DEGRADATION PROCESS OF ASPHALT CONCRETE LINING OF UPPER RESERVOIR IN ZARNOWIEC PUMPED STORAGE POWER PLANT

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Abstract: The paper deals with some faults and deficiencies of bituminous linings of the upper reservoir of the pumped storage power plant Zarnowiec. The heaves in the bottom of reservoir and the breaking of asphalt concrete lining upon the line of drains were described. The reasons of these phenomena were analysed and methods of renovation were characterised.

1. Introduction

The power plant, commissioned in 1983 and situated in Zarnowieckie lake close to Gdańsk, is the biggest pumped storage power plant in Poland. It makes use of the Zarnowieckie lake as a lower reservoir. The artificial upper reservoir of useful capacity of 13,8 million cubic meters was constructed on a hill distant about 1500 meter from the power plant. Zarnowiec power plant is equipped with four equal Francis reversible pump turbine generator motor units - each of capacity 179 MW. The main technical data of Żarnowiec power plant were presented in table 1.

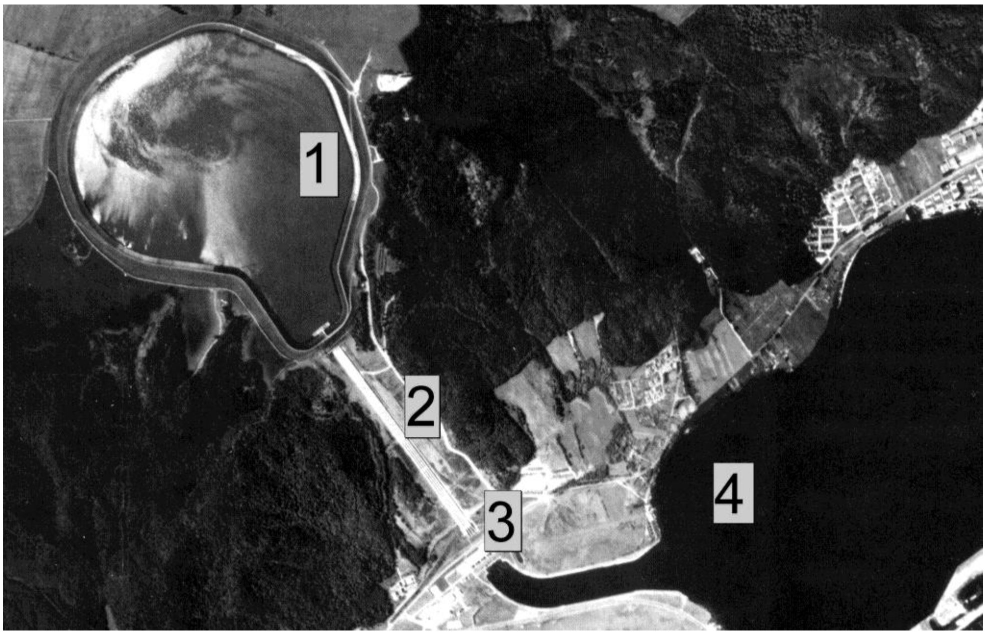

Fig. 1. Aerial view on the pumped storage power plant Zarnowiec
(1-upper reservoir, 2- pipelines, 3-power plant building, 4-Zarnowieckie Lake).

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The average total starting time for full operational power for generating mode is 180 sec and 400 sec for pumping mode. The process is fully automatic remotely controlled by Domestic Dispatching Centre in Warsaw. Short starting time allows not only to cover the demand for the peak power load but also to fulfil its interventional task for Domestic Energy System to quickly cover the power deficit. Zarnowiec power plant can also work for reactive compensation mode.

Table 1. Technical data of Żarnowiec pumped storage power plant:

Installed capacity for		
	generating mode	716 MW (4 x 179 MW)
	pumping mode	800 MW (4 x 200 MW)
Lower reservoir (Zarnowieckie lake)		
	lake surface	1470 ha
	water surface level	1,0÷2,0 m a.s.l.
Upper reservoir (artificial)		
	reservoir surface	135 ha
	useful capacity	13,8 million m^3
	water surface level	126 m a.s.l.

