Site investigation for a constrained river crossing

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ABSTRACT: The construction of a river crossing in the city of Berne, Switzerland for various utilities beneath a river, deeply eroded into bedrock, and back-filled with cobbles and boulders had to be investigated. The location in a river bend with strong flow did not allow to drill vertical holes from the surface of the water course. Hybrid seismic investigations were used along both shores and across the river bed along the proposed alignment. Geoelectric investigations were carried out across the river with electrodes suspended from a cable across the river, in zones where no electric cables were present. Vertical core borings into bedrocks on both shores were drilled in key locations. With the combined results the shafts and the alignment could be positioned in plan. After excavating the shafts to 25m depth, horizontal core borings were carried out to confirm that the micro-tunnel would be located entirely in bedrock, after lowering the shafts another 3 m.

Keywords: geophysical; geo-electric investigations; seismic; borings; site investigations

1. Location

The city of Bern, capital of Switzerland is at the border in the foothills of the Alps and the subsoil has been strongly influenced by the deposits of two major alpine glaciers, the Aare glacier from the south and the Rhone glacier from the west. The old city is located, since the middle ages, on a peninsula formed by a bend of the Aare River. Topography and geologic conditions had an important influence on the development of the city. The construction of new infrastructure must cope with these topographic and geologic conditions.

For their infrastructure (electricity, water and gas) the utility company had built a ring system around the core of the city, which required the crossing below the Aare River (Figure 1) in the southern angle bend. The crossing is approximately 120 m long,

2. Underground conditions

The glaciers have remodeled the bedrock surface and cut canyons in it. Some of these valleys have been filled in by glacial deposits and pose challenges to underground construction.

The quaternary deposits are underlain by tertiary bedrock of the Molasse formation, which has completely different surfaces (Staeger, 1992) than the present ground surface. In some area's bedrock is present at river level and forms the valley walls, yet only a few hundred meters away bedrock may be several hundred meters below the present surface.

The area of peninsula of the old city, some 30 m above the level of the Aare River, is nearly completely formed by glacial sediments. Near the train station in the west bedrock is at the ground surface. Some 500 m to the south bedrock was encountered 260 m (Elevation. 237 m) below river level. On the eastern side of the river bend bedrock is at the surface. North of the peninsula the Aare River is confined by bedrock on both sides of the river bed.

Along the south side a weir has been constructed that allows using the power of the river, earlier by water wheels, today by a hydro power station.

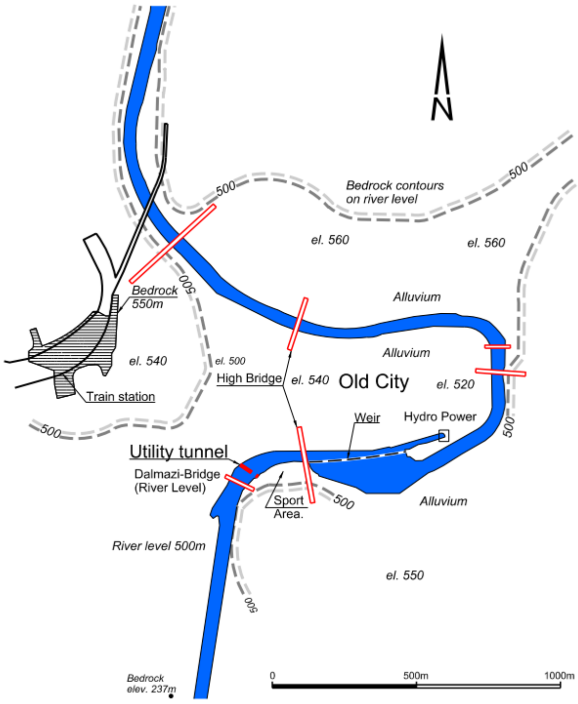

Figure 1. Central part of the city of Bern showing Aare River with bend around old city and areas with presence of bedrock and location of river crossing

2.1. Geologic conditions near the crossing

Near the planned crossing in 2005 two shallow borings on both sides of the river were available. The boring on the west shore indicated gravel with boulders between 4.50 m and the end at 7.10 m borings. On the east side bedrock was encountered in 5.6 m depth. These results correspond to the surface outcrops in the area. Thus, one had to expect fluvial gravel with cobbles and boulder to an unknown depth, which could give large obstacles to the driving of a micro tunnel.

