# LOCAL DEFECTS IN ASPHALT CONCRETE LININGS ON THE EMBANKMENTS OF PUMP STORAGE SCHEMES

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## ABSTRACT

*Asphalt concrete lining is commonly used for the upstream sealing of dams, and of embankments at the upper reservoirs of pumped storage schemes in particular. Some of such installations suffer from local defects manifesting as blisters occurring both between two layers and also inside single layer. These defects develop particularly in the zone where the water level fluctuates due to pump storage cycles. The blisters have various depths and, if not repaired, may cause local seepage through the lining, resulting in further damage to it. In the paper, the types of local damage arising due to blistering are classified and discussed in detail. The occurrence and progress of blistering is described together with a list of potential causes of the defects.*

## 1. INTRODUCTION

Asphalt concrete linings (ACL) have been used to seal the upstream slopes of dams for decades (SNCOLD, 1988; Tschernutter, 1988; Handbook, 1999). ACL is frequently used in mountainous regions in high head pump storage hydraulic schemes with frequently oscillating reservoir water levels. ACL is typically composed of a transition screed layer spread on the upstream slope of a rockfill dam, which is overlaid by a drainage layer, binder, a dense layer and a mastic coating which protects the dense layer against ultra-violet radiation.

The average service life of ACL is approx. 30 years (Říha and Buchtová, 2005). However, sometimes the service life is shortened due to various types of damage to the lining, which sometimes may be quite extensive. In the case of pump storage schemes, damage to the lining primarily occurs at upstream slopes within the zone of water level fluctuation where the asphalt surface is subject to frequent and significant temperature changes which range from -15 to +60 °C (Grätz et al., 2011).

One type of defect is local blisters, which may develop in their thousands practically all over the entire upstream slope of the dam. In this paper, the development of such blisters at the upper reservoir of the Dlouhé Stráně dam is described and compared with the occurrence of blisters at other hydropower schemes in Europe. Possible causes of the defects are listed as well.

## 2. DESCRIPTION OF THE DLOUHÉ STRÁNĚ HYDROPOWER SCHEME

The Dlouhé Stráně scheme is located in the Olomouc Region of the Czech Republic. The site has a high-mountain character and is located in the central part of the Jesenik Mountains. This pump storage hydropower scheme consists of two reservoirs – a lower and an upper one, as well as a machine hall in a cavern in the rock massif, and two penstocks and tailraces.

The studied pump storage scheme upper reservoir is located at an elevation of 1350 m above sea level (MASL). The dam height at the downstream side reaches 45 m, while at the upstream side the dam wall is about 25 m high. The reservoir has an oval shape (Fig. 1). The dam is made of rockfill excavated from the reservoir area and the tunnels for the penstocks. The reservoir bottom and upstream slopes are equipped with an asphalt concrete lining. The surface area of the lining is 71 000 $m^2$ on the bottom and 98 000 $m^2$ on the slopes. The total reservoir volume is 2.72 Mill $m^3$.

The reservoir water level fluctuates according to the operating regime of the scheme (pumping, hydropower production) over a range of 21.8 m, so approximately between 1326 and 1348 MASL (Fig. 2). The most frequent water level variation is between 1337 and 1346 MASL, and this is where the occurrence of blisters is the most frequent.

The lining is composed of layers, as shown in Figure 3. The dense asphaltic concrete (DAC) is about 80 mm thick, while the thickness of the underlying binder – a porous asphaltic concrete (PAC) layer – varies from 40 to 80 mm. The upper face of the dense layer has been coated with an approx. 2 mm thick mastic layer composed from asphalt (30%) and limestone filler (70%).

