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Unexpected geology as part of the Hosingen bypass project: examples of the importance of geotechnical investigations

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ABSTRACT: Two civil engineering structures are to be built as part of the Hosingen bypass project. Based on the topography and geological map, the rock was assumed to be shallow and only 2 exploration boreholes were planned for each structure by the project owner for the initial geotechnical study. These boreholes revealed the presence of unconsolidated material and the roof of the rock at a much greater depth than anticipated. It was therefore decided to carry out supplementary geotechnical campaigns comprising a larger grid of boreholes and geophysical surveys. The boreholes revealed a sedimentary fill up to 20m thick. This sedimentary fill was found in 12 of the 20 exploration boreholes drilled, covering a total area of almost 10,000m2, in two different locations, indicating that this layer is not linked to an isolated event. It is mainly a conglomerate containing rounded pebbles of sandstone, quartzite and shale, ranging in size from a few centimeters to more than ten centimeters, with reddish clay cement. All the pebbles are aligned parallel to the horizontal, indicating that the fill post-dates the deformation of the underlying Devonian shale and sandstone. Geophysical studies using electrical tomography have revealed the presence of several faults with different orientations in the area where the fill is thickest. In view of the new geotechnical data, the first structure, which was initially planned to use shallow foundations, has doubled in length, necessitating the installation of piles more than 25m long. For the second structure, new piles had to be drilled. This highlights the need to carry out a complete and consistent geotechnical investigation at the planning stage of the project, to avoid unpleasant surprises and additional costs during the construction phase.

KEYWORDS: Engineering structures, geotechnical studies, geotechnical monitoring of works, unexpected geology.

1 INTRODUCTION

As part of the Hosingen bypass project in Luxembourg, the construction of 2 bridges (OA876 and OA877) is planned. OA876 will allow the future carriageway (RN7 national road) to pass over a farm track, while OA877 is planned as a 50m length viaduct crossing a small valley, with a road embankment on either side of the structure.

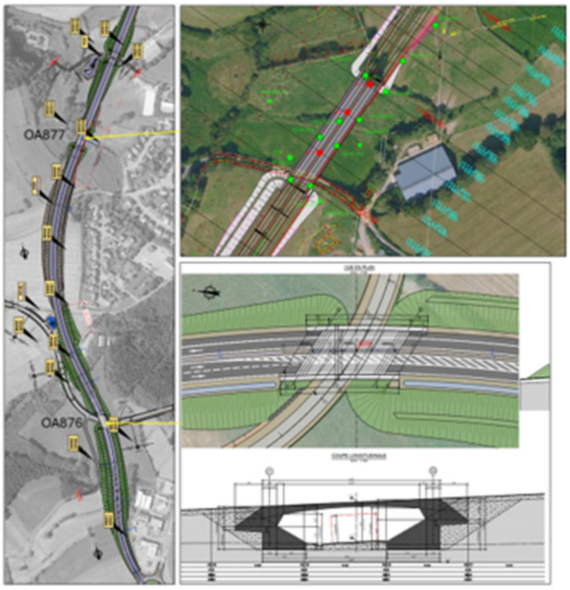

Figure 1. Location and geometry of OA877 (upper picture) and OA876 (lower picture)

On the basis of the topography of the site and the available geological maps, the project owner and the design office responsible for the statics thought that the rock would be encountered at a shallow depth in both locations, and planned to build shallow foundations for the 2 structures.

Consequently, in order to save on survey costs which, they felt were unjustified given that the rock was expected to be close to the surface, only 2 exploration boreholes were drilled for each structure, one for each abutment in the middle of the abutment, contrary to the recommendations of the Eurocodes 7 and the warnings issued by our office.

The purpose of this article is to show that in geotechnical engineering, surprises are always possible, even when the geological situation seems to be clear, and to demonstrate the usefulness of a rigorous geotechnical study complying with the requirements of current standards.

2 GEOLOGICAL SITUATION

Following the new nomenclature adopted for the new geological map of 2020, the geological layers encountered date from the Lower Devonian (Emsian) and belong to the ‘Clervaux Formation - CLE’ and to the ‘Wiltz Formation - WIL’.

The Clervaux Formation consists of a mixture of light grey, light green, pale olive green or variegated (red, green) shales interspersed with sandstones and quartzites. The sandstones can be of various colours (dark green, bluish, rarely red) and are often micaceous. The quartzites are generally greyish-white. The lithological variations are rapid and are probably due to variations in the sedimentation zone (marine, coastal and continental).