Supplementary site investigations were required to reduce the geological unknowns and the risk to construction.

3. Site investigations

The geologic conditions were judged to be rather challenging. In addition, it became clear that it was not possible, or only at excessive costs, to drill exploratory borings in the middle of the river bend. The drag forces of the "mountain" river were just too large to hold a pontoon in place. The site investigations were planned to be carried out in stages and to add or modify them as results became available.

From the beginning geophysical investigations were planned. As the tertiary molasse bedrock has P-Wave velocities above the groundwater table between 0.8 to 1.5 km/s, the P-wave velocities below the groundwater table will be strongly influenced by the water in the saturated state and will be around 1.5 to 2.2 km/s. The contrast between different layers will be less pronounced. However, hybrid seismic, a combination of refraction and reflection seismic investigation was applied, together with two core borings.

Along the shores of the river many electric cable conduits are present, which influence geoelectric fields, thus geoelectric measurements were initially discarded, as the measurements might be disturbed by external electric fields.

One of the planned shafts had to be moved due to a conflict with a flood control project, which led to an extension of the length of the tunnel from 100 to 120 m.

3.1. Seismic investigations

3.1.1. Layout of seismic lines

Three seismic profiles were laid out (Figure 2):

- across the river and
- on the eastern bank and,
- along the western bank of the river.

Each line included 200 geophones spaced 3 m. The excitation of the ground vibration was by impact of a mass of 50 kg with vacuum acceleration and an impact energy of 2.6 Nm (Geoexpert, 2005).

3.1.2. Results of seismic survey

The results of the refraction survey for the river crossing are shown in Figure 3 to Figure 5 and the hybrid seismic survey in Figure 6 to Figure 8 together with the profiles of the borings. The wave velocities underneath the river bed show only small contrast from 1600 to 2400 m/s for soil and bedrock. The limit between soil of the river and bedrock was set at 2 km/s, beneath the river bed the bedrock surface had to be expected between 20 and 30m depth. The shape of the boundary does not correspond exactly to the river bed, as one would expect. On the western side the bedrock surface was dropping westwards (Figure 3). On the eastern shore bedrock had to be expected 5 m below the ground surface. On the western shore to the south, soil reached to about 20 m depth.

The resolution of the hydride seismic profiles appeared less well defined between soil and bedrock than the limit of the refraction seismic velocity for the cross-river profile (Figure 6).

3.1.3. Remaining uncertainities

The seismic survey gave strong indications that the soil (Gravel with cobbles and sand) channel was present, however, the shape of the channel was not to the expectations. The calibration of the seismic survey with the available, pre-existing and new, borings

The execution of borings in the river would have required substantial measures for either building a platform in the river bed or anchoring a pontoon in the strongly flowing river. The cost for one or two borings with the platforms was considered excessively high.

Across the river no electric cables were present locally, thus after a longer discussion, the decision was taken to execute a geo-electric survey across the river along the same alignment as for the seismic survey (Figure 2).

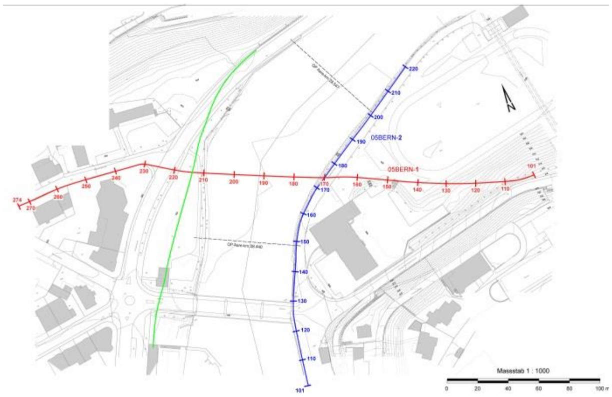

Figure 2. Layout of the seismic lines across and along the Aare river.

