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Investigation on the temperature of the asphalt-concrete facing of embankment dams

Karel Adam, Jaromír Říha *, Miroslav Špano

Brno University of Technology, Faculty of Civil Engineering, Institute of Water Structures, Veveří 95, 602 00 Brno, Czech Republic

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Abstract

Asphalt concrete is a traditional material used for the constructions of upstream sealing of reservoir dams, particularly in upper reservoirs of pumped storage hydroelectric plants. The asphalt layer is often exposed to significant fluctuations of temperature caused, for example, by heating the facing from the sun and by its subsequent rapid cooling by water during reservoir periodical filling. To better understand the physical phenomena and behaviour of the facing in terms of vapour diffusion, the state of stress, etc., it is necessary to know temperature phenomena in the asphalt facing. This paper describes the measurement of temperature in the asphalt facing of the Dlouhe Strane pumped storage hydroelectric plant and its evaluation using 1D numerical model of heat flow in the asphalt concrete facing. Numerical simulation for selected load scenarios enabled the temperature phenomena that take place in the construction of the asphalt-concrete facing to be quantified. The analysis shows that during insolation, the asphalt facing is exposed to the significant temperature rise on its surface and also over its whole thickness. Similarly during frost weather the facing becomes frozen in its entire thickness. During the day cycle the temperature in the asphalt layers changes significantly. However, the temperature in the underlying rockfill dam body becomes steady approximately at the depth of 1.0 m.

Keywords: Asphalt concrete facing; Temperature distribution analysis; Embankment dam

1. Introduction

The asphalt-concrete (AC) facing is one of the most used types of the upstream sealing of embankment dams. The AC facing is, especially in case of pumped storage hydroelectric plants (PSHEP), often extremely loaded with significant temperature fluctuations, which are caused by the fluctuation of water level in the reservoir, by direct sun exposure, by frost in the winter season and by other factors (the velocity and direction of wind, precipitation). For instance, in the summer, the dark surface of the AC facing is heated during a day to a relatively high temperature exceeding even 60 °C. Such a heated facing can then be rapidly cooled by relatively cold water when the reservoir is filled during the pumping regime of the PSHEP. During the winter months, the surface of AC facing is heated during a day in the sunny days and then exposed to negative temperatures at night. The step changes in the temperature of the facing influence the constructional-physical phenomena (diffusion of water vapours, water freezing inside the facing, the thermal state of stress and strain), which can have a partial effect on the gradual degradation of the facing and its subsequent failure. For this reason it is desirable to monitor and evaluate the course of temperature in the AC facing.

In the Czech Republic (CR), the design, construction and testing of the upstream AC facing of embankment dams was

* Corresponding author. Tel.: +420 541 147 753.
E-mail address: riha.j@fce.vutbr.cz (J. Říha).
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governed by a standard CNS 736852 [1], which was replaced in 2010 by a standard CNS 752020 [2]. The issue of AC facing sealing and their temperature load is systematically dealt with by technical commissions which in 1999 prepared Bulletin 114 [3] of the International Commission on Large Dams (ICOLD), which, among others, also gives operational problems with AC facings. Schonian's manual [4] is comprehensively concerned with the issue of AC facings of dams. A summarised basis for the design, construction, operation and repairs of AC facings of hydro-technical structures is a German guideline [5] from the year 2008 and a later Austrian methodology [6] from the year 2013, which describe the principles of design and laying of AC sealing with a presentation of examples of construction of AC facings on specific hydro-engineering structures.

Determining and modelling the temperature of the AC facing is dealt by the study of Djemili and Chiblak [7], which is concerned with factors that are involved in the changes of temperature of the facing surface. The authors give the thermal properties of each layer of the facing such as the thermal conductivity λ, the specific thermal capacity c and the bulk density ρ. The available literature shows that the temperature of the facing is affected by sun exposure (depending on the material and colour of the surface, the sunlight is reflected or absorbed), the air temperature, the position of water level in the reservoir and the water temperature, the velocity and direction of wind, and precipitation.

This paper describes an analysis of the temperature measurement in the AC facing on the upper reservoir of the Dlouhe Strane PSHEP. A part of the analysis is a heat flow modelling through the facing, using the data obtained from the measurement made by the dam safety supervision (DSS). These data were used for the calibration of thermal characteristics of the materials of the facing.

2. A description of the Dlouhe Strane dam and reservoirs

The Dlouhe Strane scheme is located in the CR, in the Olomouc Region, on the territory Loucna nad Desnou. The site has a high-mountain character and is located in the forested central part of the Jesenik Mountains. This hydro-structure consists of two reservoirs – the lower and the upper one. The analysis of temperatures was carried out for the facing of the upper reservoir (Fig. 1).

The upper reservoir (Fig. 2) is sealed using an upstream AC facing. Its composition is shown in Fig. 3. The facing consists of a 2 mm thick seal coat (mastic), an 80 mm thick layer made of dense asphalt concrete with porosity up to 3% (VABH according to CNS 73 6852 [1]), penetrated by a polymer-modified adhesive, an about 70 mm thick layer of porous asphalt concrete with porosity between 6% and 15% (VABM according to CNS 73 6852 [1]), a 200–250 mm thick base layer beneath the AC facing of aggregate of a 16/90 mm fraction, and a 600 mm thick transitional layer of aggregate of a 0/250 mm fraction on the slope. Beneath the transitional layer, there is the body of the rock-fill dam of aggregate of a 0/400 mm fraction. Here the first number denotes the grain size corresponding to 15% passing and the second one denotes 90% passing particles by weight. In compliance with the original documentation, the layers of the AC facing are designated further in the text as VABH and VABM.

3. Measurement of temperatures and related variables

On the Dlouhe Strane PSHEP, within its operation and dam safety supervision, a set of measurements is carried out, which contains both independent and operating variables and measurement of the response of the structure (seepage and displacements). Most of the measurements are carried out continuously and some of them manually at irregular intervals. The measurements required for the evaluation of the temperature of the AC facing on the upper reservoir are given below.

The temperature of the AC facing is continuously measured by twelve sensors placed inside the facing in the zone of the most frequent fluctuation of water level, where the largest differences in temperatures and the thermal stress of the facing are assumed. The sensors are placed always in three pieces in four places (Fig. 3); the TH sensors about 90 mm beneath the facing surface and the TP sensors about 170 mm beneath the facing surface. The temperature of the facing surface is measured manually at intervals connected to the patrols of dam supervisors. Manual measurement is carried out using a contactless thermometer. The results of manual measurements are influenced by a number of factors such as the velocity of wind and sun exposure.

The temperature of water in the upper reservoir is not monitored continuously. The temperature of water in the reservoir can be derived from the temperature measured continuously on the turbine sets.

The temperature of air is measured continuously using two sensors, namely in a gauging station on the dam crest and on the northern wall of the entry into the object of quick closing valves at a distance of about 140 m from the gauging station. The temperatures of air measured in both the places differ by 1.4 °C on average, and by up to 28 °C at maximum. This difference is probably caused by the different position of sensors. At the entry into the object of quick closing valves, the sensor is more protected from the direct effect of weather and is located about 40 m below the dam crest. For the evaluation of the temperature regimes, the measurement of air temperatures in the gauging station on the dam crest was used because it is located closer to the place of measurement of the temperature of the AC facing by sensors.

The reservoir water level, precipitation and the velocity and direction of wind are measured continuously in the gauging station on the dam crest close to the place of temperature measurement.

Sun exposure on the upper reservoir is not monitored.

Not all required measurements are continuous and they do not cover the whole period of the scheme operation.