The ‘Wiltz Formation’ is composed of locally silty to sandy schists and shales. Depending on the location, the rock is grey, greenish grey or blue grey. Rare thin beds of sandstone may be intercalated locally, as well as sandstone nodules. Beds rich in fossils (brachiopods, trilobites, orthoceratids) and spirifers are common, particularly in the lower part of the formation. The rock is affected by very marked transverse schistosity, sometimes breaking into thin sheets and sometimes resembling phyllite.

Between the two formations above lies the ‘Berlé Quartzite’ (‘BER’ based on the new 2020 map). This is a white quartzite in massive banks ranging from several decimetres to several metres in thickness, separated by intercalations of shale. The Berlé Quartzite is located at the top of the Clervaux formation or at the base of the Wiltz formation, without it being possible to determine definitively whether it is still part of the Middle Emsian or already part of the Upper Emsian stratigraphically.

While OA876 should only be found on rocks from the Wiltz Formation, the OA877 zone straddles the Clervaux

Formation and the Wiltz Formation, close to an anticlinal fold axis and a WSW-ENE-trending fault.

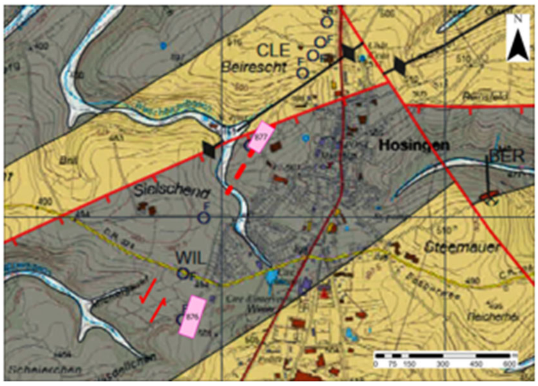

Figure 2. Geology next to the futures OA876 (south) and OA877 (north) (in purple: bridges, in red: faults, in black: fold axis)

3 RESULTS OF THE INITIAL STUDIES

3.1 *OA876*

For OA876, the sound rock (shale) was encountered at a relatively shallow depth for the southern abutment, but loose material that may correspond to an ancient weathered conglomerate overlying banks of reddish weathered sandstone was found for the northern abutment. The engineering office therefore based its design on those data, taking into account different geotechnical parameters for the two abutments, with piles driven into the healthy shale on the south side and into the weathered sandstone on the north side. Test coring at the bottom of the piles was nevertheless planned after the piles had been driven.

3.2 *OA877*

In the case of OA877, loose material consisting of pebbles in a silty-clay matrix was found to a great depth (>15m), while rock of good bearing capacity was only found at great depth. As a result, it was decided to carry out further investigations in 3 separate phases.

4 RESULTS OF THE ADDITIONNAL INVESTIGATIONS

4.1 *OA876*

For OA876, the statics engineer considered that he had sufficient information to design the foundation piles, and only 4 core samples were taken at the bottom of the piles after they had been built.

Again, for reasons of economy, the project owner refused the geotechnical monitoring that we proposed when the piles were being built. A total of 12 piles, each 11m long, were planned for each abutments (C1 to the north, C2 to the south).

For the C2 abutment, core sampling at the bottom of the piles confirmed the presence of rock as expected. On the other hand, for abutment C1, one of the boreholes confirmed the presence of rock, but in the second borehole the presence of reddish clay was noted under the base of the pile.

As these non-compliant situations represented a risk to the stability of the future structure, it was decided to carry out 5 urgent boreholes with pressurmeter tests spread over the entire abutment in order to find the sound rock. Loose materials such as those found at OA877 were also found in thicknesses ranging from 6.0m to 17m. These would appear to be the remains of heavily weathered ancient conglomerates with intercalations of weathered reddish clayey sandstone.

Figure 3. Weathered conglomerates

The rock appears deeper to the west than to the east of the abutment, as shown in Figure 4.

