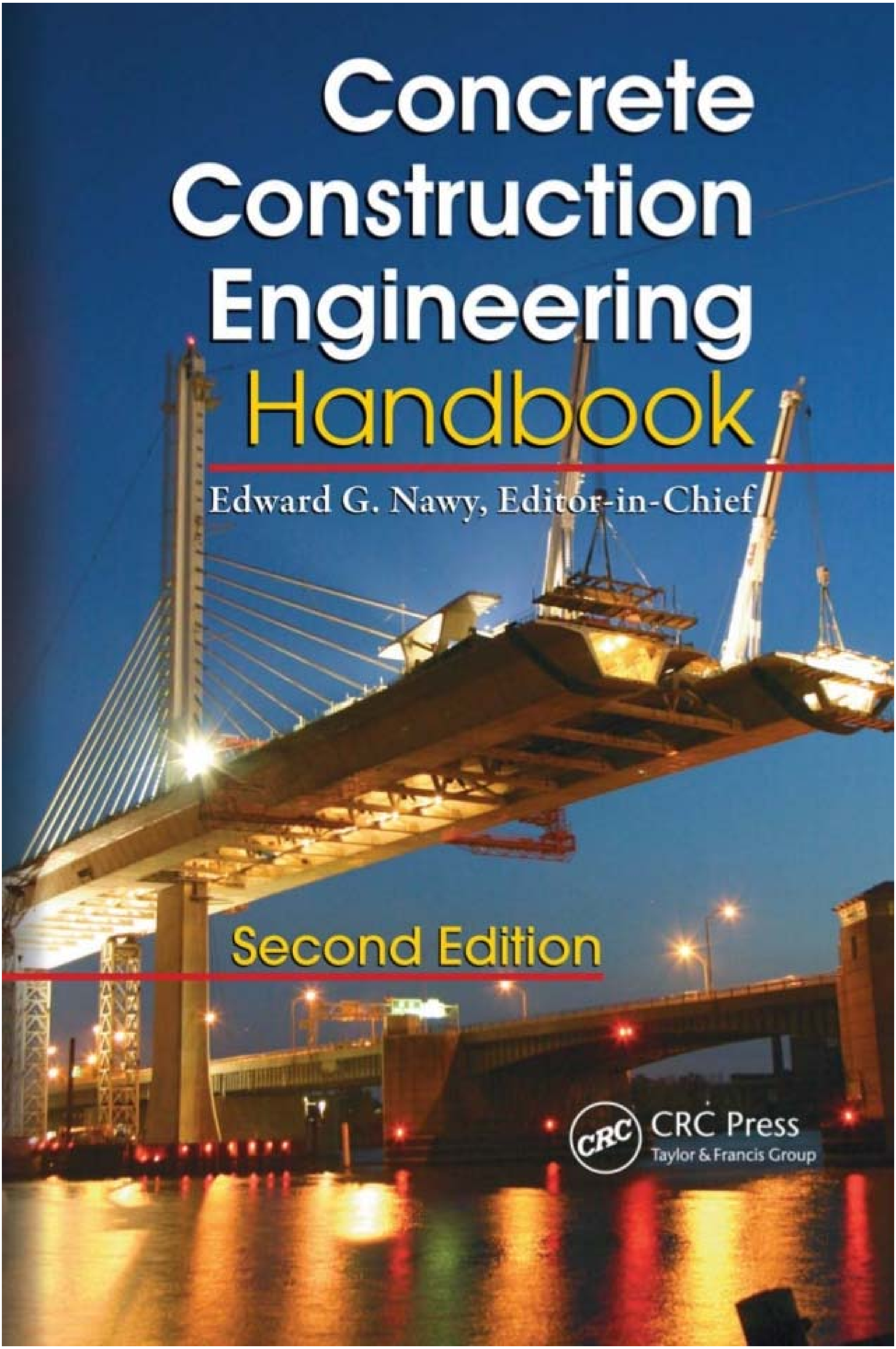
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Roller-Compacted Concrete

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20.1 Introduction

Roller-compacted concrete (RCC) has rapidly become a commonly used material for dams and massive structures. It is also used for overtopping and erosion protection of embankments and for heavy-duty pavements. This chapter concentrates on mass applications of RCC, primarily for dams; however, many of the concepts, from testing to material properties and mix designs, apply to all uses of RCC. In a sense, RCC dams can be thought of as a series of bonded pavements or parking lots stacked on top of each

