RESEARCH AND EXPERIMENTS

MATERIALS FOR ROLLER COMPACTED CONCRETE USED IN MODERN DAM CONSTRUCTION

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An International Symposium "Roller Compacted Concrete Dams" was held in Santander, Spain, in October 1995. This article gives an review and analysis of the proceedings of this symposium pertaining to the theme "Materials." The papers on this theme were distributed in the following way according to countries: Brazil – 7, Spain – 4, China – 2, Russia – 2, France – 2, and one paper each from Iran, Canada, Columbia, USA, and Japan. The general reporter on the theme was J. Diez-Gascon (Spain) [1], who devoted great attention to the history of the occurrence and development of roller compacted concrete technology and, in particular, its key components such as a reduction of the height of the block, even to one-layer blocks; the use of pozzolana materials and fine particles as part of the aggregates (less than 0.075 mm) for replacing part of the cement; use of a technology of constructing concrete masses similar to the technology of placing earth fill; and an increased rate of constructing the concrete masonry. Each of these points to one degree or an other was approved over the course of almost the entire 100-year history of constructing concrete dams, but only a decisive change to their combined use and intercoordination made it possible as a result to create a fundamentally new roller compacted concrete (RCC) technology in dam construction as occurred at the end of the 1970s and start of the 1980s. It is necessary to emphasize also the unquestionable effect on this process of the successful use of RCC in road construction and availability of the appropriate road-construction equipment, which proved itself during construction of loose-fill dams. The stimulus of the process of searching for a fundamentally new technology of placing concrete was the problem of regulating the temperature regime and crack resistance of concrete dams which became especially acute in the 1950-60s, when further construction of concrete dams became economically unjustified precisely because of the high cost of temperature control measures.

A tendency toward the use of materials with a high initial strength and, consequently, with a high heat release of the cement dominated at the early stage of concrete dam construction. Concrete with a casting consistency of the mix was placed as thin horizontal layers between two walls of stone masonry without contraction joints. A slow rate of placing the concrete together with continuous watering of the surface of the layer is a decisive factor in dissipating the heat being released and, consequently, reducing cracking in dams. An example of such technology is the Basolt dam (Great Britain, 1910), which was constructed in 70-cm thick layers without contraction joints and with the use of surface watering.

Already at this early stage it was found unprofitable to construct large concrete dams with the use of ordinary portland cement, since owing to considerable heat release it was necessary to control cracking and as a consequence of this the rate of concreting slowed. To solve this problem, cutting the concrete masses by contraction joints into sections and blocks began to be used in the 1920-1930s. Furthermore, at that time it was suggest to use cements with a low heat release by replacing a part of the clinker with pozzolana additives and, in particular, fly ash, which began to be used for this purpose in 1946.

In 1951 a report was given at the IV International Congress on Large Dams (ICOLD) concerning the concrete of the Bort dam, the binding materials of which contained 30% portland cement, 68.5% granulated slag, and 1.5% gypsum. A concrete mix with 107 kg/m³ portland cement and 21 kg/m³ surzha (kilned clay with pozzolana properties) was used in the Mettur dam (India). In 1958 the following advantages of using aluminum silicate fly ash (class F) were formulated at the VI ICOLD Congress: strength at 28 days lower and the same or higher at age 90 days and more, heat release about 50-60% less, better workability of the concrete mix, water impermeability greater, shrinkage less. However, along with these advantages...
a lower frost resistance of concrete containing fly ash was indicated. To control this it was suggested to use air-entraining additives. At that same time the use of so-called zonal placement of concrete began, when the outer and inner zones of the dam are made from concrete of different compositions and grades with respect to strength, impermeability, and frost resistance.