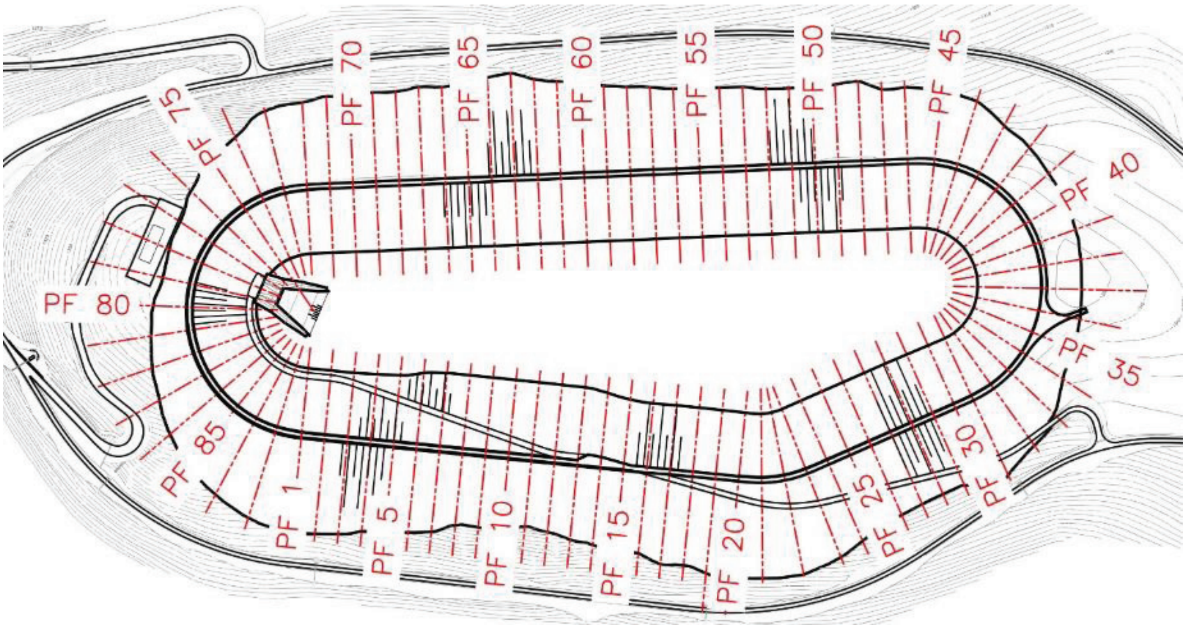


**Figure 1** : Ground plan of the dam.

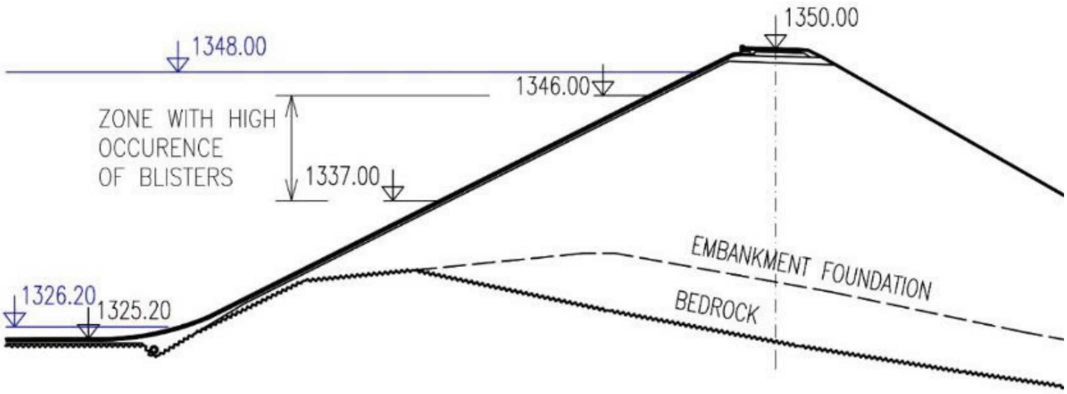


**Figure 2** : Typical cross-section of the dam.

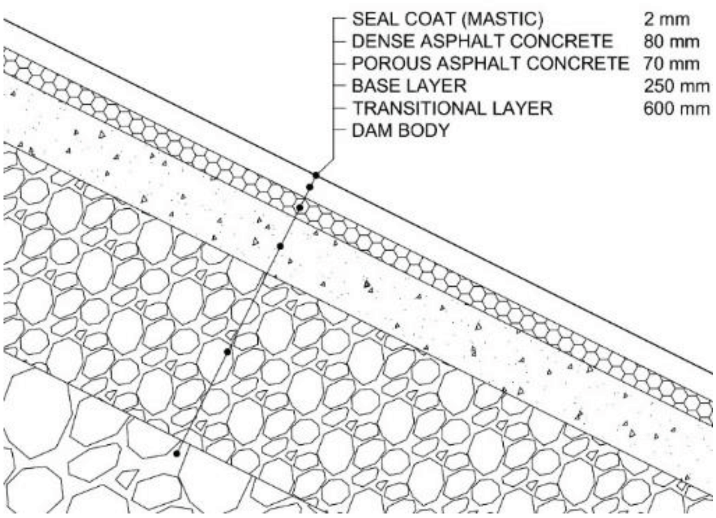


**Figure 3** : Composition of the asphalt concrete lining according to the original design.

## 3. DESCRIPTION AND DEVELOPMENT OF BLISTERS

### 3.1 Defects after the first filling of the Dlouhé Stráně upper reservoir

The defects in the ACL manifested in the form of thousands of local blisters in 2002, which was just 8 years after the scheme commenced operation in 1995. The blisters occurred exclusively in the middle zone of the slopes, which is a region subject to reservoir water level fluctuation. Their development over time is shown in Figure 4.

The blisters were of different sizes and shapes, and were spread practically all around the peripheral dam, though their intensity varied locally. Openings which were originally closed inside the dense layer developed into open crater-shaped blisters. They looked like burst pustules with a diameter of around 150 mm and a height of between 30 and 50 mm. Inside the blisters there was an opening with a depth of 30 to 80 mm. It was filled with water and crumbled components of the asphalt concrete (aggregates, asphalt, asphalt with mastic remnants).

Local minor voids inside the dense layer gradually increased and propagated to the surface of the lining, creating a hole of variable depth extending for up to 80 mm. During the operation of the scheme the openings filled with water, while during winter periods they froze and increased in size through the crumbling of the surrounding aggregates and asphalt by the expanding ice. In Figure 5 the classification of the blister stage is shown.

In 2006 it was decided that all of the asphaltic lining on the slopes, i.e. covering a surface area of about 90 000 $m^2$, would be repaired. In 2007 the damaged dense layer was scraped off together with the remaining mastic coating and replaced by a new one.

### 3.2 Defects after the repair at Dlouhé Stráně in 2007

Four years after the repairs were conducted, the first blisters appeared again (Fig. 6). In 2011 there were about 600 of them; these were locally repaired by a contractor.

The blisters in the asphalt concrete lining were spatially distributed in clusters that developed down the slope (Fig. 6). These clusters had a span of about 5 m, which corresponds to the width of the finisher used for the construction. The depth of the blisters varies from a few centimeters to nearly 80 mm (the whole thickness of the dense layer).

Regarding the arrangement of the blisters along the dam perimeter, it was found that some places are more prone to the blistering than others. The dam perimeter is divided into 87 cross-sections marked PF 1 to PF 87 (Fig. 1). The distance between two adjacent cross-sections is 20 m. The cross-sections and the most affected areas are marked in Fig. 7. Here, the eastern and western slopes are most affected by blistering. A minimal number of blisters were found in the arcs (northern and southern slopes).

