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Study of the ship lift structure at the Slapy Dam

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ABSTRACT: The paper deals with the design of the driven structures of the ship lift at the Slapy Dam, which is some 35 km upstream from Prague on the River Vltava. The dam profile is the main reason why the water route from Prague to České Budějovice is not navigable for ships of tonnage up to 300 tons. At present studies deal with several variants of the ship lift structure. Despite the fact that none of the variants has been chosen for further stages of the project preparation, the text describes in detail only one of the planned variants – the lock with high lift, which is the most interesting one from the point of view of tunnelling. This design of the ship lift uses to the maximum extent the newly built underground structures and at the same time it requires minimum work on the right bank. The excavation of the shaft and the driving will take place in the nearest surroundings of the dam and the hydraulic power plant which will require that extra safety and anti-vibration measures should be taken.

1 INTRODUCTION

The Vltava water route from Prague upstream ends at present below the Slapy Dam. The Slapy Dam is the only structure of the Vltava Cascade where the structure of the ship locking system is not finished. In 1955 the hydraulic structure was put into operation without the locking system and this situation still lasts.

Figure 1. View of the dam downstream side. In the left-hand bottom corner you can see the diversion tunnel outlet.

When the Slapy hydraulic structure was under development, its first studies already planned that the locking system should be constructed. This goal was not met due to the lack of time, high building costs and technological difficulties in connection with the filling of the reservoir. Only the building part of the navigation lock on the right bank in the upstream pool was built.

The original project planned the ship lift structure for ships of tonnage up to 300 tons. A vertical ship lift in a reinforced-concrete tower structure on the right bank below the dam was planned, situated out-side the dam body. The structure should have been connected to the diversion tunnel, which was used during the construction activities for the purpose of diverting water from the dam construction site.

2 STRUCTURE HISTORY

2.1 *Dam*

The decision to build the Slapy Dam was made as early as 1933. The gorge in the place once called Midsummer Streams (Svatojánské proudy) was chosen as the most suitable one for the dam. The structure was approved in 1949. In the same year the work on the diversion tunnel and auxiliary structures was commenced. It was the first big structure of the Vltava Cascade after the World War II. The dam was built

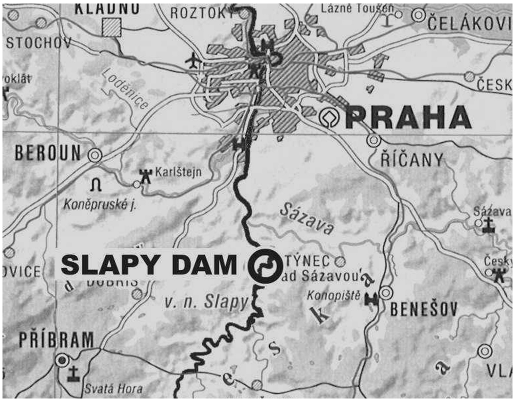

Figure 2. Map plotting.

in a dry pit, protected by fill dams on the upstream and downstream sides of the dam foundation surface. The dam was completed in 1955. The dam crest is 65 m above the bottom; the level difference is 54.6 m. The hydraulic power plant is situated in the concrete dam body. Water runs through four spillways with crest gates built above the hydraulic power plant.

2.2 *Diversion tunnel*

The diversion tunnel 10.0×12.0 m was built to allow rafts and vessels to navigate through while the construction activities were under way and most of all to divert water away from the construction site. The tunnel, 321 m long, was driven in a sound rock on the right bank and it is provided with concrete walling only in short sections by portals. The tunnel longitudinal slope is 0.15%. The diversion tunnel was closed shortly before the dam crest concreting. A concrete plug was constructed at the tunnel upstream end. It rested on cone-shaped pockets created in the wall and grouted with vertical holes, at the length of 30 m. Then, in April 1954, the filling of the reservoir was commenced. In July 1954 a vast flood came (a fifty-year one with the flow of 2200 $m^3.s^{-1}$), however the dam under construction withstood it. A positive result in favour of the capital of Prague downstream was the considerable transformation of the flood wave filling the empty reservoir.

At present the unsupported length of the tunnel is 291 m. The tunnel is accessible from the downstream water level (Fig. 3). The disposition of the tunnel and especially its length on the downstream side of the dam were designed from the beginning so that it could later be used as a navigation canal by the entrance to the locking system. The condition of the diversion tunnel was checked in detail some 20 years ago within trial blasting in connection with the shaft of the locking system. At that time the tunnel condition was quite good, only in a few places the rock under the vault toe.

