REHABILITATION OF THE LANGETENTAL FLOOD DIVERSION TUNNEL

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ABSTRACT: A 7.5 km long flood diversion tunnel was completed in 1990 bypassing the town of Langenthal near Bern regularly affected by inundations. During a major flood event in 1995 the tunnel lining was severely damaged. Repair works were carried out in 1997/98 without an interruption of the tunnel operation. These works included extensive grouting of the gap between the lining and the tunnel roof. Since the completion of these works the tunnel behaves satisfactorily.

1. GENERAL PROJECT CHARACTERISTICS

With the purpose to avoid periodic inundations, a 7.5 km long flood diversion tunnel was excavated between 1987 and 1990 capturing the flows of the Langeten river upstream the town of Langenthal. Downstream of the residential areas to be protected the flows directly enter into the Aare river.
The longitudinal profile of the flood diversion project is shown in Figure 1. The intake structure consists of a morning glory type spillway structure with a crest diameter of 20.0 m. The layout of the intake structure is designed in order that discharges above 12 m^3/s are diverted into the diversion tunnel. The design flow capacity of the tunnel is 58 m^3/s offering a flood protection to the affected communities for flood events up to a 1000-years return period.

The morning glory intake is prolonged with a 40 m long and 4.00 m internal diameter shaft. At the shaft bottom a dissipation chamber insures the proper energy dissipation and the air escape before the water is entering into the 3.30 m internal diameter discharge tunnel.

In order to underpass an ancient valley, the upstream 5’059 m tunnel stretch has a longitudinal slope of 1.0%, whereas on the downstream 2’385 m stretch the slope has been reduced to only 0.3%. Finally the outlet structure is equipped with an expanding stilling basing insuring the necessary energy dissipation prior to the confluence with the Aare river.

