karstic phenomena [Figures 2, 3]. Our task was to study these phenomena as part of natural heritage [4], [5], [6], [7], [8] to propose methods for their preservation and, of course, to inform the constructors of any new findings in order to assist them in overcoming obstacles to construction.
Karstic relief is sectioned by dolinas and unroofed caves. Dolinas are remnants of the present forming of the relief by precipitation water, which percolates vertically through rock, through the unsaturated zone of the aquifer and into underground flows. Dolinas are filled with soil to a higher or lesser degree. Vertical shafts and fissures are located at the bottom of dolinas, allowing the water to run off. The soil must be removed from the dolinas and the bottom reinforced by heaping rocks to form a vault. This is necessary because openings of shafts are usually smaller than the caves below them. The next step is to fill the sinkhole with layers of gravel. Unroofed caves are of similar or more elongated shapes. They are old caves that emerged on the surface during the lowering of the karstic relief and are without the top section of their ceilings. It is necessary to remove the fine-grainy filling (in these cases, old cave sediment) and to fill the caves with rocks and gravel. This is necessary because water would otherwise remove these sediments and expose drains to the surface.

Figure 2 One of newly discovered caves.

The epikarst is interlaced with fissures, particularly evident in cretaceous limestone and somewhat less evident in paleogenetic limestone. A number of fissures opened up on dolina bottoms and slopes. Most are filled with soil, and underground rock forms have disintegrated their walls. Because of the lowering of the karstic relief, there are many vertical shafts directly below them.
During the construction of 70 km of motorway in recent years in the Karst, over 350 caves have been exposed [Figures 1, 2, 3]. Caves can be classified according to the development of the aquifer: old caves through which water flowed when the karstic aquifer was surrounded and covered to a high level with flysch; and shafts through which water flowed vertically from the permeable karstic surface into underground water. The deepest shaft measured 110 meters. Old caves are either empty or filled with sediment; the latter represents almost two thirds of caves, while one third are already without ceilings.
The caves are exposed when vegetation and soil are removed from the surface, and particularly during the digging of the road bed. Rock blasting caused cave ceilings to collapse. Cross-sections of cave passages appeared in the road banks. Most shafts were opened when soil and sediment were removed from the bottoms of dolinas.
We inspected all the caves, drew plans, defined their shapes and rock relief, and collected sediment samples for paleomagnetic and pollen research, and flowstone samples for mineralogical research and dating. Based on the shape of a particular cave and its geological features we forecast its extensions; this assisted the constructors during restoration.
We attempted to preserve as many caves as possible. This was simplest with shafts. We closed the small entrances with concrete lids. We were also able to preserve those old caves with stable ceilings. Caves that were opened due to blasting and were located in hollowed rock had to be blasted again and filled in. Caves that were cut through during the digging of road banks, with entrances located in the banks, were closed with rock walls. Their perimeters were unstable to such an extent that entering the caves would be dangerous. Sediment-filled caves had to be closed to prevent water from shifting loam onto the road. A well-preserved cave was left open for visits by people crossing the Italy-Slovenia border. The most interesting and well-preserved caves were protected in their entirety; although they are located beneath the motorway, they are accessible. Access to these caves is through concrete pipes that finish at the edge of the road with a closed shaft.
We studied the impact of different types of detonation in caves; this information will be useful in further construction and in the preservation of karstic phenomena.

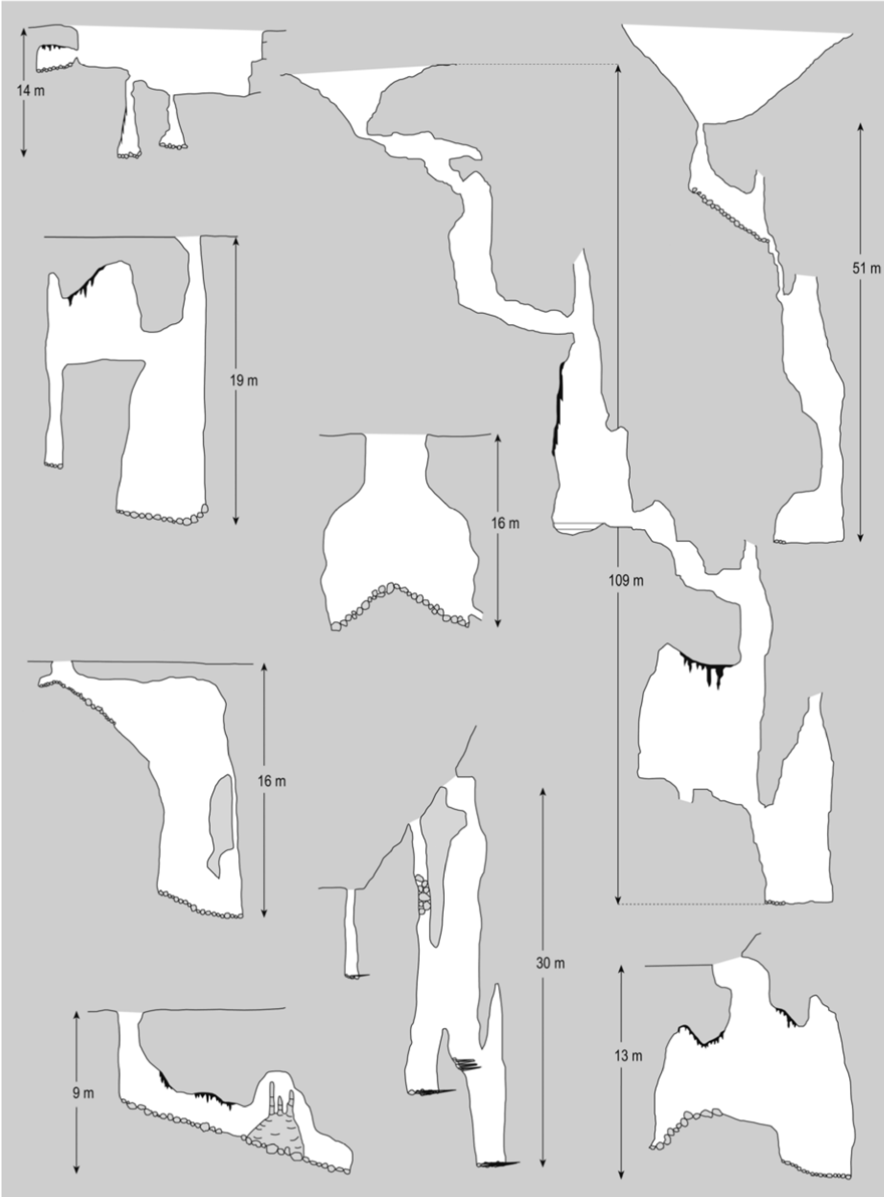

Figure 3 During the construction many caves of different shape and size open and dictate further appropriate building works.

4 Conclusion

We conclude that the collaboration of karstologists in motorway construction in the Karst has been advantageous. However, it is important that we co-operate in the planning and construction process, as well as in the later monitoring of the impact of motorways on the environment. This means that cooperation is necessary during the whole process of intervening in this vulnerable karstic landscape; only in this way will the goals of preserving natural heritage and deepening our basic knowledge of the development of the formation of the Karst and of motorway construction in this unique environment be achieved. There are different known karst types, each one demanding a different approach; this is why cooperation with constructors must be constant and ongoing. We have been able to implement these findings across most of Slovenia in the past ten years. Cooperation between road planners, constructors and karstologists is an example to be followed in the planning and implementation of other interventions into the Karst.

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