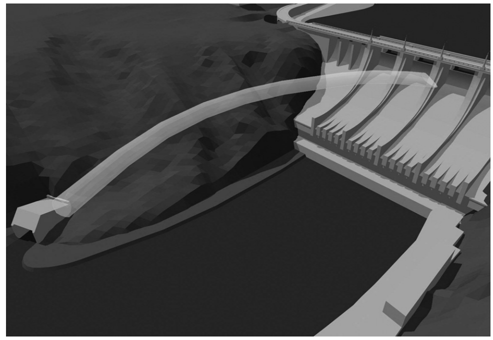

Figure 3. Existing diversion tunnel.

3 GEOLOGIC SITUATION

3.1 *Geologic conditions*

The Slapy hydraulic structure is situated in an area with monotonous occurrence of amphibolites of the argillaceous zone. The amphibolites are of the character of a fine-grained, solid, dark grey-green rock with high unconfined compression strength of up to 300 MPa. Occasionally in complete sections of amphibolites there is the so-called cushion lava forming longitudinally oval-shaped compressed schistose bodies, approx. 1.0×0.8 m. Amphibolites are very tough and resistant to chemical weathering, their faults are caused by slope movements of rock blocks and tectonic movements resulting from intensive compression of the argillaceous zone which is evident in schistose formations.

3.2 *Hydrogeologic conditions*

Groundwater absorbed in the rock base does not form a continuous horizon, its yield is small and the groundwater circulates in fissures without any relations. Apart from the surface sections, the fissures are close, frequently healed with calcite and almost water impermeable. The rock ambience permeability had been tested within research, before work on the dam was started, in holes by means of water-pressure tests and grouting tests. The value of the specific water loss was from 0.001 to 0.014 $l.s^{-1}.m^{-1}$ at the water pressure from 0.4 to 1.0 MPa. The dam profile was sealed with a grouted curtain during the construction activities. Since the dam was completed, the effect of the fissure systems pressure after afflux in the reservoir has not been tested.

4 SHIP LIFT CONCEPTION

4.1 *Original designs*

The heated discussions among experts in the Czech Republic, focused on the locking system structure at

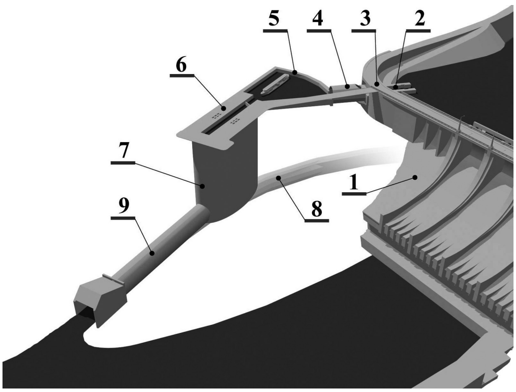

Figure 4. Design diagram. 1. Slapy dam, 2. Existing navigation lock, 3. Existing bridging, 4. New tunnel on the upstream water, 5. Passing bay, 6. Navigation lock platform, 7. Lock with high lift, 8. Closed part of the existing diversion tunnel, 9. Lower navigation tunnel, straightening the existing diversion tunnel.

Slapy, have lasted for more than 50 years. Up to the present several technological conceptions have been prepared (a lock with a high lift, a vertical ship lift in a shaft and a sloping ship lift). There were considered also alternatives of a navigation lock with s reversible pumps, a navigation lock with spare basins, a navigation lock with an ejection effect or a vertical ship lift with a complete balancing. Another proposal was an innovative design of a revolving ship lift when the ship channel moves along one carrying rail the shape of a helix Záruba (1960). Another original solution protected with a patent is a ship lift with pushed chains Záruba (1987).

4.2 *The existing state of project preparation*

The solution is designed in accordance with currently valid parameters of Water Routes European Classification Class I as regards ships of tonnage up to 300 tons. The ship lift must be able to lock a ship of effective dimensions 45.0×6.0 m. The navigation lock construction brings about a number of problems both hydraulic, nautical and static.

The last expert study (Uher and team 2006) contained three variants of the ship lift design: a shaft ship lift with a complete balancing, a lock with high lift with spare basins and a sloping ship lift.

The first and second variants have in essence the same layout, which is also used in all the previous designs. It uses as much as possible the existing navigation lock in the upstream water and part of the existing diversion tunnel for ships arriving to the lift on the downstream water.