3.2. Geo-electric investigations

Before the geo-electric survey across the river was made, tests were carried out to verify that reliable results were obtained, with geo-electric measurements along sections of the river banks. The measurements along the east bank (Figure 9) showed that in the area south of point 2, (river crossing), agreement with the seismic investigation and the borings was found. However north of point 2 the measurements were influenced by the concrete river wall and not reliable.

The results of the initial geoelectric measurements across the river are presented in Figure 11, together with the results of the vertical borings and the horizontal borings, which were later executed to verify the depth of the river channel. The initially applied Dipol – Dipol interpretation indicated on the eastern bank of the river was soil, which was in contradiction to the refraction seismic survey that indicated bedrock. The geoelectric measurements reinterpreted with a Wenner configuration provided a different picture (Figure 12) that agrees better with the refraction seismic survey and the results of the vertical borings. The depth of the trough reaches an elevation of 482 m, some 25 m below the river level. However, the level of the bedrock is known with some uncertainty. Mixed face conditions should be avoided, as in the river bed also cobbles and boulders had to be expected.

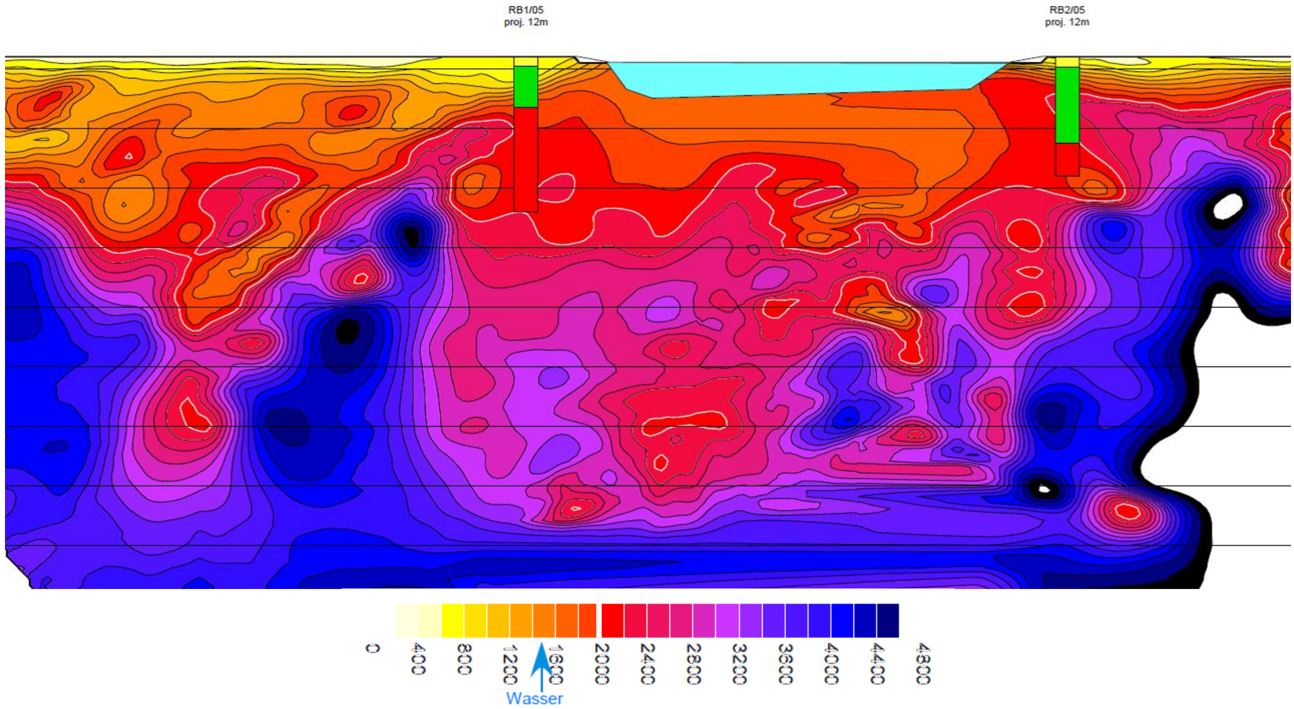

Figure 3. Refraction seismic survey across the river: The limit between water and soil to bedrock was set at 2'000 m/s (from Geoexpert, 2005)

