State-of-the-Art Review

A Review on Cement-Based Materials and Practices for Rehabilitation, Retrofitting, and Strengthening of Hydraulic Structures

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Abstract: This paper aims at compiling the most relevant information concerning the use of cement-based mortars and concretes in the rehabilitation, retrofitting, and strengthening of hydraulic structures, namely concrete dams. The most important properties of cement-based mortars and concretes as repair materials are addressed, with a special focus on its compatibility with the concrete substrate. After a brief allusion to generic preparatory works, some of the most common practices are described. The main topics are mortar and concrete toppings, i.e., patches and overlays and thickening of the dam section. Among overlays, shotcrete and underwater works are addressed in detail. Littlerock, Oberems, and Storfinnforsen dam interventions are briefly described as successful rehabilitations involving the shotcrete method, whereas the Albbruck-Dogern dam intervention is given as an example of effective underwater repair works. As for dam section modifications, Kölnbrein, Olef, and Sasanagare dams are presented as conventional mass concrete placements within rehabilitation operations, while Les Toules, Gibraltar, Santa Cruz, and Littlerock dams are references for roller compacted concrete strengthening.
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Introduction

Degradation of concrete structures is a concern, with the situation becoming even more serious when the risk of failure jeopardizes people's lives and properties, which is typical of dams in areas where populations are downstream. Concrete dam rehabilitation aims at extending the life span of these hydraulic structures by correcting or eradicating their anomalies and, consequently, reducing the risk of an incident or accident (Corns et al. 1988; ICOLD 2000).

To increase the chances of an effective and durable outcome, the anomalies, including their origin, must be well understood before the rehabilitation operation. The most frequent anomalies in concrete dams may be divided in two main groups, as a function of their origin: physical and chemical phenomena. The first ones include abrasion, cavitation, and freeze-thaw cycles, whereas the most deleterious chemical reactions are the expansive reactions in concrete [alkali-silica reaction (ASR) and internal sulfate attack (ISA)] and leaching of the cement matrix by seepage water. Swelling due to expansive reactions has numerous typical symptoms, such as abnormally closed contraction joints, distinct displacements, and cracking. One should bear in mind that cracks are common symptoms for different causes, so these should be thoroughly evaluated, as an accurate diagnosis is crucial for a successful repair. Table 1 presents a summary of the most common anomalies in concrete dams and their respective rehabilitation measures. The final selection of the materials and methodologies should account for the ease of application, durability, life cycle cost, availability of equipment, and specialized labor (Corns et al. 1988; McDonald and Curtis 1999; ICOLD 1997, 2000; Sims 2009; Delatte 2009).

A repair procedure is perceived as a specific aspect of a rehabilitation operation (e.g., patching), whereas the concept of rehabilitation is understood as a broader intervention, i.e., a combination of several repair procedures, which may or may not include strengthening. Retrofitting, on the other hand, does not necessarily imply an intervention on a deteriorated dam, as it may just aim at upgrading the structure (e.g., raising the dam height). In any of these practices, the use of cement-based mortars is a relatively common practice, due to both technical and economic reasons (Corns et al. 1988; ICOLD 2000; Novak et al. 2007).

The current document presents the features that one should consider when selecting a Portland cement-based repair material, as well as some of the most common rehabilitation measures carried out in concrete dams. References to successful operations are also presented.

Repair Materials for Hydraulic Structures

The combination of newly cast concrete with several decades of old hydraulic concrete structures may imply problems, especially with respect to the interactions between the materials with different mechanical properties. Therefore, the selection of repair material is a complex process, which often involves a compromise among its properties (ICOLD 2000; Sandström 2009).

Several authors (Emberson and Mays 1990; Plum 1991; Morgan 1996; Woodson 2009; Galvão et al. 2011) have emphasized the importance of compatibility between substrate and repair materials on the success of a concrete repair. Table 2 summarizes the compatibility recommendations when considering and selecting a repair mortar or concrete, based on the characteristics of the existing concrete (substrate), namely chemical, permeable, and dimensional, as well as structural and mechanical compatibility.

Chemical compatibility is related to the potential risks of the repair material showing adverse effects via the introduction of

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