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THE RELEVANCE OF BRITTLE FAULT ZONES IN TUNNEL CONSTRUCTION – LOWER INN VALLEY FEEDER NORTH WITH A VIEW TO THE BRENNER BASE TUNNEL

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Zones of rock deformed under brittle conditions greatly influence underground construction projects, especially in the case of deep lying tunnels, where they cause large problems, above all when they have a high water permeability. In some cases a further advance is no longer feasible, without measures to reduce the water pressure, from a tunnel engineering point of view or due to an unassessable residual risk. For the geologist, the difficulty is, when using the results of the surface mapping, to predict the geomechanical properties and groundwater conditions to the tunnel level depth.

The Lower Inn Valley in the Tyrol, in the Eastern Alpine region, Austria, contains a major fault zone. The fault zone originated as early as in the Upper Cretaceous in the course of the formation of the Gosau Basin. The ensuing formation of the Lower Inn Valley Tertiary Basin and further sinistral strike-slip faulting in the Miocene, which is cut by local younger dextral strike-slip faulting, characterise the Lower Inn Valley Fault Zone. Also, recent seismic activity in the Zirl – Wörgl area is a proof of ongoing tectonism in the region.

The planned railway project Munich – Brenner – Verona runs approximately 40 km subparallel to the Inn Valley and crosses many faults which constitute the Inn Valley Fault Zone. During the construction of the reconnaissance tunnels in the Lower Inn Valley, geological conditions were encountered which led to serious tunnel engineering problems. Fundamentally, the problems involved fault zones made up of different types of brittle deformed rock. There are two factors of significance when considering the geomechanical properties of the faults:

1. Rheology:
   Depending on the host rock, pure brittle deformation gives rise to breccia, namely kakirites. In the case of rigid carbonates - massive rock with great compressive strength - cohesionless zones of soft rock are formed. When slaty or foliated rock of low compressive strength, such as slates or phyllites are involved, slightly cohesive soft rock is formed.
2. Age of the faults:
   Geologically older fault breccia is in general cemented. Young to recent fault breccia are frequently superficially healed and thus comprise zones which are technically hard to construct in. In principle, it can be stated that the degree of cementation of a kakirite determines its geomechanical and hydrogeological properties.

Examples:
Cataclasites:
In the Vomp East Reconnaissance Tunnel, around Station 670 m, at the southern tectonic margin of the Inn Valley Nappe, in the so called Vomper Bach Imbrication Zone, several cataclasic zones were intersected in Wetterstein Dolomite. It is assumed that these thrust faults date back to the Cretaceous, with a later reactivation of these now steep dipping faults presumably occurring into the Miocene (reconstruction of the

Fault Zone Types	Host Rock	Age of Fault	Geomechanical Characteristics	Groundwater Conditions
Cataclasite	Dolomite	Cretaceous to Miocene	Consolidated, cemented fault breccia	Increased jointing results in increased water ingress
Type 1 Kakirite	Phyllite	Cretaceous to Miocene	unconsolidated fault breccia but with cohesive soft rock character	Fault breccia frequently has an impermeable character
Type 2 Kakirite	Gypsum-bearing carbonates	young or recent	Lixiviated zones + unconsolidated almost cohesionless fault breccia made up of sand and gravel sized grains	Highly permeable fault zones with large water supply under pressure

Table of Fault Zone Types

paleo-stress directions based on movement criteria).

As the mentioned faults are well cemented, there was no significant geomechanical deterioration. Deformation measurements within the tunnel showed no significant increase. There was, however, increased water ingress which was attributed to the increased amount of fractures and joints within the zone.

Kakirites:

Type 1 Kakirites

Tectonically sheared Wildschönau Phyllites, at Station 1050 in the Brixlegg East Reconnaissance Tunnel, comprised a zone of cohesive soft rock. In the zone, groundwater conditions were defined as damp. Due to the composition of the host rock, the fault had an impermeable character. It was possible to knead the material of the fault zone by hand. The rock mechanical behaviour was squeezing, with deformation slowly subsiding after several months. From a geologically point of view it is a normal fault. At the fault boundary, Paleozoic Wildschönau Phyllites are in contact with Mesozoic carbonates of the Partnach Formation.

Type 2 Kakirites

At Station 2274 in the Brixlegg East Reconnaissance Tunnel, a kakirite zone was encountered when drilling an anchor hole in the left-side tunnel wall. A major water ingress (kf~1xE-04 and 5 bar) resulted, with the flushing out of sand and gravel sized material. Consequently, for safety reasons, tunnelling was discontinued. In engineering terms, after a very thorough and costly investigation, it was determined that the fault zone consists of almost cohesionless soft rock. To date, it has not been possible to consolidate the rock using injection methods, while maintaining the water pressure, to such an extent as to be able to resume tunnelling.

The genesis of the fault can be attributed to the ss-parallel leaching in the Raibler strata. As the fault is not cemented, it appears to be of a young age. The formation of the fault is seen as a cataclasis of the lixiviated zones in connection with seismic activity along the Inn Valley Fault, with no large-scale movement occurring.

These examples show that for large engineering projects and especially deep tunnelling projects, knowledge about brittle fault zones and their condition, as consolidated, cohesive or cohesionless zones of soft rock is of the utmost importance and can be decisive for the technical and economic feasibility of a project. With regards to future deep lying tunnels in Austria, and in particular the Brenner Base Tunnel, it is recommended to investigate closely the fault zones by means of direct and indirect methods, after the surface structural geological mapping has been carried out, in order to gain the best possible picture of the geology at the relevant depth.

Cohesionless fault breccia can for instance be expected in the southern section of the Brenner Base Tunnel where recent shearing has led to the displacement of the prominent Puster Valley Fault (part of the Periadriatic Fault; see Bistacchi et al., 2001). The cataclasis zone here consists of the carbonates and the evaporites of the Eastern Alpine Crystalline Basement, the Mauls Tonalite Lamella and the Brixen Granite.

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