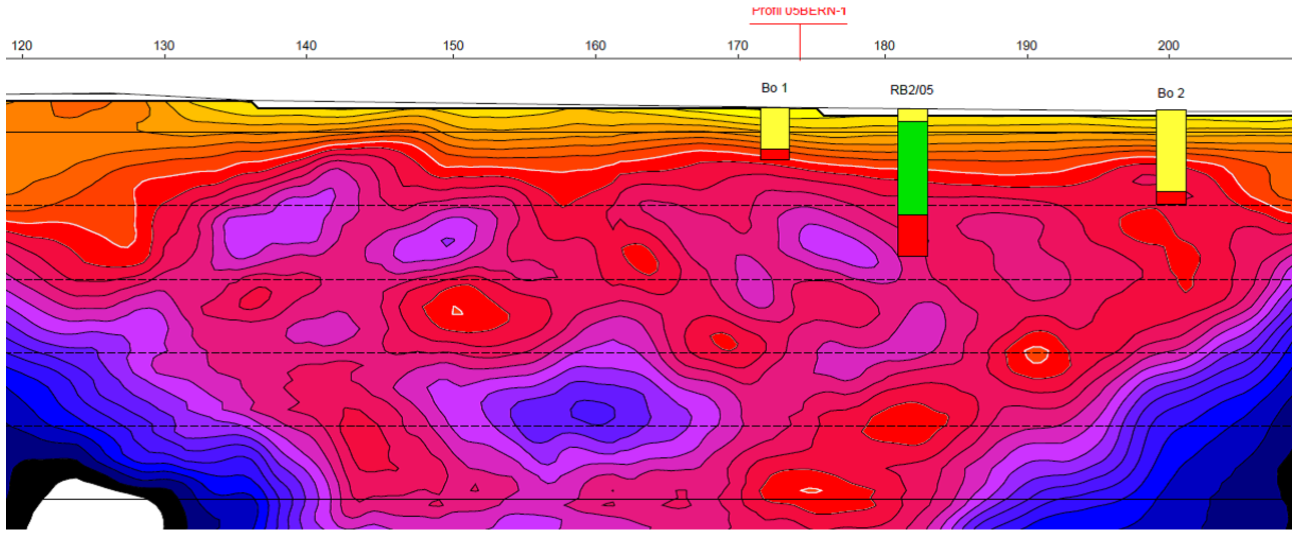

Figure 4. Refraction Seismic survey along the east shore of the Aare River, with the logs of three available core borings

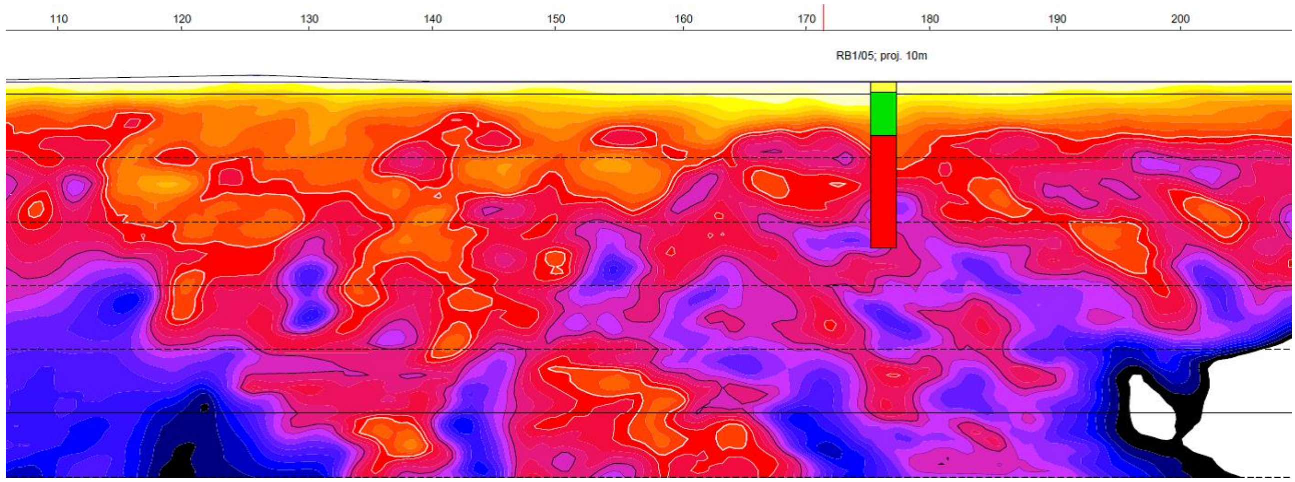

Figure 5. Refraction seismic survey along the west shore of the Aare River, with limits as v_p = 2'000 m/s with core boring (from Geoexpert, 2005)