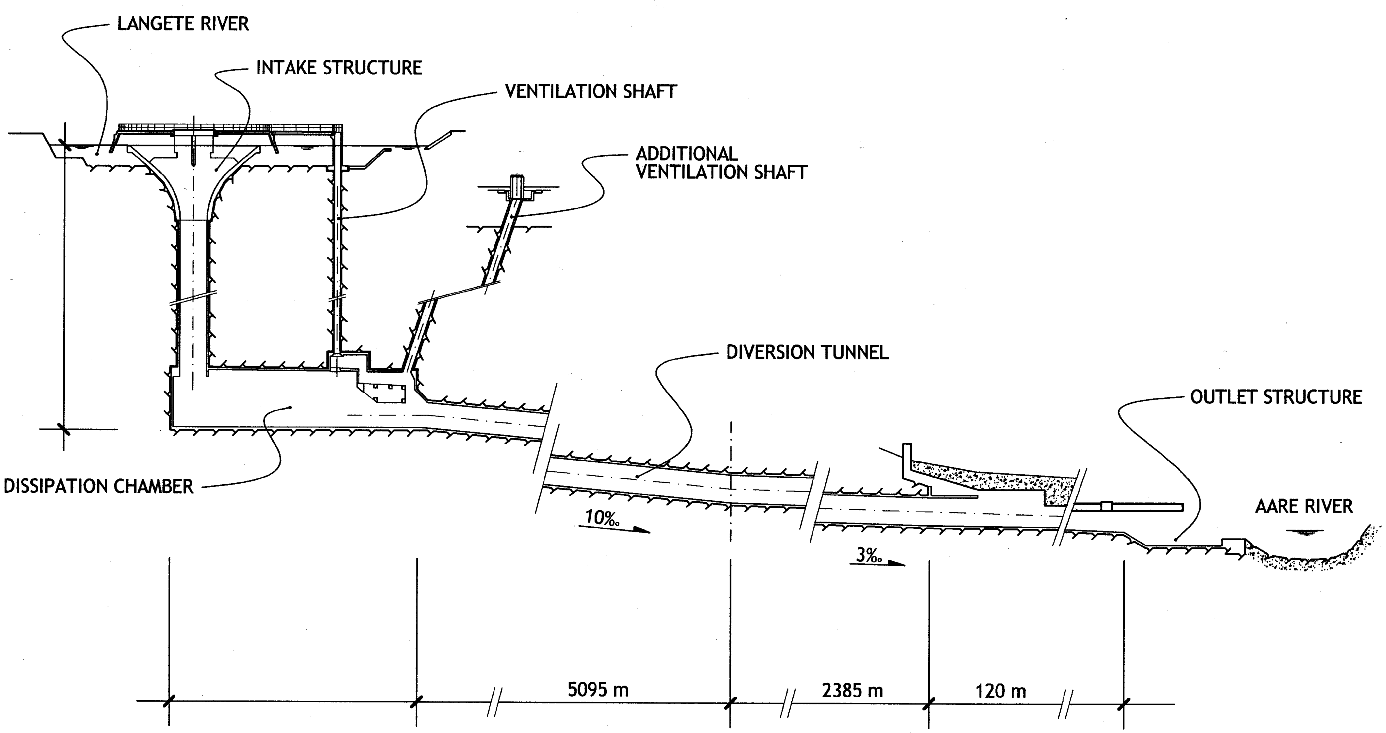

Figure 1: Schematic longitudinal profile of the Langeten flood diversion project.

2. TUNNEL EXCAVATION AND LINING

The tunnel is located in competent sandstone and siltstone formations with only limited fracturation. The excavation using a double shield 3.83 m diameter TBM has thus not encountered particular difficulties except that on February 9th 1989 a gas explosion resulted in a temporary stop of the site activities. Following an improvement of the ventilation equipment the excavation works could be recovered and completed on June 1990.
Figure 2 shows the tunnel profile with the 20 cm thick honeycomb type lining segments systematically installed along the entire tunnel. Laboratory investigations on rock samples as well as previous experiences in similar formations in swiss tunnels indicated a limited but long term swelling potential of the sedimentary rock formations. With the purpose to avoid an excessive loading of the lining it was thus decided to adopt a particular design solution for the gap between the concrete lining and the rock.

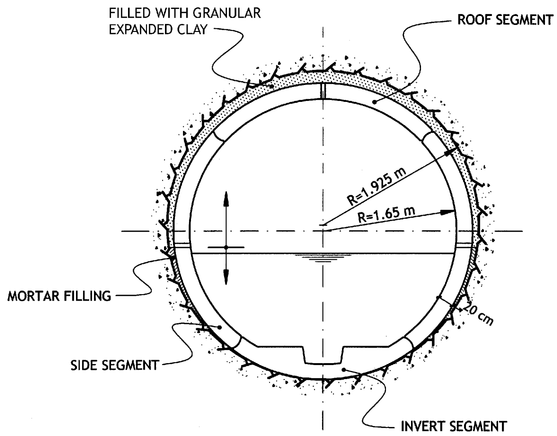

Figure 2: Typical cross section of the Langeten flood diversion tunnel

As shown in Figure 2, the two lateral segments were equipped with one horizontal hole from which the lower part of the gap between the lining and the rock was filled with conventional cement mortar. The gap of the upper half section was filled from the opening in the roof segment. As filling material granular expanded clay (Leka) was used with grain sizes between 0.3 and 0.6 cm. This highly compressible material was inflated from the opening in the roof segment.

3. DAMAGES ON THE TUNNEL LINING

On the 25/26 of December 1995, a severe flood was recorded in the Langeten river with a peak flow reaching 50 m^3/s representing a flood event with a 100-years return period. Due to the longitudinal tunnel profile, both free flow and pressure flow conditions occur in the tunnel for discharges exceeding approx. 30 m^3/s. During the flood event low frequency pulsating conditions with periodic blow-out of relevant air pockets were observed at the tunnel outlet.

After the flood, the inspection of the tunnel revealed extensive damages on the lining. In particular as shown in Figure 3 more than 120 roof segments were displaced vertically up to 15-20 cm. Furthermore evidence of the Leka filling material wash-out could be observed at several locations leaving voids above the lining and disclosing locally the excavated rock. Despite relevant dislocations, no roof segments were completely failed out of their position. To mention that no connections were provided between the segments.