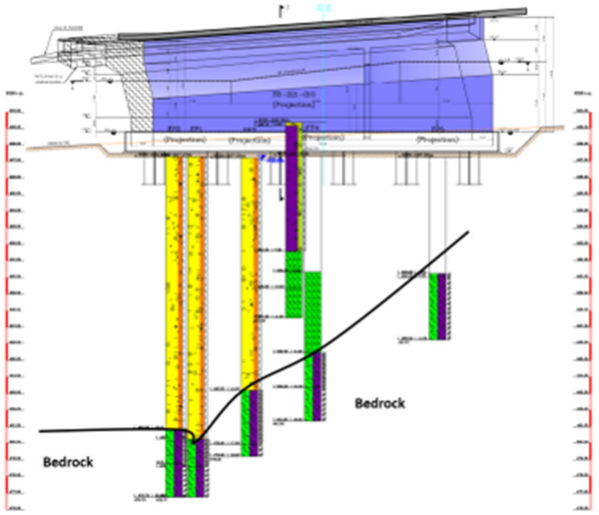

Figure 4. Level of the rock roof

4.2 *OA877*

A total of 17 reconnaissance boreholes has been drilled in 4 phases (initial phase in 2019 (see 3.2), 2021, 2022 and 2023). These include 11 cored boreholes with external diameters of 114-116mm, 3 boreholes with external diameters of 63-66mm for pressurmeter testing, and 3 small-diameter hammer core holes.

In addition to the boreholes, geophysical investigations were carried out using 4 electrical tomography profiles to clarify the geological situation throughout the study area.

All the exploratory boreholes and electrical tomography confirmed the presence of loose material consisting of rounded pebbles in a silty-clay matrix, with thicknesses varying between 4.7m and 20m.

A significant discrepancy was observed over short distances (< 20m) between the level and type of rock on either side of the structure's axis, but also transversally, confirming the presence of several faults, as already suspected following geophysical measurements.

Unlike what was observed at abutment C1 of OA876, the rock roof is higher on the west side than on the east side of the axis (see Figure 5). There is therefore a risk of differential settlement between the two abutments of the structure, but also within the same abutment.

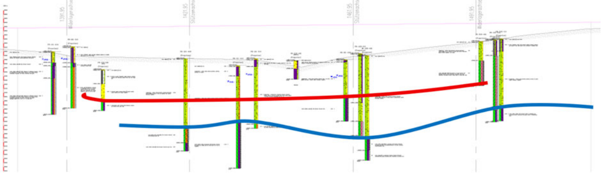

Figure 5. Difference in the level of the rock roof between the west (red) and the east (blue) side of the axis

As the foundations will therefore have to be constructed using piles, the pressuremeter boreholes were used, in combination with laboratory tests on representative samples, to obtain design values for the piles.

In addition, water levels were found very close to the surface in each of the boreholes, and piezometers were installed to monitor changes in water levels over time, allow pumping tests to be carried out to determine the permeability of the soil, and also allow samples to be taken to determine the aggressiveness of the water in relation to the concrete.

5 GEOLOGICAL AND GEOTECHNICAL INTERPRETATION OF INVESTIGATION RESULTS

Geophysical surveys and monitoring of earthworks in the rock trench immediately to the north of OA877 have revealed the presence of 3 different fault directions: the 2 directions shown on the 2020 geological map, but also a 3rd fault direction that was previously unknown and unrecorded. The extension of this 3rd fault, present in the rocky trench, intersects both OA877 and OA876.

These faults appear to have formed a tectonic sedimentary basin, creating favourable conditions for a fluvial fill, and also preserving part of it from erosion. This sedimentary fill covering a total surface area of more than 10,000m^2, in 2 different locations more than a kilometer apart, indicating that this layer could be found in several locations and would not be linked to an isolated event. It is a conglomerate containing rounded pebbles of sandstone, quartzite and shale, varying in size from a few centimeters to more than ten centimeters, with a reddish clayey cement interspersed with beds of more or less clayey sandstone. All the pebbles are aligned parallel to the horizontal, indicating that the fill post-dates the deformation of the underlying Devonian shale and sandstone.

In the absence of fossils, the age of this horizon has not yet been established, but the similarity of facies, composition and colour with the Triassic layers known in Belgian Lorraine, Germany and Luxembourg, as well as the geological history of Luxembourg, suggest that these layers may also be Triassic in age. Indeed, they bear a striking resemblance to the Buntsandstein conglomerate that outcrops in the Folschette quarry some thirty kilometers to the south-west.

This would be the first time that layers of this age have been found in the Oesling region, much further north than the outcrops already known in Luxembourg and Belgium. Figure 6 shows the suspected ancient sedimentary basin for the 2 structures.