2. Technical data of the upper reservoir

The upper reservoir was built on the moraine hill located over 2 km far from Zarnowieckie Lake. Embankments of upper reservoir were made of soil excavated from the hill. The main part of these soils is clay. The typical cross section of embankments is presented at figure 2, and the parameters of upper reservoir are collected in table 1.

The water from the reservoir is conducted on turbines by four steel pipelines of total length about 1100 m each, and diameter varied from 7000 mm to 5400 mm. The maximum fluctuation of the water surface level is 16 m high and occurs in 5 hours of turbine work and in 7 hours of pumped work.

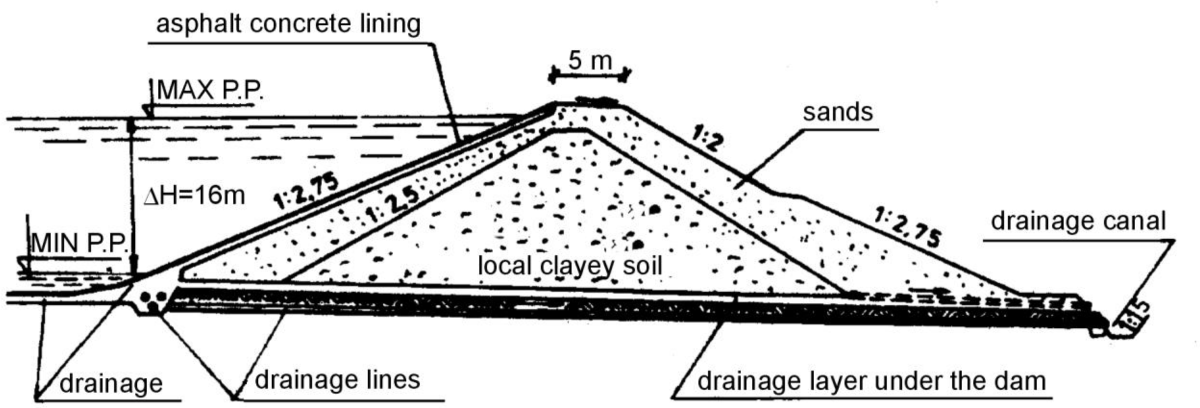

Fig. 2. Typical cross section of upper reservoir embankments

Water side slopes of the dam and the bottom part of the reservoir are covered with the asphalt concrete lining places on the gravel drainage layer, which thickness is 24 cm on the slopes and 40 cm on the bottom. The filtration coefficient of drainage layer is 500m/day.

The asphalt concrete lining is composed of two different parts. Each of them is about 7 cm thick. The lower part of asphalt concrete has an open structure and was placed on the drainage layer covered by the cationic emulsion (5 kg/m^2). The upper part of asphalt concrete layer, placed on the bottom part, is watertight. The asphalt concrete was placed directly on the soil surface mainly because of technical and financial reasons.

3. The characteristics of upper reservoir asphalt concrete linings

Each layer of asphalt concrete lining was prepared of component mixed in accordance with recipe presented in table 2.

Table 2. Asphalt concrete components (%)

Material	base course layer	watertight layer	sandy asphalt concrete
basaltic grit 12/16	26,7	-	-
basaltic grit 8/12	19,2	18,6	-
basaltic grit 5/8	14,3	18,6-	-
basaltic grit 2/5	9,6	18,6	-
basaltic fines 0/2	-	28,9	36,8
sand	20,0	18,6	41,4
calcareous meal	5,7	8,5	13,8
road asphalt D70	4,5	6,8	8
Summary %	100	100	100

The asphalt concrete was prepared, conveyed, placed and compacted in accordance with all generally accepted rules and standard recommendations. Designed thickness of asphalt concrete lining on slopes was maintained. On the bottom of the reservoir, due to the insufficient equality of surface, asphalt concrete lining thickness varied between 2 and 10 cm. Check tests confirmed good quality of asphalt concrete lining, which has fulfilled all physical and mechanical parameters requirements specified by design engineers. The asphalt concrete had a good watertightness ($k \leq 10^{-9}$ cm/sec) and stability, was fully resistant on flow of and had correct flexibility. Except joints, the whole surface of the asphalt concrete lining was even and smooth.