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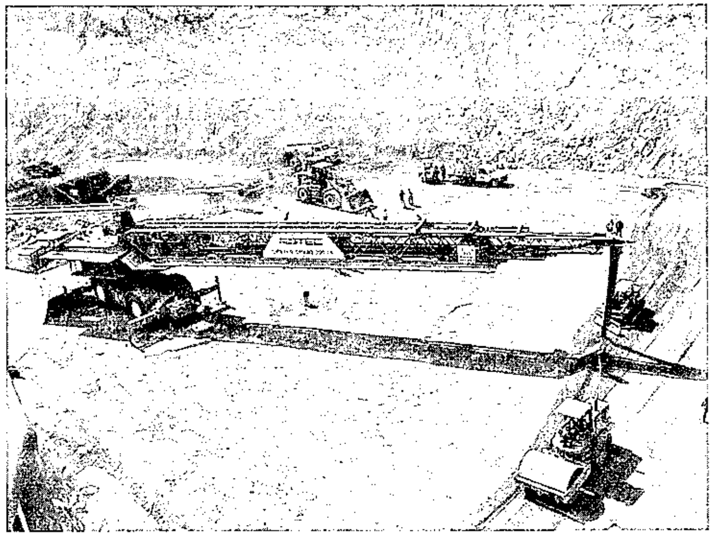

FIGURE 20.1 Placing RCC with 110 lb. of cement and 54 lb of fly ash per cubic yard using a 24-in. conveyor at Rompepicos Dam, Mexico. (Photograph courtesy of Ernest K. Schrader.)

other. This chapter provides an explanation of what RCC is, how it differs from conventional concrete, what its special properties are, and how to use it effectively. The chapter covers specific technical and construction issues, including aggregates and mixture proportioning, laboratory testing, properties, engineering and design, cost, and construction. Emphasis is placed on areas of controversy and significant interest, such as cost savings, mixture proportions, material properties, watertightness, lift-joint quality, and design options.

20.1.1 What Is RCC?

Roller-compacted concrete is concrete, but it is placed by nontraditional methods. It requires a drier or stiffer consistency than conventional concrete. RCC can have a much broader range of material properties than conventionally placed concrete. It can use aggregates not meeting normal requirements, it can be placed at very high production rates, and it can be much less expensive. By definition (ACI Committee 207.5R, 1999), RCC is concrete that has a consistency that allows it to be compacted with a vibratory roller. Usually a 10-ton vibratory roller intended for compaction of asphalt and granular base is used because of its high compactive energy with high-frequency and low-amplitude vibration. RCC is often mixed in a continuous process rather than in batches. It is delivered with dump trucks or conveyors, spread in layers using a bulldozer, and given final compaction with a vibratory roller. Figure 20.1 shows a typical application of mass RCC on a medium-sized dam, using a 24-in. conveyor delivery system. A condensed summary of the RCC process has been described in earlier literature (Schrader, 1988; Schrader and Namikas, 1988). More thorough summaries have also been published (ACI Committee 207.5R, 1999; Hansen and Reinhardt, 1991; ICOLD, 1989; Jansen, 1989; Schrader, 1994, 1995c,d, 2002, 2003a). Freshly mixed uncompacted RCC generally looks like damp gravel that might be used for a road base, although some mixtures that have a wetter consistency look more like a conventional no-slump concrete. Not until the cement has reached a point near final setting or until the hydrated interior is exposed does RCC have the visual appearance of normal concrete. Portland cement is normally the primary cementing medium, although fly ash or natural pozzolan is often used for a major portion of the cementing material. Slag cement has also been used. Low-cement-content mixtures typically use natural nonplastic fines or rock dust as a filler to compensate for the lack of paste that would otherwise exist. At times, the fines have cementing abilities.

20.1.2 History

The rapid worldwide acceptance of RCC dams is a result of need, success, and economics. Materials used occasionally 30 to 40 years ago, in hindsight, could be considered to be RCC. These applications were typically stabilized gravel fills, and the material was not viewed as an engineered concrete. In the 1960s, a high-production, no-slump mixture that could be spread with bulldozers was used at Alpe Gere Dam in Italy (Gentile, 1964) and at Manicougan I in Canada (Wallingford, 1970). A similar process was used as late as the 1980s at Burdekin Falls Dam in Australia. These mixtures were almost RCC, but they were consolidated with groups of large internal vibrators mounted on backhoes or bulldozers, a procedure that is currently used at times with conventional low-slump mass concrete—for example, at the Tekeze Arch Dam in Ethiopia.