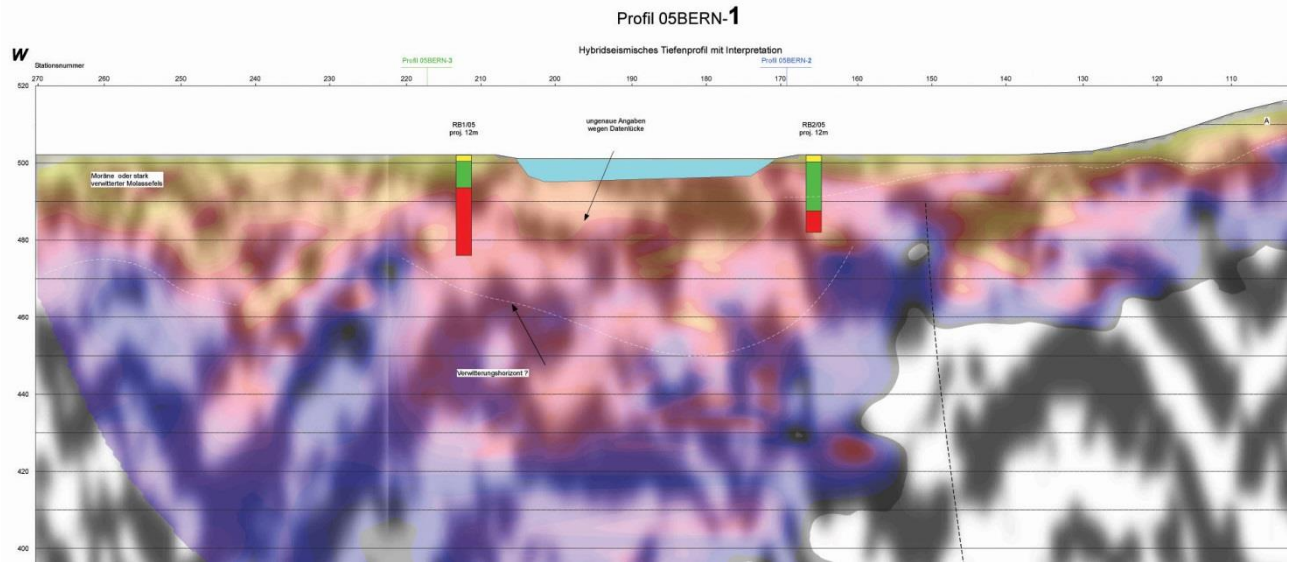

Figure 6. Hybrid seismic survey profile across the Aare River (from Geoexpert, 2005) comparison with boring logs (yellow: Pavement; green: gravel; red: bedrock). Colors according to combination of refraction and reflection waves after manual interpretation. Limit of weathered zone