The next part of the paper describes the most interesting variant from the point of view of tunnelling – the lock with high lift (Fig. 4). One of the problems of this design is the arrangement of structures with respect to ensuring optimum entry and exit conditions from upstream and downstream pools. In order that a ship enters and leaves on the downstream water it is necessary that this manoeuvre on a straight line. For this reason it is necessary to straighten the existing diversion tunnel in the point of the connection of the vertical shaft. The sudden change of the course of a ship which is necessary with respect to the above specified disposition will take place when the ship stops in the passing bay on the upstream water.

5 LOCKING SYSTEM STRUCTURAL DESIGN

5.1 *Upper navigation canal*

An upper navigation canal will be driven from the existing navigation lock, running partly through an open cut and partly through a short navigation tunnel. The new profile will be driven by means of NRTM (New Austrian Tunnelling Method) with a primary support of the excavation with a sprayed concrete layer and a system anchorage. Final walling will be of cast-in-situ reinforced concrete. On both sides of the tunnel will be (escape) footbridges, their vertical parts will be, within the fluctuation of water level of 1.50 m, used as guard rails.

The navigation tunnel will end in the passing bay tank of trapezoidal layout. The passing bay will be situated in an excavated pit, slopes of the cuttings will be supported with permanent anchors and protected with a sprayed concrete layer. The passing bay tank structure will be made of cast-in-situ reinforced concrete for water structures. The foundation surface of the passing bay bearing structure will be permanently drained with a drain system connected to the downstream water because of the pressure effects on the structure. The passing bay will have two mobile binding systems. With the systems it will be possible to turn the ships if they avoid each other in the passing bay.

In the downstream direction the passing bay tank is connected to the lock with high lift.

5.2 *Lock with high lift*

The navigation lock will be situated in a shaft of an elliptic layout 60.0×25.0 m, cross-section area is approx. 1300 m^2 and depth 60.0 m. The clearance of the lock is 45.0×6.0 m, the intermediate space will be used for spare basins (Fig. 6).

The shaft will be excavated gradually from the surface, it will be secured with primary walling of sprayed concrete with a system anchorage. To prevent the effect of shocks on the structures of the dam and the operated hydraulic power plant, before the excavation is commenced a secured perimeter nick will be

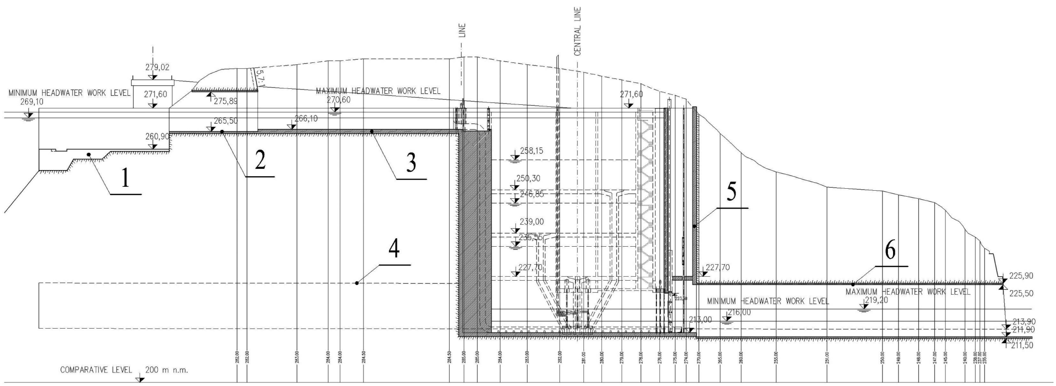

Figure 5. Longitudinal profile. 1. Existing navigation lock, 2. New tunnel on upstream water, 3. Passing bay, 4. Closed part of the existing diversion tunnel, 5. Lock with high lift, 6. Lower navigation tunnel, straightening the existing diversion tunnel.

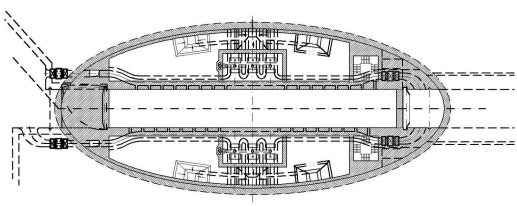

Figure 6. Plane section of lock with high lift.

made by means of a hydro cutter along the height of the shaft. The trench, 0.6 m wide, will be filled with bentonite mud. The final (secondary) walling will be of cast-in-situ reinforced concrete. Waterproofing with a permanent drain system connected to the downstream water will be inserted between the primary and secondary walling. This will eliminate effects of possible hydrostatic pressure from fissure systems on the final shaft structures. The inner clearance of the shaft enclosure will be approx. 60.0×25.0 m.