During the 1970s, a number of organizations were involved with trials, laboratory evaluations, and the development of various philosophies concerning mass RCC. A number of RCC applications for portions of dams and spillways, for temporary structures, and for noncritical uses were completed during this first decade of significant RCC development, including the placement of more than 1 million cubic yards of RCC at Tarbela Dam. In 1974, a preliminary design with extensive laboratory testing was completed by the U.S. Army Corps of Engineers for the Zintel Canyon Dam. This would have been the world's first RCC dam, but because of funding issues the dam was not actually constructed until 1992.

The work with RCC in the 1970s formed the basis for RCC dams as they began to appear in the 1980s. Growth and acceptance of this new process was dramatic. In 1983, only one major all-RCC dam existed in the world (Willow Creek in Colorado) (Schrader 1982a,b). About the same time, Shimijagawa Dam, a rolled-concrete dam (RCD) was completed in Japan. RCDs typically use RCC for the interior portions. By 1996, just 13 years after completion of the first all-RCC dam, about 200 large RCC dams worldwide were completed, under construction, or under design. There are now too many to keep track of, with many hundreds of projects being documented. In the United States alone, about 300 documented uses of RCC in dams can be found, including 46 dams higher than 50 feet, more than 30 dams lower than 50 feet, 126 uses of RCC to allow overtopping of embankment dams, more than 10 uses of RCC for added support of existing concrete dams, several for raising the height of existing dams, and several uses for earth-dam rehabilitation applications, among the many miscellaneous uses.

Although the United States initially had the greatest number of RCC dams, they are now more prevalent in countries such as China, Spain, and Brazil, and their popularity is increasing in Vietnam, India, and elsewhere in Asia and Southeast Asia. RCC dams can be found on every continent except Antarctica. RCC dams are in use, under design, or in the planning stages in countries that have climates ranging from arctic to tropical and are at elevations ranging from sea level to very high mountain regions. Figure 20.2 through Figure 20.9 show examples of completed RCC dams of various mixes, sizes, and locations.

Rolled-concrete dams are now being used extensively in Japan, where over 30 projects have been completed, are under construction, or are in various stages of planning and design; however, RCD has not become popular outside of Japan. The process uses a relatively low-cement-content RCC for the interior portion of the dam, but typically encases the entire mass of RCC with at least 10 ft of conventional concrete. This includes the upstream and downstream faces, the foundation, and the upper portion of the dam, although the current trend seems to use more RCC and less conventional concrete. Monolith joint spacings are typically the same as those used for conventional concrete dams. The result is a very attractive dam that looks and behaves like a traditional concrete dam, but the RCD procedure tends to compromise the substantial cost savings and reduction in schedules possible with dams that are almost entirely RCC. The trend in the United States has moved from using RCC primarily for new dams to using it more for rehabilitation and support or the buttressing of existing dams, for raising the height of existing dams, and for providing emergency spillway capacity over existing embankment dams. This trend is expected to develop in other countries as they begin to realize the benefits and additional uses of RCC. Figure 20.10 shows the use of RCC to provide a buttress and an overtopping spillway at the Tongue River embankment dam in Montana.

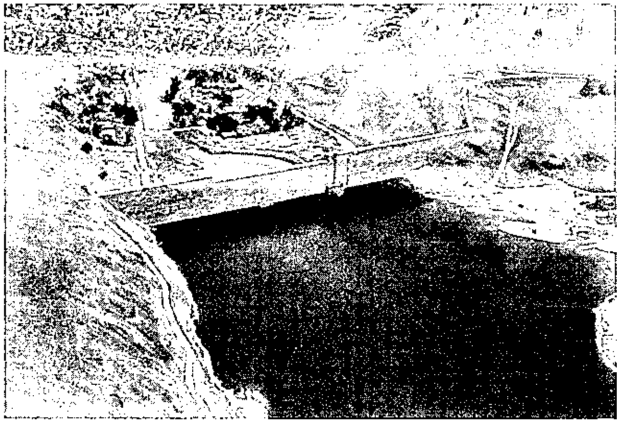

FIGURE 20.2 Willow Creek Dam in Colorado, which was the world's first major all RCC dam and used mostly 80 lb of cement and 32 lb of ash per cubic yard. (Photograph courtesy of Ernest K. Schrader.)

