

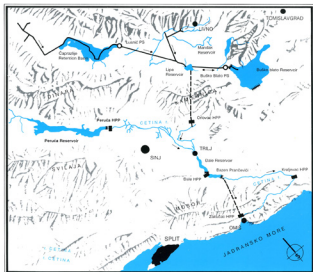
PERUĆA DAM

CROATIA

REMEDIATION



CETINA HYDROPOWER SCHEME



The Peruća dam, together with the reservoir and hydroelectric power plant, is a part of the hydropower scheme constructed in the Cetina River catchment. The Cetina catchment area is 4,150 km², and the mean discharge at the mouth into the Adriatic Sea is 102 m³/s. The Peruća dam forms the 541 mil. m³ reservoir regulating about 40% of total Cetina river water volume. Thus, the Peruća reservoir has a significant effect on water regime regulation and consequently on power generation in this hydropower scheme which is in average about 3,000,000 MWh per year and presents the main energy source for the southern part of Croatia.

The dam is of rockfill type, with zoned cross-section consisting of centrally placed clay core, filter layers and crushed stone upstream and downstream shells. The dam is 63 m high and 450 m long in crest. Since the dam is founded on the permeable limestone the watertightness of the dam profile and the reservoir is achieved by construction of 200 m deep and 1,600 m long grout curtain with total surface area of 280,000 m² (Fig.1).

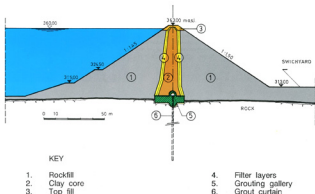
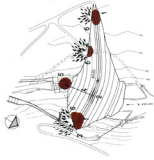


Figure 1. Dam cross-section

The explosive set in the Peruća dam by the former Yugoslav Army was blasted at 10:48:55 on January 28, 1993. The reservoir level was 356.20 m a.s.l. The exact explosion time was recorded by the seismic stations. The seismogram analyses have proven that the explosions took place in approximately 10 s intervals, that 20-30 t of TNT explosive charges were blasted, and that the energy released during the explosion corresponded to energy of an earthquake of magnitude 2.4.

The major damage was suffered by the left dam end, where the right wall, spillway gate and the access spillway bridge were destroyed, and the crater 25-30 m in diameter and about 10 m deep was formed in the dam crest by the spillway. The highest central dam section, some 50 m long, subsided for approximately 2.5 - 3.0 m. A crater 20-25 m in diameter and 6-7 m deep developed on the right dam end. Since the majority of the explosive was set in three points in the grouting gallery, the gallery was completely destroyed in approximately 110 m long stretch. The concrete cracks appeared on the remaining 260 m; however, it generally retained its cross-section shape. The completely and heavily damaged gallery sections were filled with the clay core material (Fig. 2). According to the results of measurements carried out from January 29, 1993 to February 10, 1994, the settlement was the most intensive in the highest central dam section, namely 1.5 m or 2.5% of the dam height; 90% of the settlement occurred during the reservoir discharge from January 29, 1993 to March 12, 1993. Thus, the total central dam section settlement, including the initial settlement during the explosion, was 4-4.5 m.



LAYOUT

KEY

1. Craters on the right and left dam ends
2. Subsidence in the central dam section
3. Spillway
4. Drainage outlet
5. Chunks of clay core
6. Caved-in gallery entrances
7. Gallery completely destroyed
8. Gallery completely filled with clay

I, II, III, IV, V - ASSUMED BLASTING POINTS

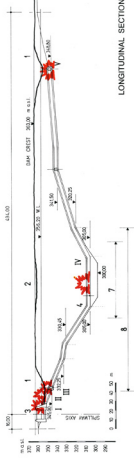


Figure 2. Peruca dam layout and longitudinal section



Reconstruction of the completely destroyed gallery; excavation of clayey material mixed with the concrete blocks from the gallery, carried out under the protection of steel arches and concrete panels.

A view of the Peruća HPP power house and switchyard after the explosion. The water was flowing through the destroyed grouting gallery and drainage outlet to the switchyard carrying along the clay core chunks reaching 0.50 m in diameter.



Partly destroyed grouting gallery with deposited clay.



