The asphalt and geomembrane dam lining database and its use at the Dlouhe Strane dam rehabilitation

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The asphalt and geomembrane dam lining database and its use at the Dlouhe Strane dam rehabilitation

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The Dlouhe Strane hydropower pumped storage scheme is located in the Jeseniky region of the Czech Republic. It was built in the period (1978 – 1996) and was put in operation in 1993. At both upper and lower reservoirs, the asphalt facing was used as an upstream sealing. The lower asphalt sealing has been in service for ten years without any problem, however at the upper reservoir some problems occurred with bitumen facing in 2002. Until 2004, thousands of blisters arose, due to an improper aggregate in asphalt concrete, on the face at the zone of water level fluctuations. Severe climate conditions (the upper dam crest elevation is 1350 m above SWL) contributed significantly to asphalt degradation. Therefore, in summer 2004 it was decided to reconstruct the damaged upstream facing at the upper reservoir.

In fact, two possibilities of reconstruction were taken into account – placement of a new asphalt concrete sealing or application of geomembrane facing. One step in the decision process was formed by the risk based failure mode and effect analysis (FMEA) of possible rehabilitation scenarios.

During the preparation phase of the anticipated reconstruction of the pumped storage scheme Dlouhe Strane upper reservoir asphalt sealing, a comprehensive database was compiled to improve and extend knowledge of embankments with asphalt or geomembrane upstream sealing. The database contains more than five hundred records consisting of basic and more detailed information about 367 schemes where the upstream bituminous coating was used and 136 schemes where the plastic sheet was applied (64 at embankment dams). The data were assembled using many sources e.g. company folders, bulletins, journals or experts’ experience and knowledge. During processing the register and making statistical analyses, invaluable data were obtained for the subsequent FMEA of reconstruction scenarios. The analysis was directed at failure modes, their consequences, methods of reconstruction and at time prior to the first reconstruction or at a time interval between two failures.

Keywords: Dam, Failure, Geomembrane sealing, Asphalt concrete sealing
1 Introduction

Following needs for comprehensive information about applications of asphalt and geomembrane upstream sealings of embankment dams, the database of individual schemes, their parameters, operational experience and coat failures was compiled. This paper summarises information about available references of asphalt concrete (AC) and geomembrane facing (GM) applications at embankment dams. Applications and reconstructions of the AB and GM coatings at the schemes worldwide were analyzed with respect to the planned reconstruction of the Dlouhe Strane dam.

2 The sources of information

The data about existing upstream AC and GM sealings applied at embankment dams or upper reservoirs of pumped storage schemes were obtained, processed and verified, using various sources. Those were:

- ICOLD bulletins [1], [2], [3], proceedings of questions discussed at ICOLD congresses [4] to [6] and ICOLD reports,
- data obtained from contractors and dam owners (CARPI, WALO, STRABAG and others),
- technical magazines and journals, namely The International Journal on Hydropower & Dams, International Water Power & Dam Construction,
- www.pages.

All the data were compiled in an organised tabular form (spreadsheets), separately for AC and GM coats. Above all, the information assembly was focused on schemes built and operated under similar climatic and performance conditions like the ones at the Dlouhe Strane upper reservoir.

3 The asphalt concrete facing

3.1 The database structure

The database was compiled in a tabular format using a spreadsheet. Both dams and upper reservoirs were included into the database and analysed within the study. The data set was divided into two groups – the schemes with
reconstruction mentioned in the available sources and the schemes where no data about reconstruction had been found.

The database contains basic information about water structures including the scheme title and its location, the year of construction and reconstructions, the dam type and its geometry, parameters of the sealing and finally, the dam owner and contractor.

3.2 Summary information about AC facings

Data about 367 embankment dams with an asphalt concrete upstream sealing were assembled. The figure 1 shows the percentage of installations in continents.

![Pie chart showing allocation of dams with asphalt concrete sealing in the world](image)

**Figure 1:** Allocation of dams with an asphalt concrete sealing in the world

Most of the dams were built in continental Europe where the AC technology was originally developed and used predominantly in locations with the lack of traditional - natural (earthen) sealing materials.

69 records of reconstructed dams were found; the most frequent repairs included recovery of mastic and were followed by local repairs of facing (patching) or repairs of larger areas of AC coat.

The data were organised in terms of the scheme service period prior to reconstruction (between reconstructions) - see Fig. 2. Relatively frequent
defects were those which occurred during the first five years of operation. Those were caused mainly by technological reasons and a consequent improper maintenance of the asphalt surface. Less serious damage was represented by local cracks, blisters or sliding. More failures occurred after twenty years of operation, the maximum of repairs occurred after the period of 30 to 35 years which is the lifetime of the AC sealing.

![Classification of dams with an AC upstream facing – prior to the first reconstruction](image)

Any asphalt sealing has usually the lifetime about 30 years and a mastic cover approximately 15 years. In places where mastic suffers from an ice or sun action and a frequent reservoir water level oscillation, the lifetime usually decreases to 5 years. In a similar way, an analysis was made with schemes where no data about reconstruction had been available (Figure 3).
Classification of dams with an AC upstream facing – dams with no reconstruction data

4 Geomembrane sealing

4.1 The database structure

The tabular database of dams with a geomembrane sealing has a similar structure as the previously mentioned AC database. Scheme titles and locations, dam types, parameters of sealing (thickness, a number of layers), owners and consultants are mentioned as well. The preliminary search was focused on all GM installations worldwide including vertical faces of concrete dams. In the following phase only embankment dams with an upstream GM sealing were analysed.

