CONCRETE DAM PERFORMANCE AND REMEDIAL MEASURES

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INTRODUCTION

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Portland cement concrete is inherently durable. Still, some concrete dams may need to be improved because of deficiencies in their design and construction, or as a result of environmental attack. Older dams may suffer from a combination of effects. Common problems include alkali-aggregate reaction, freezing and thawing, leaching, and sulfate attack. Infiltration by aggressive waters may remove essential constituents from the concrete. Soft water moving at a relatively high velocity under pressure may be very detrimental. The extent of deterioration will vary with the composition of the aggregate and that of the cement. Absorptive aggregates may be susceptible to freeze-thaw damage. Where structural cracking has occurred so that water is freely admitted, the effects of leaching and freeze-thaw cycling may be intensified.

The stability of a concrete dam may be jeopardized by various forces and conditions. Overstressing may cause cracks in the dam or in its foundation. As a consequence, resistance to shear on the plane of fracture will be reduced. The performance of an arch dam is highly dependent on the extent of deformation in its abutments under the range of applied loads. Very high concrete tensile stresses may develop if the rock adjustment is excessive. A buttress dam particularly may suffer from overstressing accompanying natural deterioration of its thin structural members.

Cracking is one of the early symptoms of structural adjustment, but in most cases it does not cause serious impairment. Cracks that develop during construction are most likely to be due to temperature variations. After the dam is placed into service, cracking may be induced by loading as well as by thermal expansion or contraction. Although concrete is inherently strong in compression, it is relatively less resistant to shear and tension, which may be caused by differential foundation deformation or dynamic forces induced by earthquake. Because the effects of these phenomena are not entirely predictable, certain precautions conventionally are adopted in the engineering of concrete structures. In addition to the customary controls of mixes and temperatures during construction, rock foundations are carefully shaped to ensure uniform support, and joints are introduced into dams to accommodate displacements. Even with a maximum of attention to such details, concrete dams can be expected to undergo some adjustments attended by cracking. Although such changes normally will be well

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within safe limits, the appearance of cracks must be regarded as an indication of potential deficiency requiring evaluation.

The stability of a gravity dam may be influenced adversely by excessive uplift on its base, on lift joints, and/or on foundation planes. Yet, until well into the twentieth century, uplift was given little attention by designers. The need for drainage was poorly understood. Many gravity dams constructed in those earlier years therefore had only marginal stability. Even where internal and foundation water pressures were considered, and drains were provided, their placement and details were not likely to ensure long-lasting relief. Drains tended to plug, and many systems were inaccessible for maintenance. The advantages of drainage tunnels and galleries were not fully recognized until years later.

Strengthening of a concrete dam may be required to compensate for such oversights or to accommodate greater service demands. Improvement of seepage control often is a first consideration. Stability may be enhanced substantially by cleaning drains or by extending the drainage system. In some cases, seepage may be reduced by sealing the upstream face.

Repairs in some projects have been made by removing defective upstream face concrete, setting steel forms or precast concrete panels to reestablish the original geometry, and filling the space with concrete. The deteriorated upstream faces of multiple-arch dams in some projects have been restored by placing steel-reinforced shotcrete on the surface after thorough chipping to expose sound old concrete.

Increasing use has been made of stressed tendons to reinforce dams and to provide foundation anchorage. In the last 50 years, stressed anchors have been used to strengthen many gravity dams, as well as the concrete buttresses in other dams. Posttensioning of a gravity dam may be an especially suitable remedy where the lift joints were inadequately treated in construction and so are weak in tension and shear. The installation of stressed tendons to enhance stability can be accomplished without reducing water storage. Reinforcement by this method may be attractive where addition of concrete mass would be difficult, or objectionable, as in seismically active areas.

High tensile stresses in the concrete of buttresses have been reduced by installing steel tendons along the upstream edges or at the lateral faces. These are anchored into the foundation and posttensioned, preferably while the reservoir storage is lowered. Tendons have also been effective in stabilizing abutments for several arch dams. They have sometimes been installed in conjunction with concrete beams for this purpose.

At many projects, demands for continuing service may rule against lowering the reservoir to facilitate certain structural modifications. Unloading of the dam is of significant benefit in strengthening measures that entail addition of concrete or buttressing on the downstream side. Even a partial lowering of the water level will substantially increase the effectiveness of the added features.

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OVERSTRESSING OF ARCH DAMS THROUGH SHEAR FORCES

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The Structural Behavior of Arch Dams

The primary structural function of an arch dam is to transfer the water load to the valley slopes by an arching effect. But, except in very special cases, a certain fraction of the water load also will always be transferred to the bottom of the valley by so-called cantilever action. This load transfer cannot take place without inducing important shear forces in the cantilevers, with maximum intensity of these forces at the toe of the dam. An additional share of the water pressure acting on the dam is transferred to the foundation by twisting moments (torsional effect), which also generate increasing shear forces toward the foundations. Unless special measures are taken, shear forces will even be produced in the arch itself, especially at its abutments.

Thus, as a rule, important transverse shear forces will exist all along the foundation surface of any arch dam, with the tendency to decrease toward the central part of the dam and to disappear at the crown and along a certain structurally defined “line of symmetry.” Figure 19-1 shows the

Figure 19-1. Arch dam. Flownet of the shear forces toward the foundation.