The comprehensive investigation works were planned in order to exactly determine the sites and extent of damage caused to the dam sections, particularly the clay core. However, due to permanent danger of the enemy attack on the dam site, only the dam settlement monitoring was performed. Therefore, the Feasibility Studies for the dam remediation were based on the results of the visual inspection of the dam damage and the settlement results. The initial concepts were as follows:

- * in the left dam end, reconstruct the central, core section of the dam,
- * in the right dam end, due to small height, reconstruct the complete dam cross-section,
- * reconstruct the dam crest along the entire length and to the height of 5 to 10 m,
- * reconstruct the grouting gallery in full length,
- * the downstream rockfill shell is not seriously damaged and can assume the function of the dam supporting section,
- * reconstruct the spillway in full,
- * take care of the Cetina flood water evacuation during remediation works through the bottom outlet and the Peruća HPP headrace tunnel,
- * take into consideration the monitoring of the dam behavior after its remediation.



Cracks in the gallery arch concrete.

Four basic remediation alternatives have been set, as below:

1. Dam core section reconstruction along the complete length.
2. Dam core remediation in central part by construction of the plastic concrete cut-off wall, dam core section replacement in the left dam end and reconstruction of the complete cross-section in the right dam end, according to the original design documentation specifying the clay core.
3. Central dam core section remediation by grouting and jetgrouting procedure, and reconstruction of the left and right dam ends as in the Alternative 2.
4. Construction of upstream screen as the impermeable dam element, replacement of the core section in the left end and reconstruction of the complete cross-section in the right dam end by rockfilling.

The Alternative 1, considered construction of the impermeable dam section of clay and asphalt concrete, and the Alternative 4, the construction of the upstream screen of reinforced concrete slabs, clay and PEHD foil, thus altogether seven solutions have been analyzed.

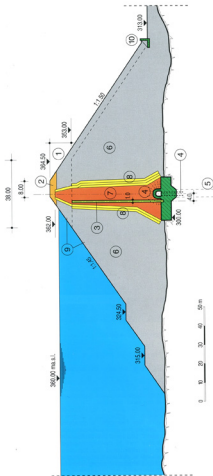
Downstream displacement of concrete gallery arch for about 15-20 cm.



Segment of partly destroyed gallery in the right dam end.

The dam remediation alternatives have been compared by quantitative and qualitative analysis, and the analyses results have shown that the Alternative 2. is the most favorable.

The basic concept of the dam remediation according to this Alternative is construction of the plastic concrete cut-off wall as an impermeable element in the central dam part, and replacement of some 100 m of the dam core section in the left end and about 100 m of the complete dam cross-section in the right end, according to the original design, with clay core as the impermeable dam element. In the central dam section, where the cut-off wall is to be constructed, the top dam section shall be reconstructed to the height of 5-10 m, according to the original design. The grouting gallery is planned for reconstruction from the access tunnel in the left end to the second access tunnel in right end dam section (Figs. 3 and 4).

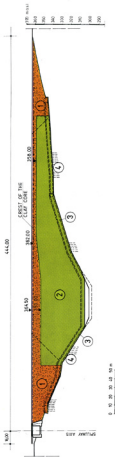


KEY

1. Dam crest reconstruction (5-10 m)
2. Crushed clayey stone
3. Cut-off wall
4. Grouting
5. Grout curtain constructed in 1955

6. Rockfill
7. Clay core
8. Filter layers
9. Rip-rap
10. Supporting wall

Figure 3. Final solution - typical cross-section



KEY

1. Dam reconstruction according to original design
2. Plastic concrete cut-off wall
3. Reconstructed gallery
4. Grouting

Figure 4. Final solution - longitudinal section

According to this Alternative the plastic concrete cut-off wall is planned to be constructed in the dam clay core, upstream the grouting gallery, on the 4 m center-line distance. The cut-off wall shall be 1 m thick, constructed using the hydraulic trench cutter from the dam platform sufficiently wide to provide for simultaneous construction of cut-off wall and running of traffic along the entire dam length. The cut-off wall shall be founded on the concrete slab, namely rock, while the foundation joint impermeability would be achieved by grouting from the grouting gallery. The area of the downstream filters would be consolidated by grouting, in order to obtain the quality contact between the core and the downstream dam rockfill shell. Thus, the possible more extensive deformation of the cut-off wall, primarily due to the hydrostatic pressure, shall be avoided.