The original project demand to cover all asphalt concrete by mastic and bituminous emulsion. However the results of check tests were good and engineers abandoned those layers. After failure of asphalt concrete lining in 1982, engineers returned to original project and between 1984 and 1985, near 60% of upper reservoir slopes have been covered with protection layer made of asphalt D200, PS-175 and 145. All repairs were made manually. The hot liquid asphalt were placed on the cold inadequate clean surface, so the connection between new and old layers was improper and asphalt has flowed to the bottom of slope.

4. Damage of bottom lining due to compressed air present in soil subsurface

In June 1979, when near 70% of the reservoir bottom was covered with asphalt concrete, after sudden night rainfall many bottom heaves occurred (fig. 3). They have had maximum diameter of 150 cm and maximum height of 50 cm. Most of heaves have scratched or cracked on the top. The compressed air has flowed through those cracks.

The heaves were caused by two reasons. Firstly the atmospheric pressure had suddenly decreased for 12 hPa after 2 months of high barometric pressure. Secondly the drainage in bottom part of slopes has been completely silted-up by fine parts of soil flushed with rainfalls. When the rain was falling the upper part of the slope was uncovered so the rainwater has flowed into drainage layer and toward into the soil under the bottom of the reservoir. Migration of water caused high pressure of air present in soil pores.

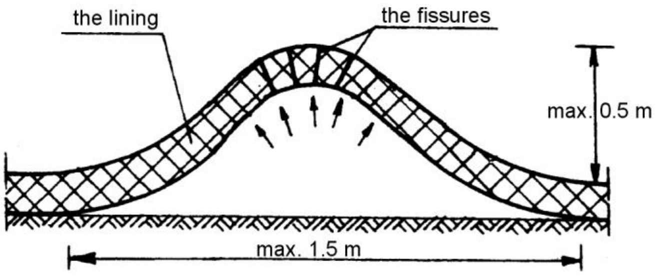

Fig. 3. The bottom air heave

The high difference between atmospheric and under bottom air pressure was the main reason of the damages. All heaves have appeared in those places, where the lining was thinner than 5 cm. Repairs were made by cutting of the heaves and making cork of the asphalt concrete (fig. 4b).

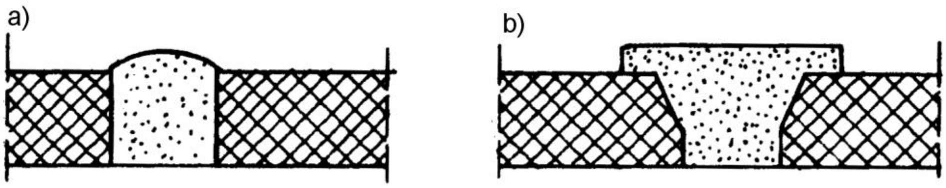

Fig. 4. Asphalt concrete cores in bottom lining a) incorrectly arranged, b) correctly arranged

5. Breakdown of asphalt concrete lining upon slope toe drainage

Few months after first start-up, 27th of July 1982, sudden breakdown of 250 m asphalt concrete lining situated along the toe of the slope took place. Damage was very dangerous because the water has flowed through the whole cross section of drainage washing out fines particles of drainage aggregate. Probably the improper rinsing of silted-up drainage has caused the failure. Too high water flow has washed out not only soil particles causing silting but also smaller particles of drainage aggregate. The every 10 m bored holes in bottom lining were corked with asphalt concrete, but unfortunately at least one was made inadequate (fig. 4a), so the water pressure has pushed them through the drainage layer making inlet into the bottom subsoil.

Damaged asphalt concrete was removed, drainage was perfectly repaired and the new asphalt concrete lining were places at the area of 5 m width and 250 m long.

6. Puncture and collapses of bottom asphalt concrete lining

During the next start-up tankage of upper reservoir to the 120 m a.s.l. many punctures and collapses of asphalt concrete lining has occurred.

Some hard objects left in the subsoil of the bottom lining have caused punctures. There were some steel, concrete or wooden elements, which act as a knife on the bottom asphalt concrete lining loaded by high water level pressure. Prior to the renovation of these punctures all hard objects were removed from subsoil. Then the bottom was corked with the new asphalt concrete.

Insufficient compacted and stabilised subsoil has caused collapses of bottom lining. In this cases the lining has not been cracked but each and every collapse was filled with the asphalt concrete.