The shaft inner structures that will be used as spare basins are designed to transfer different hydrostatic pressures during regular water level fluctuation while the navigation lock is being filled and discharged. The lock will be filled and discharged by means of long bypasses closed with check gates. Bypass inlets on the upstream water will be on side walls between the tank and the lock. Check gates will be controlled with hydraulic face jacks. Shafts of bypass closures will be up to the level of the lock platform. In the downstream head the hydraulic face jacks of check gates of bypasses will be situated above the level of maximum downstream water. The navigation lock platform will be at 271.60 meters above sea level and the minimum water depth in the lock will be 3.0 m, the bottom at 213.00 meters above sea level. On the walls of the navigation lock will be installed floating binding elements for big and small ships and ladders. The lock platform will be lit.

The lock will have three twos of spare basins, interconnected with filling and discharging channels in the middle of the lock length with long bypasses. Particular channels will be closed with check gates controlled by hydraulic face jacks installed in the dry shaft integrated into the layout of spare basins. For the purposes of installing technology and its operation the shaft will be accessible from the lock platform. In the section of the channels between the check gates and the lock will be slots of box dam and the space will be filled with air. Particular levels of the spare basins will be connected to the atmosphere through the aeration pipe.

The head gate will be of boards with a vertical axis of rotation controlled by a hydraulic face jack. The gate sill with surface at 266.10 meters above sea level will be of minimum length, thus a ship hull will be prevented from sinking to the bottom when the water level drops while the lock is being emptied. In front of the gate will be the slot of the box dam for filled tube stop logs.

The tail gate situated outside the navigation lock layout will consist of a lift gate controlled by a hydraulic face jack installed in the dry shaft. The shaft floor will be at 227.70 meters above sea level, a box dam board will be permanently installed in the slots against downstream water. Access allowing technology installation and its operation will be possible from the lock platform top. The gate sill will be at 213.00 meters above sea level. The long bypasses will be emptied into the downstream water in the profile between the tail gate and the box dam.

For the purposes of operation and maintenance of the navigation lock and the spare basins there will be two dry access shafts with a staircase and a central

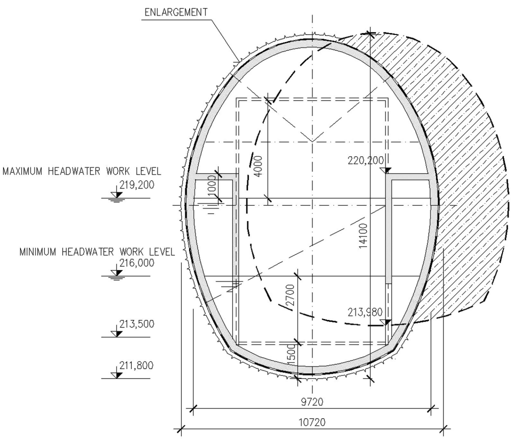

Figure 7. Cross-section of the lower navigation tunnel. Extension of the existing profile of excavation in the place of connection to the shaft.

space for material and equipment transport. Particular landings of the staircase will allow access to the floor of the machine room of tail gate closures, the machine rooms of closures of filling and discharging channels of spare basins and pressure covers provide access to particular spare basins. A small passenger lift will be designed to transport people.

5.3 *Lower navigation canal*

The lower navigation canal will consist of a tunnel running right in the direction of the longitudinal axis of the lock with high lift, connected to the straight end section of the diversion tunnel. The existing tunnel will have to be profiled anew (while using principles of NRTM with the primary support of the excavation with a sprayed concrete layer and a system anchorage). Final walling will be of cast-in-situ reinforced concrete (Fig. 7).

The remaining part of the diversion tunnel, approx. 130 m long, will be used for the fill of muck which will be subsequently grouted and the tunnel profile will be closed. When the operating level in the channel is at 216.00 meters above sea level, the minimum water depth will be 2.70 m (2.20 ship draught and 0.50 m margin). The tunnel bottom at the depth of 2.70 m will be min. 213.30 meters above sea level. Maximum level will be at 219.20 meters above sea level. On both sides of the tunnel will be (escape) footbridges with the top at 220.20 meters above sea level, their vertical parts will be, within the fluctuation of water level of 3.20 m, used as guard rails. The tunnel will be lit.

While the lower navigation tunnel is being driven and equipped, a pit will be excavated outside the tunnel portal in the River Vltava bed.

6 SAFETY ISSUES

6.1 *Safety measures taken during construction activities*

According to the task the work on the construction should be carried out while the hydraulic power plant works full out and the water level in the reservoir must not get lower.

