Stability of the bedrock of castle building for geotourism purposes

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Abstract. The geological structure of the Slovak Republic is very complex and varied. This fact in the course of centuries has had an impact on the castle buildings built here. The subsoil of these structures has different petrographic composition, tectonic disturbances and other geological complexities that threaten the stability of these structures and endanger the objects in their surroundings. In recent years, these structures have begun to receive deserved attention. In the past, the problems of severely disturbed blocks in the subsoil were mainly addressed and had to be rehabilitated for these reasons. These were mainly buildings whose subsoil is built with carbonate rocks. A perfect example of a long-term solution to these complex problems is also the Strečno Castle. A lot of effort and money has already been devoted to solving the stability of the bedrock, which also adversely affects the stability of the castle. However, the extensive set of works that have been carried out here over a long period of time have not brought a complete solution to the problems that occur here. For this reason, continuous work is being carried out here under the guidance of experts to eliminate the effects of erosion of the bedrock in particular. In the present work, the activities and measures that have been implemented here in stages up to the present are briefly described chronologically.

1. Introduction
The geological structure of the territory of the Slovak Republic is very varied and complex. It belongs to the Western Carpathians, which are part of the European Alpine orogen. The varied geomorphology of the terrain has served in the past centuries to construct many castle buildings, which are numerously represented in the whole territory of Slovakia. The current view of these buildings is significantly different than in the past. Suppose in the past the problems of stability of only some selected buildings, mostly preserved buildings or historical symbols, were dealt with. In that case, today, attention is also paid to the ruins of less known castle buildings. In recent years, not only state institutions but also various civic associations have been involved in the conservation, restoration and completion of these buildings. However, this restoration must be preceded by a more detailed geological survey. These buildings are primarily built on tectonically disturbed bedrock. This fact is also reflected in the fact that large blocks are sometimes loosened from the bedrock. Such events have been recorded in recent years, for example, on the buildings of Trenčiansky Castle or Strečno Castle. Appropriately designed sets of methods based on monitoring these processes can significantly eliminate the consequences of weathering processes.

A good example is the already mentioned the Strečno Castle. Both natural factors - weathering or seismicity, as well as anthropogenic influences - the partial demolition of the castle at the end of the
17th century or limestone mining in the adjacent quarry - contributed to its destruction. In the 20th century, it was mainly the castle's bedrock that had to be addressed. These works had to be carried out because of the danger to road users on the very significant communication. At the same time, the issue of partial stabilisation and restoration of the castle building itself was also addressed.

As already mentioned, there are several similar buildings in Slovakia. The use of these buildings has nowadays much more possibilities than in the past. Nowadays, in addition to their traditional use, these buildings can be incorporated into itineraries of non-traditional forms of tourism, the spectrum of which has been expanding considerably recently. In the past, for example, these objects often served as backdrops for film productions.

2. Geological subsoil
Geomorphologically, the site belongs to the Malá Fatra area. The Váh River, which flows below the castle, divides this mountain range into Krivánská Malá Fatra and Lúčanská Malá Fatra. The geological structure of this area is very complicated. This part is classified as a core mountain range of the Central Western Carpathians. The area is built up by envelope units, Mesozoic rocks that stratigraphically belong to the Middle to Upper Triassic, which form part of the Chocá escarpment. These are carbonate sediments where dark grey dolomites predominate over bench limestones. To a much lesser extent, there are also interbedded rocks of clayey-silty to sandy composition. Granitoid rocks of the nuclear mountain range are also found in the gorge. A major problem of the bedrock of the castle is the significant faulting of the massif by numerous fractures. As a result of exogenous processes, mainly erosion, large blocks of rock are being released, which threaten the traffic on the adjacent main road I/18 located below the castle. This tectonic structure is also linked to the occurrence of numerous caves that can be found here. Speleologists have already discovered 11 caves of different sizes, varying in length (from 10 to 20 metres) and height. This research has been going on since the 1980s when one of them was also explored in detail. It has been confirmed that some of them were known to people several centuries ago. In the past, injection works carried out here have closed some of these karst formations. It is believed that the total number of these caves is not finite, and more will be found in the future. This fact confirms the geological complexity and further complicates the solution of the stability of the castle bedrock [1, 2].