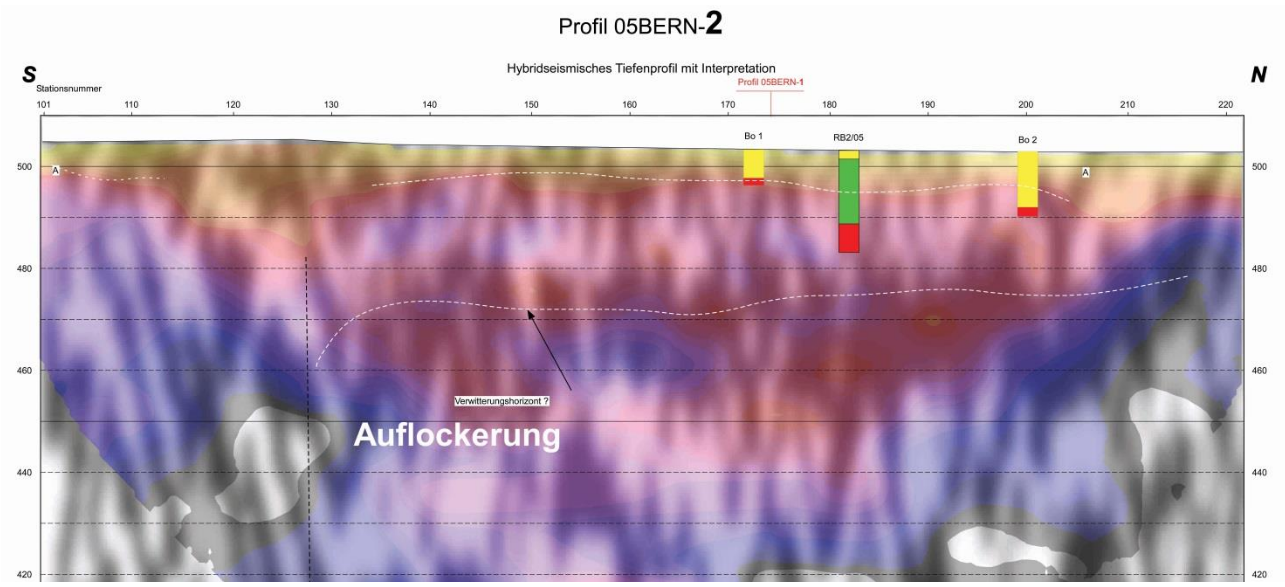

Figure 7. Hydrid seismic survey along the eastern shore of the Aare River (from Geoexpert, 2005) with manual interpretation of disturbed zone (Auflockerung) or weathering zone.

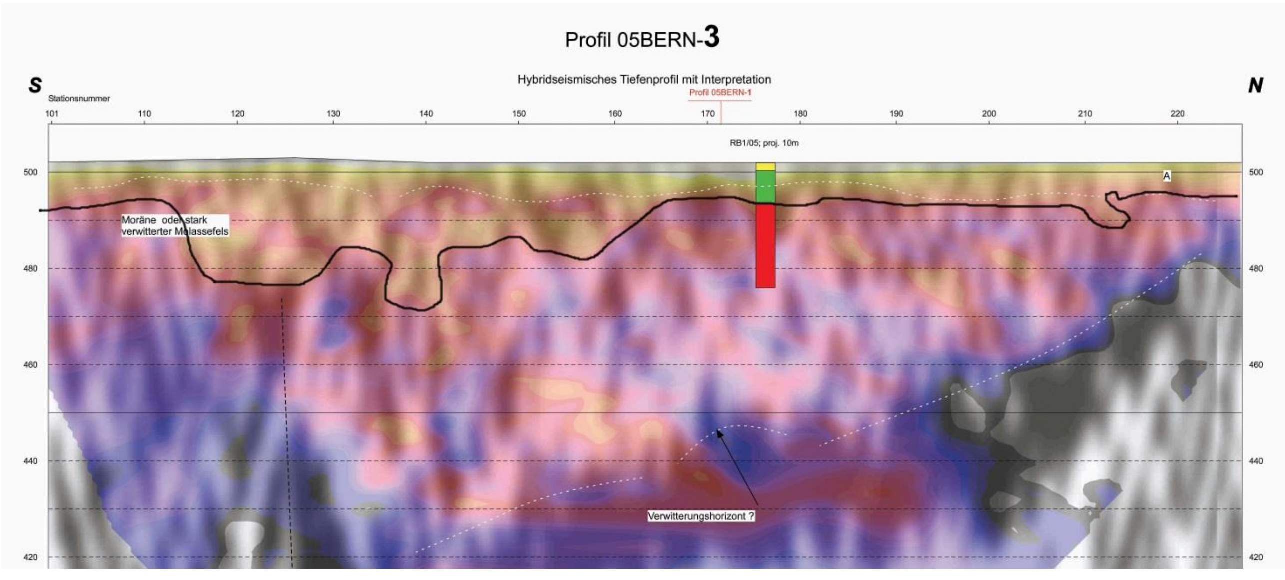

Figure 8. Hybrid seismic survey along western shore of the Aare River (from Geoexpert, 2005) with combined manual interpretation. Bedrock surface (solid black line) and weathering boundary of bedrock (-----).