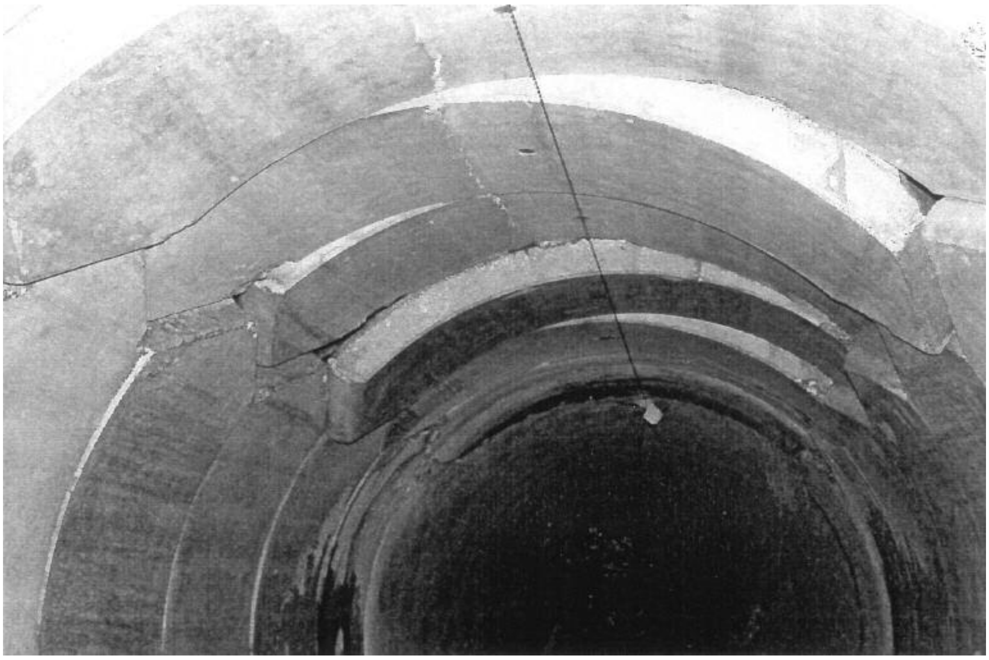

Figure 3: Typical damaged zone after the flood event

The schematic position of the roof segments is shown in Figure 4. To be noticed that at any damaged location the segments displacements were alternated upward and downward with nearly no displacements at the top of the section. As shown in Figure 4 a rotation centre could be identified above the tunnel crown.

After the damage and following some preliminary investigations, Lombardi Engineering Ltd was charged with the identification of the damage causes and the proposal of remedial measures.

Based on a detailed hydraulic investigation, it could be identified that the flow conditions occurring in the tunnel for discharges above approx. 25 m^3/s induce significant pressure fluctuations and pulsations on the lining. Dynamic and highly unstable pulsating pressures occur not only at the transition between the free flow and the pressure flow, but are propagating along the entire lower tunnel stretch (2’385 m). The pulsating action is promoted by an insufficient flow aeration at the intake structure resulting in relevant air velocities and pressure gradients in the tunnel.

This pulsating action combined with the presence of a granular, non-cohesive and highly compressive filling material, and the absence of any connection between the segments has resulted in the possibility of the roof segments to move in a vertical direction. After the joints between the elements have been opened, the granular expanded clay could easily be washed-out by the flow leaving voids behind the roof segments. In other terms, the segments and the filling material behind were unable to withstand the dynamic action of the flows which in this case due to the particular tunnel configuration are particularly relevant.

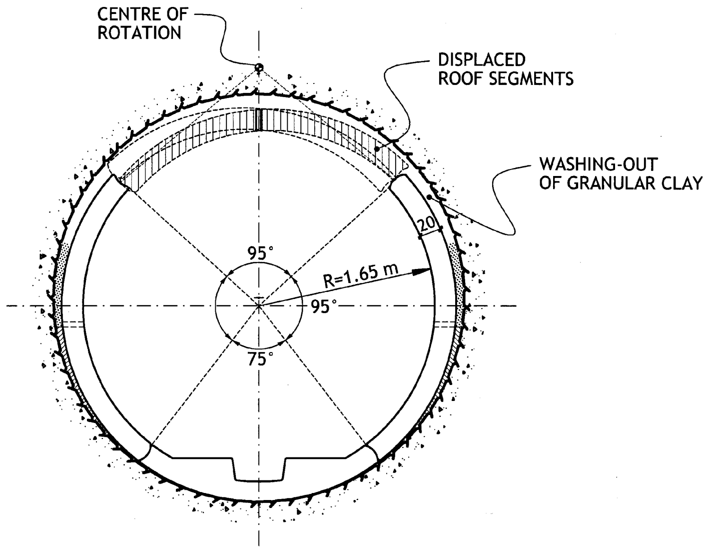

Figure 4: Schematic alternating displacements of the roof segments

4. REHABILITATION PROJECT

Based on the previous conclusions, a rehabilitation project was developed with the purpose to repair the damages and avoid similar events in the future. In order to insure a proper tunnel operation, the rehabilitation project included the following works:

- Repositioning of the displaced segments and, where required, repair of the damaged parts.
- Consolidation of the granular expanded clay filling material using a cement grout mix.
- Improvement of the flow conditions in the dissipation chamber at the bottom of the intake shaft with the purpose to insure a proper flow desaeration and energy dissipation.