The issue about using fine fractions of aggregate passing through a No. 200 ASTM (0.075 mm) screen was discussed at several ICOLD congresses (New Delhi, 1951; Paris, 1955; New York, 1958; Rome, 1961; Edinburgh, 1964) and then was forgotten up to the XV ICOLD Congress (Lausanne, 1985). The suggestion on excluding all fines passing through a No. 200 ASTM screen and sometimes also a No. 100 ASTM screen was defended at the congress in Paris in 1955, which was substantiated by the increase of impermeability, longevity, and strength of the concrete as well as by the decrease of water requirement. At the next ICOLD congresses these approaches were supported by some and refuted by others, although it is clear that all these opinion and the entire issue as a whole depend on the character and purpose of the fine fractions of aggregates either as a microfiller of natural or artificial origin or as a pozzolana material — freshly ground rock flour obtained during dry crushing of rocks. The most active from the viewpoint of the ability to bind calcium hydroxide (Ca(OH)₂) precipitating during hydration of portland cement are siliceous sedimentary rocks such as diatomite and tripoli, which contain the maximum amount of amorphous silica. Ground quartz containing the minimum amount of amorphous silica is the least active additive.

Quartz flour (dust) was used for the first time in domestic practice as a pozzolana additive to cement on the construction of the Uglich and Rybinsk hydroelectric stations. A so-called three-component cement, obtained by combined grinding of portland cement clinker, granulated blast-furnace slag, and quartz sand, was developed. The successful 50-year operation of these hydrostations attests to the competence of using ground quartz as a binder component for hydrotechnical concrete.

During construction in 1989-1992 of the 110-m high RCC Capanda dam (Angola), aggregates, in connection with the absence of sand in the river floodplain at the construction site, were obtained by crushing rocks — sandstones, for which a quarry and crushing and grading facilities were organized. The selection of the quarry was decided jointly with the selection of the type of hydrostation powerhouse. There were two powerhouse variants — underground and open — approximately equal in construction cost. But the open variant of the powerhouse made it possible to excavate more than 1 million m³ of rock for preparing aggregates, which permitted giving preference to this variant. When using rock flour on the construction of the Capanda dam an important role was given to "freshness," i.e., preservation of surface activity of particles of the dry grind.

Problems of the use of rock flour were the subject of studies presented in many papers at the symposium in Santander [3, 4, 6, 7]. In Brazilian experience considerable attention is devoted to the use of 100% crushed basaltic rock, as positive factors of using basaltic flour studies show an increase of impermeability and strength and decrease of possible expansion of concrete as a result of alkali–aggregate reaction.

The new period of developing the technology of constructing concrete dams with the gradual introduction of roller compacted concrete can be reckoned from the start of the 1970s to the present time [1]. The idea to combine the advantages of the concrete with the traditional technology of constructing rockfill structures (with transporting the fill material by dump trucks and compacting by rollers) arose somewhat earlier. The first use of RCC in hydraulic engineering occurred in 1960-1961 for the core of the Shihmen dam on Taiwan. The RCC was prepared at the same concrete plant as ordinary concrete and had a continuous particle-size distribution and maximum aggregate size of 76 mm. The content of binders was 107 kg/m³. The concrete mix was transported by dump trucks, leveled in 30-cm layers by bulldozers, and compacted by the passing dump trucks and bulldozers.

The Alpe Gera dam with a height of 174 m, crest length 528 m, and volume of concrete 1.7 million m³ was constructed in Italy in 1958-1964. The dam was constructed by the long-block technology with sectional cutting every 12 and 17 m, the concrete was placed as one-layer blocks 0.7-m³ thick. The concrete mix was compacted by suspended packet vibrators installed on bulldozers. The joints between sections were cut mechanically by a special machine after placing each layer. Impermeability of the dam on the upstream side was provided by a continuous metal facing 3-mm thick. Concrete with a cement content of 300 kg/m³ was placed in the lower part of the dam. In the remaining part of the dam the cement content was 115 kg/m³, except the downstream face, where it was 250 kg/m³.

An analogous method of placing concrete was used on the construction of another Italian dam — Quaira Della Minera, where the positive experience of constructing the Alpe Gera dam was developed creatively, thanks to which it was possible to do away with the metal facing, in addition, the dam was cut into 25 sections each 25-m wide.