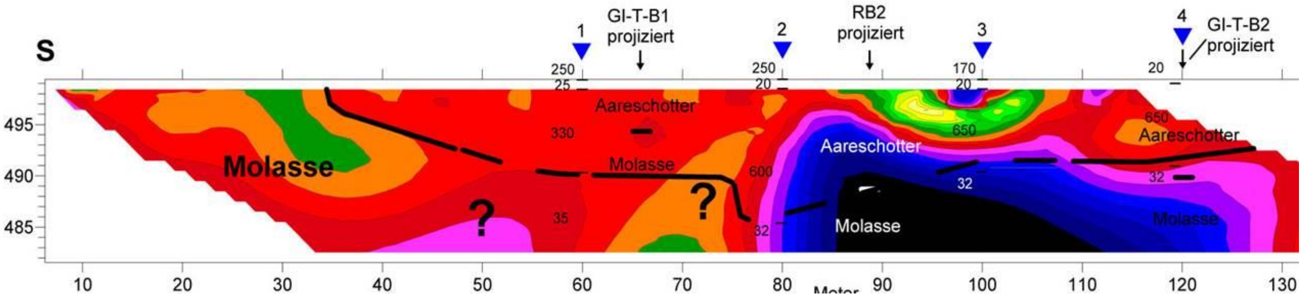

Figure 9. Geoelectric investigations along east bank of Aare River, north (right) of point 2, the sounding was influenced by concrete (Terratec,2006)

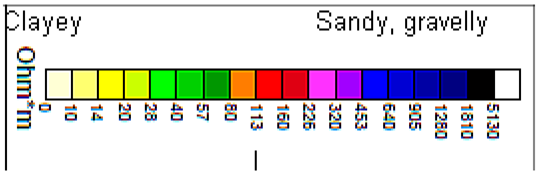

Figure 10. Scale of Geoelectric interpretation in ohm.m.

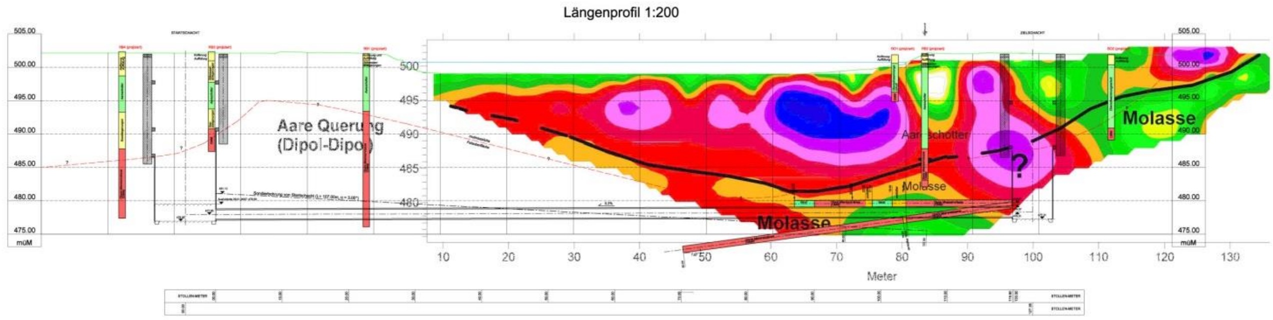

Figure 11. Longitudinal section with results of horizontal and inclined boring from retrieval shaft and geo-electric survey with initial Dipol interpretation (Terratec GmbH, Heitersheim, German, 2006): East = Right side of figure; West = left side of figure.