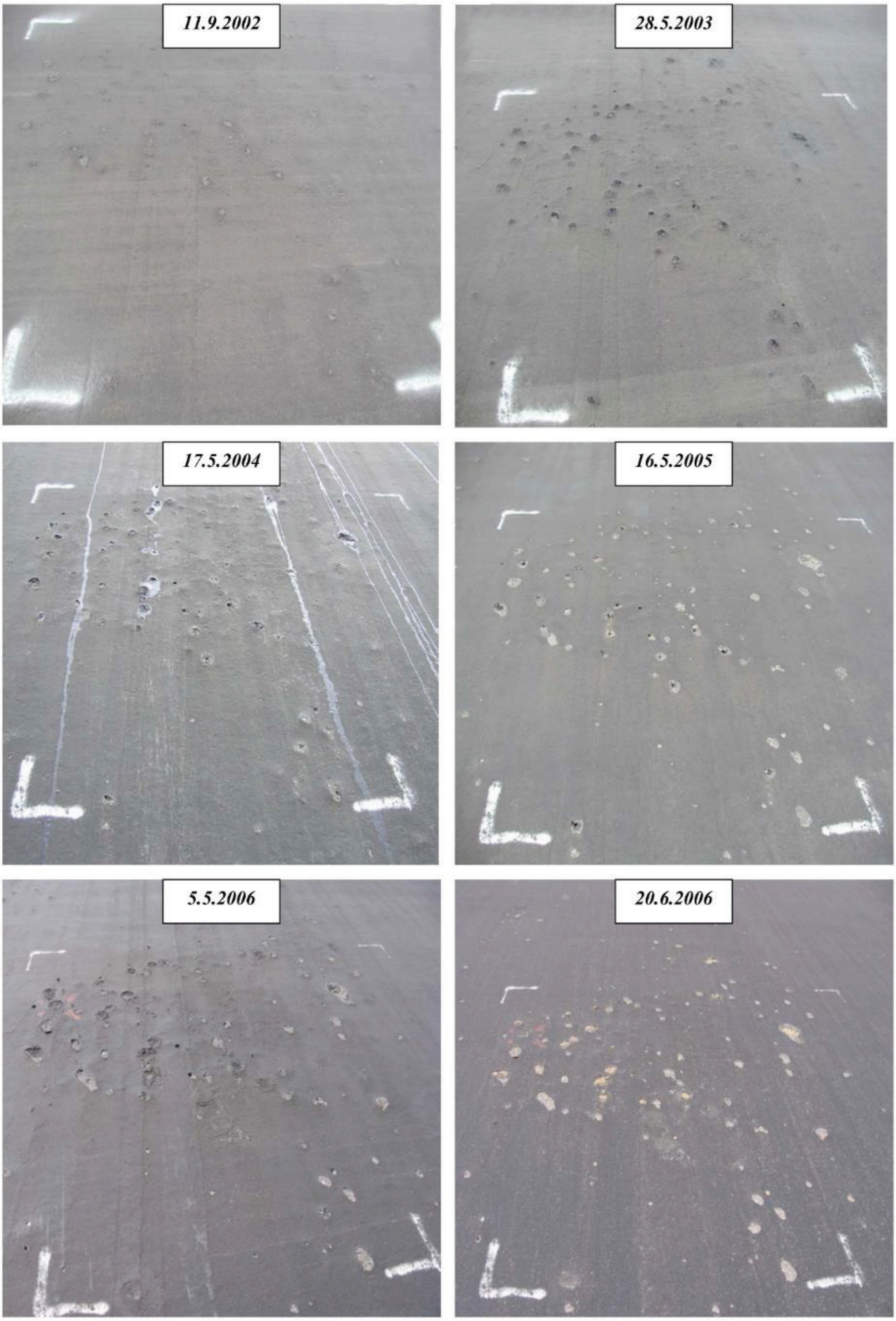


**Figure 4** : Development of blisters.

| Stage | Exhibition of the defect stage |
|---|---|
| Minor voids (1-2 mm) inside the dense layer |  |
| "Hidden" defect – increased void (5-10 mm) inside the dense layer |  |
| Distorted surface of the lining |  |
| Opened blister on the surface |  |

**Figure 5** : The stages of blister development

**Figure 6** :. Blisters developed 4 years after the repairs were carried out

**Figure 7** : Arrangement of blisters in clusters extending down the slope.

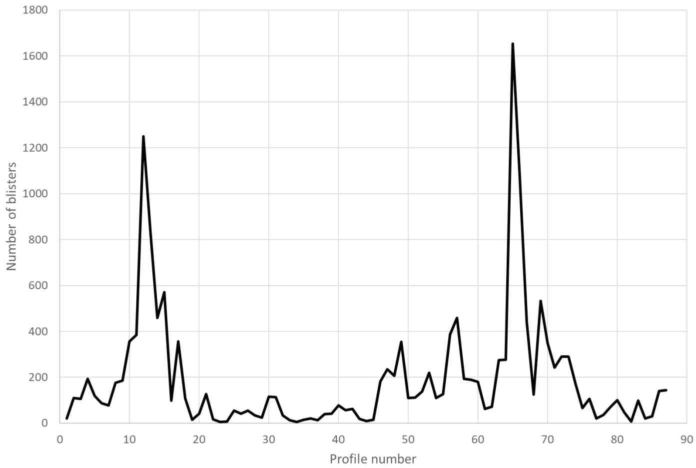


**Figure 8** : Arrangement of blisters in profiles along the dam perimeter

## 4. COMPARISON WITH OTHER HYDRAULIC SCHEMES

Similar defects have also been reported at the Porabka and Żarnowiec reservoirs in Poland, the Längental Dam in Austria and the upper reservoir of the Markersbach pump storage plant in Germany. The documentation of blister development shows that the extent of blistering is different at individual schemes. It was reported at the Längental and Markersbach schemes that hundreds of blisters occurred in the linings and were locally repaired. At the Polish dams thousands of blisters were counted, while at the Dlouhé Stráně (EDS) upper reservoir, the annual number of blisters reached about 12 to 16 thousand only a few years after the completion of the scheme, and the same occurred shortly after it was repaired (Fig. 9).