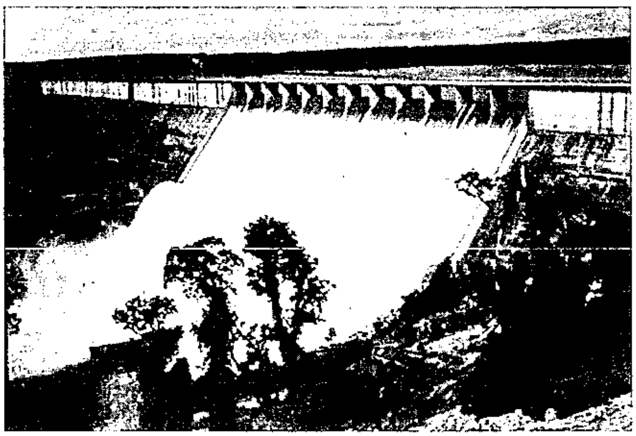

FIGURE 20.3 Urugua-I Dam in Argentina, which used 105 lb of cement per cubic yard (no ash). (Photograph courtesy of Ernest K. Schrader.)

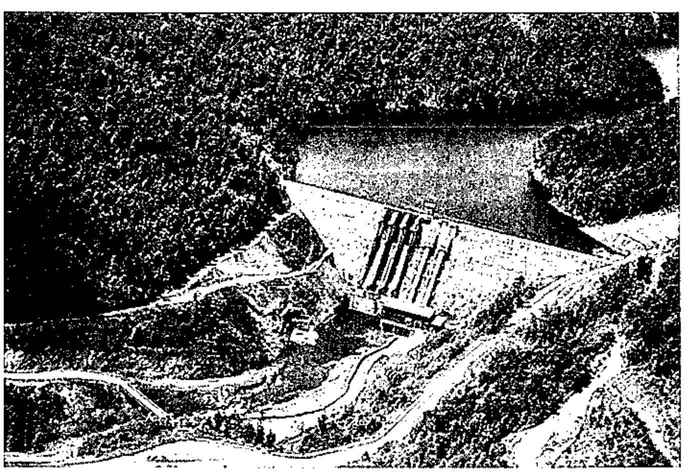

FIGURE 20.4 Balambano Dam in Indonesia, which used 121 lb of cement and 81 lb of fly ash per cubic yard. (Photograph courtesy of Ernest K. Schrader.)

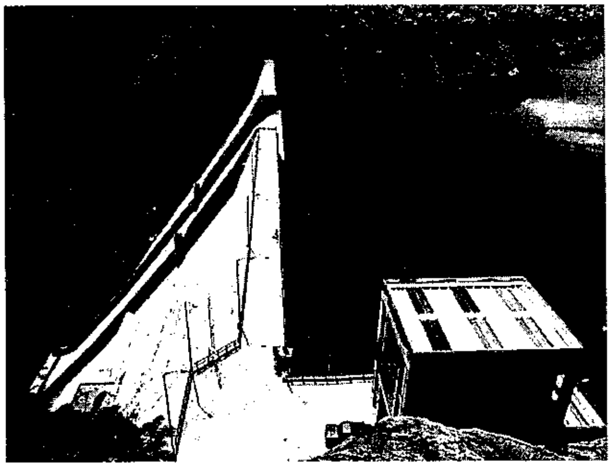

FIGURE 20.5 Miel I Dam in Colombia, which is 620 ft high and used low to medium cement content mixes and no ash. (Photograph courtesy of Ingetec S.A., Colombia.)

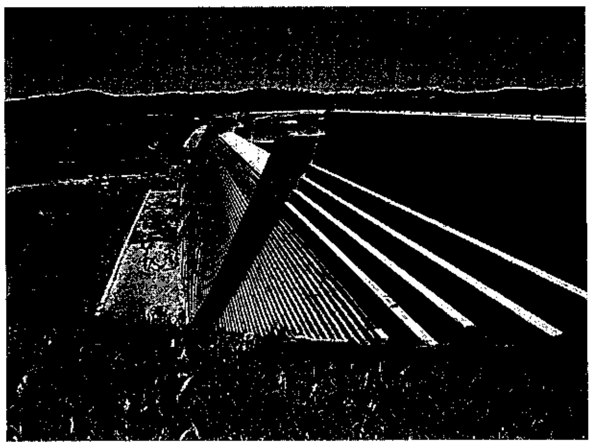

FIGURE 20.6 Burnett River (Paradise) Dam in Australia, which used 106 lb of cement per cubic yard (no ash). (Photograph courtesy of Ernest K. Schrader.)