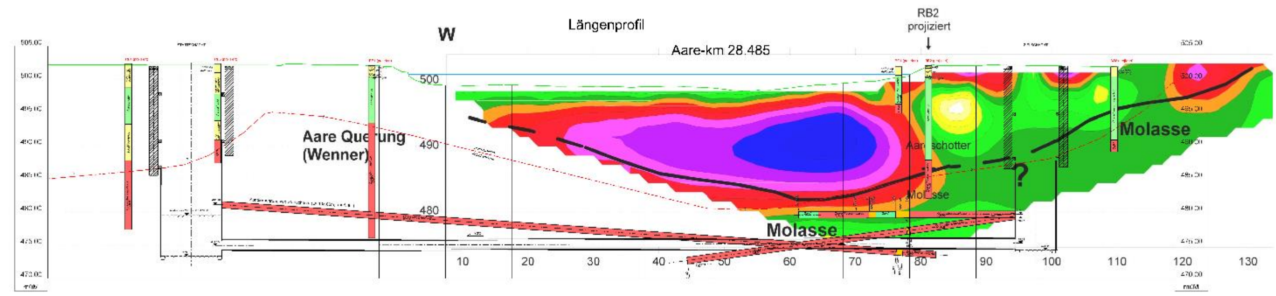

Figure 12. Longitudinal section with results of horizontal and inclined boring from start and retrieval shaft and geo-electric survey with recalibrated Wenner interpretation (Terratec GmbH, Heitersheim, Germany)

3.3. Horizontal Borings from shafts

Driving the micro-tunnel was foreseen between two vertical shafts on both sides of the river. The length of the micro-tunnel initially was planned at 100 meters distance, due to a project of possible flood control tunnel, the western shaft had to be moved 20 m, resulting in a 120 m long tunnel. Additional vertical borings were carried out on the west bank that confirmed bed rock dipping to the west, as predicted by the refraction seismic survey (Figure 3). The first horizontal boring was drilled from the east shaft as the deepest part below the riverbed was expected closer to the eastern shore (Figure 11) on elevation 480 m. This boring encountered broken rock from 16 to 18 m then sand to 21 m and another meter of broken rock and sand again from 29 to 31 m. A second 40 m long boring inclined at 8° was drilled from elevation 479.4 m which remained entirely in solid bedrock, except for the broken zone from 16 to 16.5 m. At that time the decision was taken to lower the alignment of the micro-tunnel by 4 m to elevation 475.31 m.

The sub-horizontal 110 m long boring from the western shaft was drilled through solid rock, but encountered the broken rock again between 102.0 and 103.0 m. This zone corresponds most likely to a vertical broken zone (fault) and may also correspond to a steep rock wall below the river bed.

4. Driving the microtunnel

The microtunnel was driven from the western shaft to the east through solid bedrock, mainly sandstone of the Upper Marine Molasse (Obere Meeresmolasse) without problems until 102 m when water entered the face and washed-out the bentonite in the ring void between pipes and bedrock. The start shaft was flooded within a short time, about 30 minutes. This water was flowing in from the broken zone identified by the horizontal borings,

A series of strong pumps, totalling 10m^3/min was required to pump the water from the start shaft. Pumping was continued and the drive could be completed. Water then flowed into the retrieval shaft and was pumped out there. The void between pipes could be grouted and the cable duct be completed.

5. Other findings from the site investigation

The area south of the retrieving shaft is formed by the horizontal area with a sports race track. Beneath this ares the refraction seismic survey (Figure 3) and the hybrid seimic survey (Figure 6) indicate stronger rock with compressive wave velocities (3.5 to 4 km/s) that indicate more competent rock or compiled boulders of rock. At the eastern end of the sports track test soundings exist that indicate bedrock in 7 m depth. We suspect that before the City of Berne moved to the present site in the middle ages, the date of founding the city is 1192 the river also flowed through the area of the sports area. This branch of the river might have been closed by man-made activities, such that the river flowed along the southern edge of the peninsula and hydraulic energy in mills could be used. The celtic and roman settlements in the area of Bern were located on another peninsula formed by the meanders of the river a few kilometers to the north. The need for usable hydraulic energy from the river may be a reason that the city was moved to a new site.

6. Conclusions

The combination of geophysical methods, refraction and hybrid seismic with geoelectrical methods, both applied at thier limits, provided a rather clear picture of the depth of the river channel. The more expensive methods of core drilling could thus be focused in the zones of the most interest and the microtunnel be located at a level below alluvial deposits .

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