3. Historical development of the castle
This castle is located between the towns of Žilina and Martin. The castle was built on an older foundation, probably a Slavic hillfort. The first mention dates back to the beginning of the 14th century, when the Strečnian manor, of which this castle was the seat, is mentioned. Among the oldest buildings of the castle is a prismatic residential tower, accessible from the south by a bridge spanning a moat. In later times, other buildings were built, such as a courtyard with castle palaces and a chapel or a well. The castle was built by the Balas family and served as a protective object of the toll station, which was located below the castle by the Váh River. In later times, it was owned, among others, by Matúš Čák Trenčanský or the Hungarian Queen Barbara of Celje. Shortly before the anti-Habsburg uprising, at the beginning of the second half of the 17th century, the castle was completed thanks to František Vešeléni. At this time, the castle has the largest surface area. The rebuilding of the fortifications made it the most modern castle in the Central Povazie region. After the suppression of the rebellion, the castle was in the hands of Imrich Tókóli's troops. In 1698 Leopold I had the conquered castle destroyed. By demolishing the fortifications, destroying the roofs, windows and doors, the building was devastated. Later owners failed to restore the castle to its greatest glory. The subsequent major destruction occurred at the beginning of the 20th century. At this time, the castle came into the possession of Samuel Hahn, when the material from the castle began to be sold as building stone. Fortunately, this destruction soon ceased in 1904. Soon after, however, around 1909, limestone also began to be extracted from the castle quarry for the nearby lime kiln located next to Nezbudská Lúčka. Fortunately, the slow and intermittent mining was not enough to significantly disturb the remains of this castle, and soon after the establishment of the Czechoslovak Republic, thanks to the Czechoslovak Tourist Club, it ended ultimately. During the

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Second World War, German artillerymen shelled the positions on the castle occupied by the Czechoslovak army. As a result of these battles, this building was significantly damaged, threatening the adjacent main road between Žilina and Martin [3-6].

4. Addressing the stability of the bedrock and the castle itself

The stability of the bedrock and the castle itself has been addressed several times and is still being addressed today. We can learn about the solution to this problem not only from expert works [7-13] but also from the contemporary press. Another important milestone was the inclusion of this castle among cultural monuments. From the historical point of view, the efforts for the stability of the subsoil and the castle can be divided into several time stages.

The first efforts to stabilise the castle came from the Hungarian Heritage Commission. In 1910 the castle was structurally secured and reinforced. However, the crowns of the walls were improperly covered with cement mortar and the statically disturbing parts were reinforced with iron rods. During the intense fighting of the Second World War, these security features were also severely damaged.

The second major reconstruction only began in 1974. Already at the end of the 1950s, a geodetic survey was carried out, and a study for the conservation and accessibility of the building was carried out. The need for reconstruction began to be seriously considered as early as the early 1960s. Inspections of the condition of the building and its subsoil revealed that, in addition to the stability of the castle building, the safety of the adjacent first-class road was seriously threatened. A significant event that significantly contributed to the salvation of this object was the inclusion of the castle in the list of immovable cultural monuments. This reconstruction was both technologically (unexpected problems often arose) and financially very demanding. For this reason, work continued until the mid-1990s. During the course of the conservation and protection work, many partial activities were carried out. These activities included, for example, archaeological surveys, the securing of the rock barrier to the actual conservation and completion of the castle buildings. At the beginning of this long-term action, it was necessary to remove the trees and debris that had accumulated in large quantities over several centuries. This activity was carried out with the participation of archaeologists. The removal of these deposits uncovered many new objects, the restoration and protection of which also had to be incorporated into the project. There was also a problem with constructing the scaffolding on the eastern wall of the barrier, where the original option had to be changed and replaced by the construction of a suspended scaffold. Prior to its construction, loose rock blocks were removed, and a protective net was stretched. At the same time, a wooden palisade was built next to the main road. The foundations of the castle walls were then reinforced with micro piles. Several methods were used to ensure the stability of the bedrock, which is geologically very complicated. Firstly, there was the embedding of fifteen-metre anchors, made of prestressed steel, the use of micro piles and grouting. The final phase of the work concentrated on the structural and architectural work. During this phase, stone was used to complete the masonry and build up to its present form, both from the rubble and imported from the surrounding area. From today's point of view, this work was not carried out in a very appropriate manner. An example is the binder used, where cement mortar was inappropriately chosen. Following the implementation of these works, it was noted that all the problems were still not over, and further works would be required to address the problem of loose blocks in the subsoil in particular.