The vertical shaft, some 60 m deep and some 1300 m^2 of excavated area, is a mining work of extraordinary dimensions. Excavation and driving will take place in relatively complicated hydrogeologic conditions (extremely hard amphibolites with compression strength of 300 MPa, broken into blocks with fissure groundwater under the pressure of up to 50 m of water column). Work will be carried out in the nearest surroundings of the dam and the hydraulic power plant, in the nearest place the shaft is 100 m away from the dam body. The establishment of the perimeter nick along the entire height of the shaft before the excavation is commenced is an extensive anti-shock measure taken for the purpose of separating the blasting operations from the outdoor environment. The said designs will be worked out in detail in the following stages of the project documentation.

6.2 *Safety measures during the ship lift operation*

As similar structure is found neither in the Czech Republic nor even abroad, the proposal of safety measures will be based on structures of a similar character, that means navigation locks with a big gradient.

If an accident of a ship in the lock occurs, the advantage of this variant is that it is possible to fill or discharge the lock as an emergency and thus the ship can be relatively quickly moved to one of utmost positions. For purposes of inspections and access of rescue teams there will be a section with ladders along the entire height of the navigation lock.

It is possible to anticipate that despite all the safety measures there will be a group of people that will refuse this way of transporting. In this instance these tourists will be transported by minibuses.

7 INCORPORATING THE WORK IN THE LANDSCAPE

7.1 *Effects on the environment*

The variant of the lock with high lift is to the maximum possible extent situated in the underground so that its adverse effect on the landscape is minimal (Fig. 8). In comparison with the other variants this one offers the slightest impact on the surroundings.

The lock with high lift construction is designed to meet the strictest ecological requirements as it is

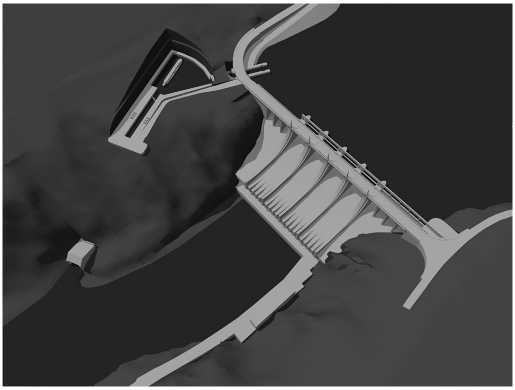

Figure 8. Perspective – bird's eye view.

situated in a beautiful landscape of the River Vltava valley, used as a holiday area by inhabitants of the capital which is some 35 km away.

7.2 *Ship lift as a draw for tourist*

It is expected that the entire ship lift system will be accessible tot the public. The variant of the lock with high lift is probably the least attractive from among the assessed variants if compared with the sloping ship lift when the ship is on the ground level all the time and thus the passengers can watch the valley. In order that the peace of mind of passengers is preserved the navigation lock and the lower navigation tunnel will be lit on walls. Within the reach of the work will be founded a centre to be visited by both ship passengers and the people who will only come to see the work. It is anticipated that the public will be interested in the work as it will be, owing to its extraordinary parameters and its design, a popular destination of tourists. This is also taken into account when the return on the investment is considered.

8 CONCLUSION

It is possible to say that the presented design prepared as a study is feasible on the basis of current conditions.

Safety risks in connection with the construction and operation of the locking system do not exceed common risks associated with the use of water routes and therefore they do not represent any obstacles to the construction.

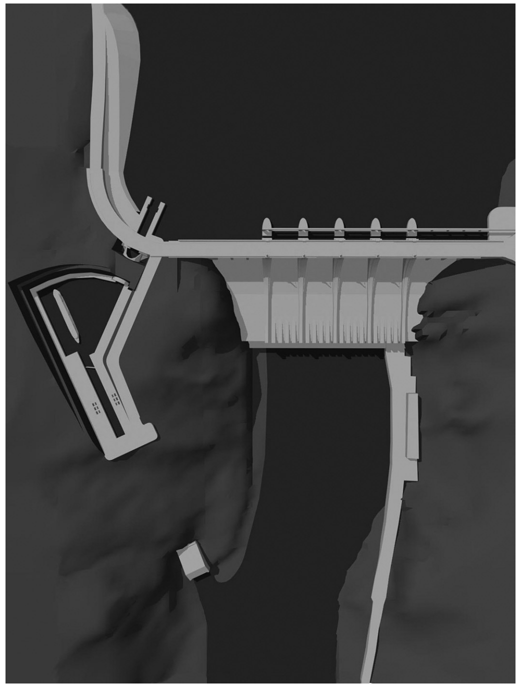

Figure 9. Incorporating the work in the landscape.

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