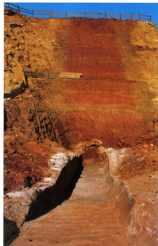
The grouting gallery remediation shall be carried out for several reasons. One of the most important reasons is that its reconstruction would actually be the investigation work which would enable good insight into the clay core damage in the area of the highest hydrostatic pressures along the entire dam length, including the mine planting sites. When reconstructed, the gallery shall allow for high-quality contact grouting of the cut-off wall and its foundation, control of grout curtain impermeability and corrective actions where required. In exploitation, the gallery shall serve for control of the cut-off wall impermeability and, if necessary, for additional corrective actions in order to prevent seepage.

The gallery reconstruction shall generally be carried out in two ways. In sections where the gallery is not caved-in, supporting with steel arches is planned, while the concrete lining shall be carried out by 15 cm thick shotcrete reinforced with double steel mesh. In damaged gallery sections, the excavation shall be carried out under the protection of steel arches and concrete panels, and the 80 cm thick concrete lining shall be constructed.



Reconstruction of partly destroyed gallery with steel arches and shotcrete layer.

The dam remediation works started on August 1, 1993, by remediation of the grouting gallery. Contrary to the forecasted 5-6 months remediation duration, the works lasted about a year since the damage was considerably more intensive than expected. The reconstructed gallery is 350 m long.



Final excavation in the left dam end.

In the course of the dam remediation design documentation development, the Cetina River flood wave characteristics were checked and it was determined that the spillway discharge capacity should be increased from the present 360 m³/s to 420 m³/s, so that at maximum operating level of the reservoir the 10,000-year recurrence period water wave could be discharged. The consequence is an increase in flood level by approximately 1.5 m, requesting the increase in the dam crest elevation from 363 m a.s.l. to 364.5 m a.s.l., namely widening of the downstream dam shell for about 6 m.

In order to prevent the slurry losses during the cut-off wall construction, the clay core consolidation grouting was performed. 5,600 m boreholes were drilled. The average grout mix consumption was about 100 l/m³ of a borehole. In the highest central dam section, on some 55 m long stretch, the average grout mix consumption was about 170 l/m³ of a borehole, while on the remaining length of some 200 m it was about 53 l/m³ of a borehole. The grout mix composition was 80% cement and 20% bentonite, with the dry matter and water ratio between 1:2 and 1:2.5.

In March 1994, the works were initiated for removal of the material from the top dam section to the El. 358 m a.s.l., namely 353 m a.s.l., from the dam core section in the left end to the El. 329 m a.s.l., and from the complete dam cross-section in the right dam end to the El. 344 m a.s.l. About 120,000 m³ of dam material was excavated, which is about 14% of the total dam volume of 874,000 m³. The care was taken that the material shall be reused in the dam, thus it was disposed in its immediate vicinity.

When the excavation works were completed, the gallery construction on these dam sections was started. The gallery was completed late in July 1994. The backfilling was immediately continued in the left and right ends to the El. 353 m a.s.l. and 358 m a.s.l., respectively, from which the cut-off wall construction is performed. When the cut-off wall construction is completed, the dam shall be backfilled to the crest on El. 364.5 m a.s.l.



The rebuilt gallery with the access tunnel in the left dam end.



The plastic concrete cut-off wall is being constructed on 256 m of dam length. Its depth varies between 17 and 50 m, and the total surface area is about 9,000 m². The guide trench is excavated by the hydraulic trench cutter under the slurry protection. The plastic concrete composition is: 112 kg of cement, 36 kg of bentonite, 102 kg of rock flour, 1,527 kg of sand and 337 l of water. The laboratory tests of the concrete have shown that after 28 days the concrete compressive strength was 1.67 MN/m² and modulus of elasticity 341 MN/m².

The plastic concrete cut-off wall construction in the dam clay core - excavation by hydraulic trench cutter.

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CROATIAN NATIONAL ELECTRICITY

Backfilling the left dam end, El. 338.50 m a.s.l.