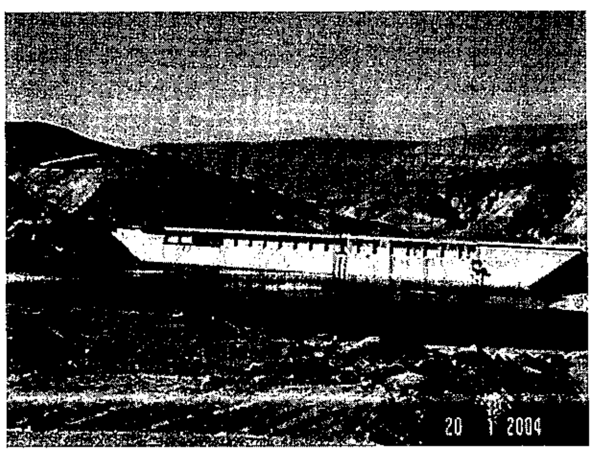

FIGURE 20.7 Mujib Dam in Jordan, which primarily used 143 lb of cement per cubic yard (no ash). (Photograph courtesy of Lahmeyer International, Bad Vilbel, Germany.)

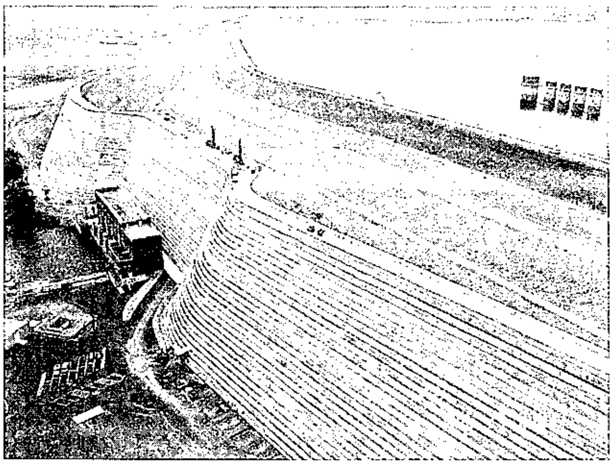

FIGURE 20.8 Saluda Dam in South Carolina, which was built downstream of an existing unstable embankment dam using 150 lb of cement and 150 lb of dumped waste ash per cubic yard. (Photograph courtesy Paul C. Rizzo Associates; Monroeville, PA.)

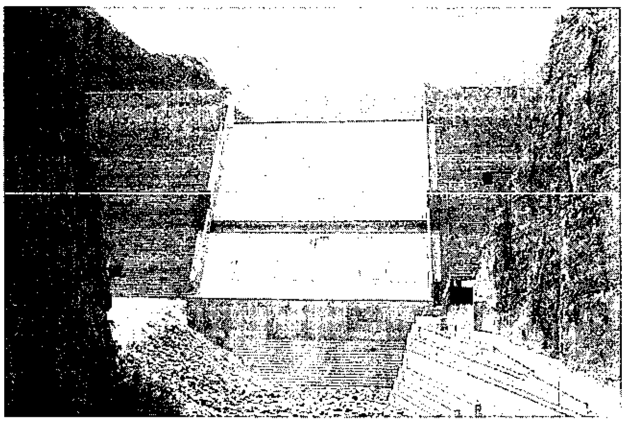

FIGURE 20.9 Rompepicos Dam in Mexico, which is 350 feet high; mostly used 73 lb of cement and 54 lb of waste ash per cubic yard. (Photograph courtesy of Ernest K. Schrader.)