Although the damages on the tunnel lining were confined to the lower stretch, it was considered necessary to proceed with the proposed grouting works along the entire tunnel in order to take into consideration any possible flow condition.

Preliminary investigations were performed with the purpose to optimise the grouting procedure considering that no experience was available on the behaviour of the expanded clay during grouting. In particular it has to be mentioned that the granular clay is permeable to water but not to the grout mix in order that the tendency of the granular material is to float on the grout slurry.

As shown in Figure 5, preliminary laboratory investigations revealed that with an adequate procedure, the grouting of the granular clay was generally possible at relatively low grouting pressures. Difficulties were expected in the presence of a high percentage of fractured spheres since the permeability of the filling material is then reduced.

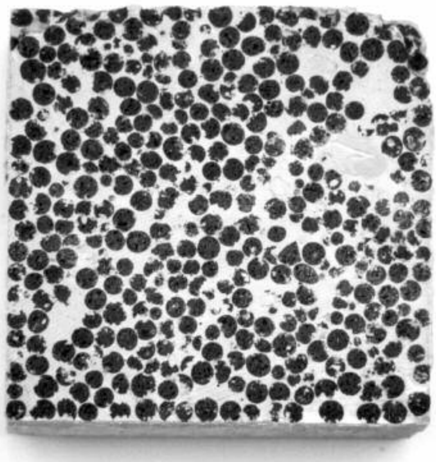

Figure 5: Results of a successful grout test of the granular expanded clay (laboratory test)

Following the preparation of the final design and the tender documents, the rehabilitation works were started January 1998 with the repositioning and repair of the damaged roof segments.

5. ORGANISATION OF THE REHABILITATION WORKS

To avoid any inundation risk of the communities to be protected by the flood diversion tunnel, it was necessary to maintain the tunnel in operation during the repair and rehabilitation works. As regards the floods occurrence, no season was identified with a reduced flood risk, in order that a sophisticated flood alarm system was installed on the site. To mention that the only vehicle access to the tunnel is at the outlet structure with a possible escape for the personnel using a ladder in the ventilation shaft of the intake structure.

The entire rehabilitation works had thus to be carried out without any permanent installations in the tunnel since only one hour after the alarm, the tunnel had to be given free for flood discharge.
The site organisation was thus heavily influenced by the severe and restrictive conditions under which the tunnel rehabilitation had to be carried out.

After the relocation and repair with mortar of the damaged segments, grouting holes were drilled in the upper half of the tunnel lining. After the drilling works, all the joints between the segments had to be sealed with mortar in order to avoid any grout escape. In total nearly 14 km of joints were sealed within 3 months.

The grouting was carried out using a fine Rohrbach Cement (H50) with Blaine values of approx. 7000 cm^2/g. A grout mix with a Water Cement ratio of 1.0 and the addition of 2% bentonite was used resulting in a highly stable and relatively fluid grout mix. Figure 6 shows the tunnel during the grouting works.

Figure 6: Progress of the grouting works without any mixing plant in the tunnel.

As regards the grouting installation, no equipment could be installed in the tunnel in order that an innovative solution was required. Following the evaluation of various alternatives it was decided to prepare the grout in two permanent plants from which high pressure pipes conveyed the mix up to the grouting front. Pressure relieve valves and parallel grouting at various holes allowed to control the grout pressure at the injectors and avoid any clogging of the feeding pipes. To mention that the piping system allowed to reach distances of up to 3.5 km between the main plant and the grouting front.

Despite some minor difficulties related to the uncommon and restrictive working conditions, the tunnel rehabilitation could be completed within 7 months, with 1 month ahead of shedule and within the budget. Approximately one year later the intake structure was equipped with a second 1.2 m diameter ventilation shaft completing the rehabilitation project of the Langetental tunnel.

Although no floods of the 1995's magnitude have occurred, the behaviour has been satisfactory during minor flood events without any visible sign of segment displacements or lining damages.