The critical situation in the section Strečno - Dubná skala has long been pointed out that it is in a critical condition. There were frequent falls of variously sized snowdrifts on the road. In 2007, there was also a fatal accident here as a result of falling debris. For this reason, it was eventually decided to address the issue of the weathering on both the road and the railway line beneath it. Towards the end of the summer, at the end of August and beginning of September 2008, another major rehabilitation activity began here to protect traffic from falling blocks from the rock walls. Suitable weather conditions allowed the completion of this work by the end of the year. It was a condition that the work was carried out with
two-way traffic on the road. However, short-term traffic interruptions were also necessary for safety reasons. This was particularly necessary while the rock walls were being cleared. Pneumatic pads were also used to release large blocks. The work was carried out over a longer stretch, including in areas of forest cover where pruning was necessary. The special mesh was then placed on the cleared rock face, which also followed the unevenness of the rock face. The mesh was attached to the wall with steel bolts and in the peripheral parts with steel bars with eyes for stretching the steel rope. During the work, these measures proved to be ineffective, and for this reason, steel bolts were additionally used. Due to the considerable disturbance of the wall, there were frequent problem situations, such as the boreholes being blocked or even rock blocks being blown out. For this reason, the construction of an anchored reinforced concrete wall was also carried out later. Dynamic barriers were also used for rehabilitation. The work was carried out under constant professional supervision. This was necessary because of the complexity of the geological structure, which became apparent as soon as the rehabilitation work began. It was necessary to react to new findings that emerged during the work with new measures and changes to the work procedures.

Already in 1996, due to the loosening of the rock block, an optical-mechanical dilatometer was permanently installed to measure the magnitude of the displacements in both the horizontal and vertical planes. In 2014, the displacement on the x-axis was already 4.4 mm. For this reason, the government decided in 2015 to install two more automatic dilatometers that allow online measurement of movements at critical points of the massif. Subsequent measurements showed that movements are also taking place in both opposite directions. The issue of remediation was still being stretched in government in 2016. The proposals that increased the budget for future rehabilitation included plans to build reinforced concrete galleries used in alpine passes. This option was proposed as a long term solution to the traffic safety problem. In addition, drone surveys have yielded information that up to four blocks under the castle building have been disturbed and not one as originally thought. As part of the remediation, a set of engineering measures were proposed to address the problem. The total implementation time without gallery construction was proposed to be eight months, with gallery construction a year and a half. A period of time for traffic exclusion and also a period of time for traffic restriction was envisaged. At the start of the last works that were undertaken, there was an incident in July 2017 when a 100-tonne section of the rock wall unexpectedly collapsed. Frequent rockfalls had already been recorded a month earlier. For this reason, the road was closed, and a layer of gravel was piled on top for protection and then clearing of the wall continued. The remediation work was planned in several stages. The first stage, which was completed late in the first half of 2018, involved immediate emergency measures in the most critical sections. Anchoring of unstable blocks, application of shotcrete with reinforcement, filling of overhangs with concrete fill, grouting, and backfilling took place. Attention was also paid to the repair of the castle foundations. In the following stages, the main issues to be addressed are monitoring the rock wall and the construction of dynamic barriers in critical areas.

5. Conclusions
Strečniansky Castle is one of the many castles that have been preserved in Slovakia. Due to its location adjacent to the main road and its complex geological subsoil, it has received much attention. The castle was built on a very unsuitable and unstable subsoil, which is now becoming a problem where it is necessary to address the stability of the castle buildings and the stability of the subsoil itself. For this reason, there has been a lot of safety work done in the past to solve these problems. However, the knowledge gained in these remediation works shows us that the bedrock of the castle has many hidden secrets that are beginning to be revealed from the very beginning of the works carried out here. The simple fact that the road that runs under the castle does not yet have an alternative to replace it is responsible for the attention that has been paid to this object. For this reason, it is, therefore, necessary to continue to pay increased attention to monitoring the movements of the rock blocks and subsequently to ensure remediation work in advance. These activities can significantly help not only road safety but
will also ensure the stability of the castle building, which is a national cultural monument and an increasingly popular tourist attraction.

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