7. The collapse of bottom asphalt concrete lining upon the shaft well

The upper reservoir was located on the former farm terrain. There was a shaft well localised directly in the bottom part of the reservoir. The well was filled with sand and covered with asphalt concrete lining as the rest of the bottom. In 1988 the big collapse of asphalt concrete lining was discovered. The asphalt concrete lining was pushed 2 meters deep into the shaft well by the water pressure. Close to the shaft well, quite a few failures of bottom lining were noticed. There were collapses and heaves width 3 m diameter and height (depth) of 50 cm. There were also furrows 20 cm deep and 20 to 50 cm width with 20 m overall length.

All those failures were caused due to the water flow under the bottom lining of reservoir. The collapsed well was the inlet.

8. The smallpox of the slope asphalt concrete lining

The large quantities of the smallpox (fig. 5) on the slope lining of the upper reservoir were confirmed after 10 years of Zarnowiec pumped storage power plant working. The smallpox was situated mainly in the area of the highest water level variation, nearby the joints, where the closing bituminous layer had not properly done.

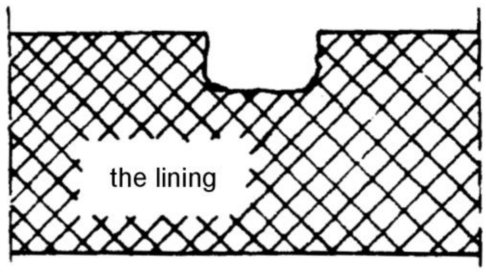

Fig. 5. Asphalt concrete cores in bottom lining a) incorrectly arranged, b) correctly arranged

Till now loosing some particles of basaltic grit causes the smallpox. The grits are washed-out by the water or ice.

There are many smallpox blisters in the same area where the smallpox is situated. The gravel grits moving to the top surface of lining (fig. 6) cause the smallpox blisters. When the grip is out the big smallpox hole appears.

Inadequate compaction of asphalt concrete mixture in the area of joints is the main reason of that kind of failures.

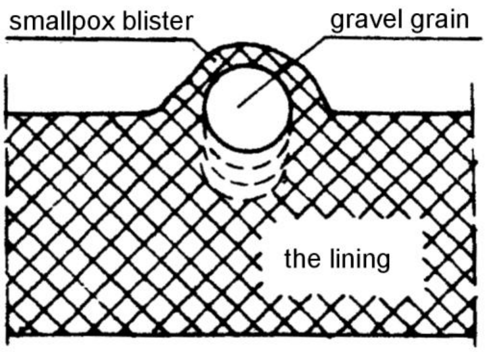

Fig. 6. Asphalt concrete cores in bottom lining a) incorrectly arranged, b) correctly arranged

9. Breaking of asphalt concrete lining upon drainage layer

In July 2001 at the toe of slope the lining upon the drainage layer collapsed causing some outflow of water trough the drainage. Some small particles of drainage aggregate were washed off. The main reason of this breaking was insufficient elasticity of asphalt concrete lining. One year after renovation the same kind of failure was noticed close to the renewed area.

10. Conclusions

All presented faults and failures were quickly and well repaired. They do not threaten the safety of the whole reservoir structure. Well made drainage system is able to take over leakage caused by every type of asphalt concrete lining faults.

From the beginning bituminous layer has a limited tension resistance and strain capability. During 20 years of exploitation resistance parameters were weaken by the ageing process of bituminous. The robust repairs and proper maintenance guaranty appropriate exploitation of the upper reservoir for the next years.

Main reason of many fault was insufficient compaction of bituminous material and no thorough closing of joint in the upper layer of asphalt concrete lining. Also the improper content of bituminous material in asphalt concrete mixture, the lack of protecting layer of mastic had influences on occurred faults.

11. References

1. Bednarczyk S. (1993): Some faults of bituminous linings on the upper reservoir and tail water canal of Zarnowiec pumped storage plant (in Polish: „Mankamenty wykonanych z betonu asfaltowego okładzin zbiornika i kanału elektrowni szczytowo-pompowej Żarnowiec”) – Zeszyty Naukowe Akademii Rolniczej we Wrocławiu nr 234 /1993;