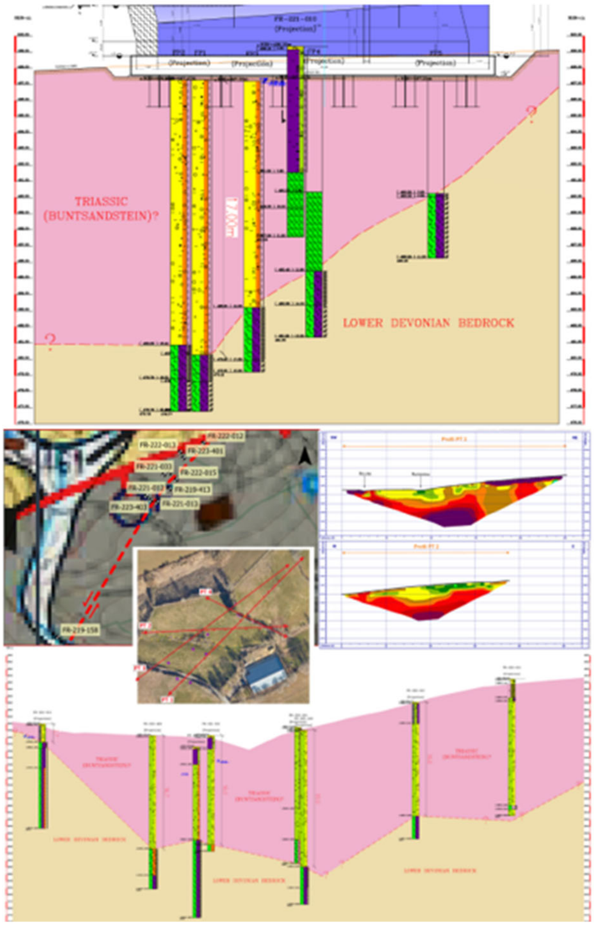

Figure 6. Interpretation of the 2 triassic basins, OA876 above and OA877 under, with the results of the ERT confirming the basin structure and the presence of faults

This is further proof that we should not rely solely on geological maps, which did not indicate this terrain at all. An update of the geological map would be necessary to show these unrecorded layers, which could extend even further than the two locations where they were discovered.

6 CONSEQUENCES

The presence of these unrecorded triassic layers, linked to inadequate geotechnical studies at the outset, has very significant consequences for the 2 engineering structures. These consequences could have been avoided if sufficiently consistent geotechnical studies had been carried out at the initial design stage.

6.1 *OA876*

For OA876, 4 additional piles of 24m length (deeper than the 11m length piles initially planned and already in place) had to be re-drilled, in order to reach the sound Devonian bedrock throughout and ensure a uniform level of support for the foundations.

This resulted in significant additional costs associated with the additional piles and the resulting stoppage of the worksite.

6.2 *OA877*

In the case of OA877, in addition to the engineering structure, technical embankments up to 12m high had to be built on either side of the abutments to allow the road to cross the valley and connect the cut areas in the south to the planned tunnel in the north. Stability calculations showed that, for such embankment heights, stability could not be guaranteed on the loose materials resulting from the weathering of the Triassic layers.

As a result, the north abutment had to be moved further north in order to be positioned in Devonian rock, away from the loose sediments resulting from the erosion of the Tiras layers. The viaduct will therefore be twice as long as planned, requiring two intermediate piers. A solution with three spans of 30m, 40m and 30m was therefore proposed. The use of a single intermediate pier would not be possible, as it would be located directly at the bottom of the small valley, creating additional geotechnical and hydrogeological complexity related to the diversion of the watercourse, at least during the construction phase. The foundations will be constructed using piles over 25m long, whereas shallow foundations were initially planned.

This time, given the very specific geological and geotechnical context, and learning from the negative experience of OA876, the project owner agreed to geotechnical monitoring throughout the works.

7 CONCLUSIONS

These 2 examples illustrate that surprises are always possible in geotechnical engineering, even if the situation seems clear at first glance. They also show the need to carry out complete geotechnical study in compliance with the recommendations of the various standards. Properly conducted studies from the outset would have made it possible to anticipate the actual situation as accurately as possible and to adapt the project at the design stage.

The need for competent geotechnical monitoring during the construction phase was also highlighted. Such monitoring makes it possible to confirm hypotheses and, above all, to react immediately in the event of a discrepancy between the results expected based on the study and the actual situation when the work is carried out. This means that the project can be adapted quickly without any damaging stoppage of the works.

8 ACKNOWLEDGEMENTS

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