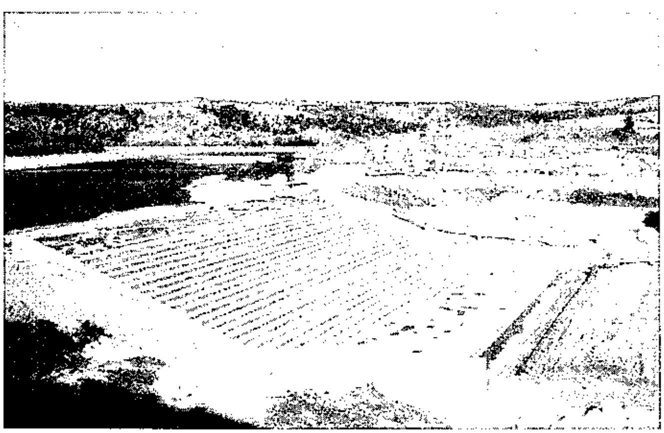

FIGURE 20.10 RCC used to provide a buttress and overtopping spillway for the Tongue River embankment dam in Montana. The mix primarily used 150 lb of cement (no ash) with surface layers of the stilling basin having higher cement content.

As with conventional concrete, there is no known limit to the size or height of dams that can be designed and constructed with RCC. Currently, dams on the order of 300 ft high are common, and dams about 600 ft high are not unusual, such as the 620-ft Miel I dam in Colombia. Very large dams such as Longtan in China and Gibe III in Ethiopia are beginning to emerge. Dams up to about 900 ft high, with nearly 20 million cubic yards of RCC are also being designed, such as Diamer Basha in Pakistan. The performance of RCC dams has been very good, although like other dams some projects have had issues with regard to cracking and seepage (Schrader, 1988, 1994, 1995a,c,d, 2002, 2003a; Schrader and Namikas, 1988). These two specific issues are discussed later in more detail.

20.2 Advantages and Disadvantages

20.2.1 General

The list of RCC dam advantages is extensive, but some disadvantages should be recognized. Some of the potential advantages can only be realized with certain types of RCC mixtures, structural designs, production methods, weather, or other conditions. Likewise, some disadvantages only apply to certain conditions and types of mixtures. One condition that remains constant with RCC is that each job must be thoroughly evaluated on its own. What is advantageous for one project with a given set of conditions may not be advantageous for a different project, and what is a problem at one location may actually be a benefit at another location. No single design, mixture, or construction method is ideal for all projects. Although it is almost routine for efficiently designed RCC dams to be the least costly alternative when compared to other types of dams, in some circumstances RCC may be more costly. A situation in which RCC may not be appropriate is when aggregate material is not reasonably available but an abundance of good material is available for impervious fill. When a large spillway capacity is necessary, RCC dams usually are the most economical because the spillway can be placed over the dam, and the non-overflow portion of the dam can be allowed to overtop in an emergency. Fill and embankment dams typically require a separate, very expensive spillway excavated into an abutment and, because they cannot be allowed to overtop, they usually have added height to ensure that overtopping is avoided.

20.2.2 Cost

Typical reasons for using RCC are the reduced cost and time it offers. Savings can be dramatic, sometimes in excess of 50%; however, in reality, some projects lacking the proper planning, equipment, and supervision have not saved any time, and the potential cost savings have been lost. Some projects have experienced added costs because of design decisions by the engineer or owner that resulted in expensive or time-consuming options—for example, architectural concrete, nonessential extra nonessential galleries, excess conventional facing concrete, elaborate spillways added to the face of the dam after finishing the RCC, and arbitrary decisions to use imported or excessive cementitious materials and expensive aggregates when they really were not necessary. Each project must be evaluated on its own. A trade-off in appearance and other characteristics that may be associated with high costs must be acceptable to the owner and compatible with technical requirements.

It is difficult to obtain final actual cost data for RCC dams, although bid price data for various portions of the RCC are abundant, and several reasonable summaries of approximate overall costs are available in various references (Forbes, 1988; Hansen and Reinhardt, 1991; Schrader, 1988, 1995c,d; Schrader and Namikas, 1988). Apparent discrepancies in costs reported in publications and in costs discussed at various meetings exist for two primary reasons: First, the work and materials included in the costs can be very inclusive (e.g., mobilization, joints, engineering, facings, diversion, spillway, forming, galleries, drains, foundation preparation), or the costs may include only the very basic costs of RCC production (aggregate, cement, mixing, and placing). Second, costs are sometimes based on unit bid prices, which can be unbalanced and not the true prices and do not include subsequent added costs for claims, litigation, time extensions, modifications, and overruns.