From the comparison of the blistering documented at EDS and the Polish schemes (Fig. 9), it can be seen that at EDS blistering started relatively early after the scheme commenced operation. The extent of the blistering grew during the first decade of operation, though after some years it decreased and stagnated. In case of EDS the initial development of blisters was extreme when compared with the mentioned Polish dams.

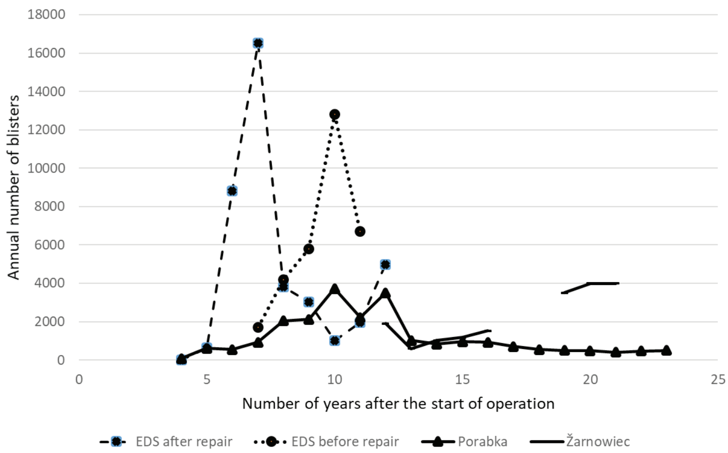


**Figure 9** : Comparison of the blistering at different schemes.

## 5. POSSIBLE CAUSES OF BLISTERING

The causes of the origin and development of blisters have been discussed by experts for decades (Fabian and Ditter, 1988; Szling and Szymański, 1991; Handbook, 1999; Sobolewski et al., 2010; Akhtarpour and Khodaii,, 2013, Wang et al. 2019). It is considered that blisters may gradually develop due to a combination of various reasons which influence both their intensity and their spatial distribution. These factors include the poor quality of individual components of the asphaltic concrete used (asphalt, aggregates, filler), and improper construction techniques or properties of the lining subbase. Extreme load, i.e., water level oscillation and variations in the surface temperature of the lining within the range from -20 to 60 °C should not be counted as causes of defects as they are taken into account by the design parameters.

Some authors have developed special theories about the causes of blistering. One opinion, which originates from highway engineering, is that blisters are the result of the development of volatile gases or water vapour beneath the asphalt layers. This phenomenon is exacerbated by significant increases in surface temperatures (Grätz et al., 2011). Croll (2008) suggested that the creation of blisters is a result of the gradual growth of upward buckling induced by cyclic changes in stresses due to surface temperature fluctuations. Some authors (Szling and Szymański, 1991; Sobolewski, 2010) attribute the development of blisters inside the upper dense layer to the use of aggregate with high porosity or containing clayey components. This material supports an increase in humidity inside such layers and produces local blisters. Wang et al. (2019) attribute the blistering to the capturing of moisture within the dense layer. They suggest that the moisture is most likely introduced by water spraying during rolling.

## 6. CONCLUSIONS

Blistering is a phenomenon which occurs in asphalt concrete lining at some pump storage schemes. These are usually schemes where frequent water level oscillation is accompanied by a wide range of lining surface temperatures. It usually starts several years after the scheme is put into operation. There are several theories about the causes of blister formation. However, none of them have been reliably proven yet. It is probable that blister formation is the result of a combination of material quality, mixture properties and both construction processes and loads.

To prevent blistering it is necessary to find appropriate tests to allow the development of a sufficiently durable mixture for dense layers. It is obvious that in the case of pumped storage schemes it is necessary to apply the above standard approach to all phases of construction to prevent or reduce the blistering effect.

## ACKNOWLEDGEMENT

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