4.2 Summary of GM

Data about 136 GM applications at dams were obtained in total. Out of this set, only 64 installations were at embankment structures. Figure 4 shows the use of GM in relation to individual continents.
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Figure 4: Location of dams with a GM facing at embankment dams all over the world.

Fewer available data about single applications, types of dams or a GM sealing protection type influenced credibility of conclusions and a total summary. Another problem was the lack of information and references regarding failures, repairs and reconstructions of the GM sealing.

In the context of the anticipated reconstruction of the Dlouhe Strane upper reservoir sealing, further investigation was focused on reference schemes with similar conditions and operation. The following special cases and GM sealing modifications at embankment dams were identified:

- In many cases the plastic sheet was protected by:
  - concrete slabs – Contrada Sabetta, Landstejn, Dobsina, La Coche, Codole, Bovila;
  - soil or rockfill – Miel, Odiel, Isanlu, Valence d’Albi, Gorghilio.
- Geomembranes were frequently used for reconstruction of:
  - asphalt concrete sealing – Moravka dam, Winscar dam, Lechsstaustuffe 2 Prem;
  - concrete sealing face (CFRD) – Crueize, Rouchain, Gorghilio, Strawberry, Salt Springs, Midbotnvatn.
Geomembranes were used for sealing of the following upper reservoirs:

- Tenerife island – planned 11 irrigation reservoirs at volcanic plains;
- the pumped storage Okinawa reservoir in Japan (154 m above SWL);
- reconstruction of the Gorghilio upper reservoir in Italy (600 m above SWL) and reconstruction of the Lechstaustuffe 2 Prem embankment in Germany (748 m above SWL);
- an experimental area at the Cerny Vah upper reservoir (30 m² only).

5 Conclusions

Finally, the schemes with an asphalt concrete sealing and a geomebrane facing were compared with respect to the construction year (or the GM installation at reconstructed faces) (Figure 5) and in respect to an altitude (Figure 6).

![Figure 5: Classification of dams with AC and GM upstream facings – the construction year](image-url)
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Figure 6: Classification of dams with AC and GM upstream facings – altitude

Final statements are as follows:

- The AC sealing is used approximately 5.5 times more frequently than the GM one.

- The geomembrane facing is often used for reconstruction of an original upstream sealing element (AC, CFRD).

- References to application of the geomembrane facing are sparse, especially at upper reservoirs of hydroelectric pumped storage schemes, i.e. under similar conditions like at the Dlouhe Strane upper reservoir.

- Available data about the AC sealing provide a more detailed and extensive base of knowledge of its behaviour, potential damage and a possible reparation. The reason is a number of applications and a relatively long period of its use (more than 70 years). In many cases of older embankments equipped with the geomembrane sealing, the plastic sheet was protected by concrete elements or an earthen layer. Therefore, the data about a very good condition of older covered plastic sheets unfortunately provide poor references to durability and a
lifetime of exposed plastic membranes. The summary overview and comparison of both technologies and their applications are in table 1.

Table 1: The number of upstream sealings of an identified type- overview

<table>
<thead>
<tr>
<th>Upstream sealing type, dam type</th>
<th>Number of schemes</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC facing - embankment dams</td>
<td>218</td>
</tr>
<tr>
<td>AC facing - embankment dams – upper reservoir of PSHP(^1)</td>
<td>140</td>
</tr>
<tr>
<td>AC facing - similar conditions like at the Dlouhe Strane reservoir</td>
<td>30</td>
</tr>
<tr>
<td>GM facing – total</td>
<td>136</td>
</tr>
<tr>
<td>GM facing - embankment dams - total</td>
<td>64</td>
</tr>
<tr>
<td>GM facing - embankment dams – covered (protected) plastic sheet</td>
<td>13</td>
</tr>
<tr>
<td>GM facing – embankment dams – uncovered plastic sheet</td>
<td>51</td>
</tr>
<tr>
<td>GM facing – embankment dams</td>
<td>42</td>
</tr>
<tr>
<td>GM facing – upper reservoirs of PSHP(^1)</td>
<td>9</td>
</tr>
<tr>
<td>GM facing – similar conditions like at the Dlouhe Strane reservoir</td>
<td>02(^2)</td>
</tr>
</tbody>
</table>

\(^1\) PSHP - pumped storage hydroelectric plant

\(^2\) An exposed plastic sheet at an altitude higher than 1000 m above SWL, a frequent occurrence of ice cover and the water level oscillation, severe winds.

More profound knowledge about the AC and GM upstream sealing installations, the summary of potential damage, failures and consequences, advantages and disadvantages of both types of sealings were obtained through the search and analysis. The information and knowledge were used in the following FMEA analysis carried out as a part of a decision-making process regarding the choice of an optimal reparation method at the Dlouhe Strane upper reservoir.
6 References


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