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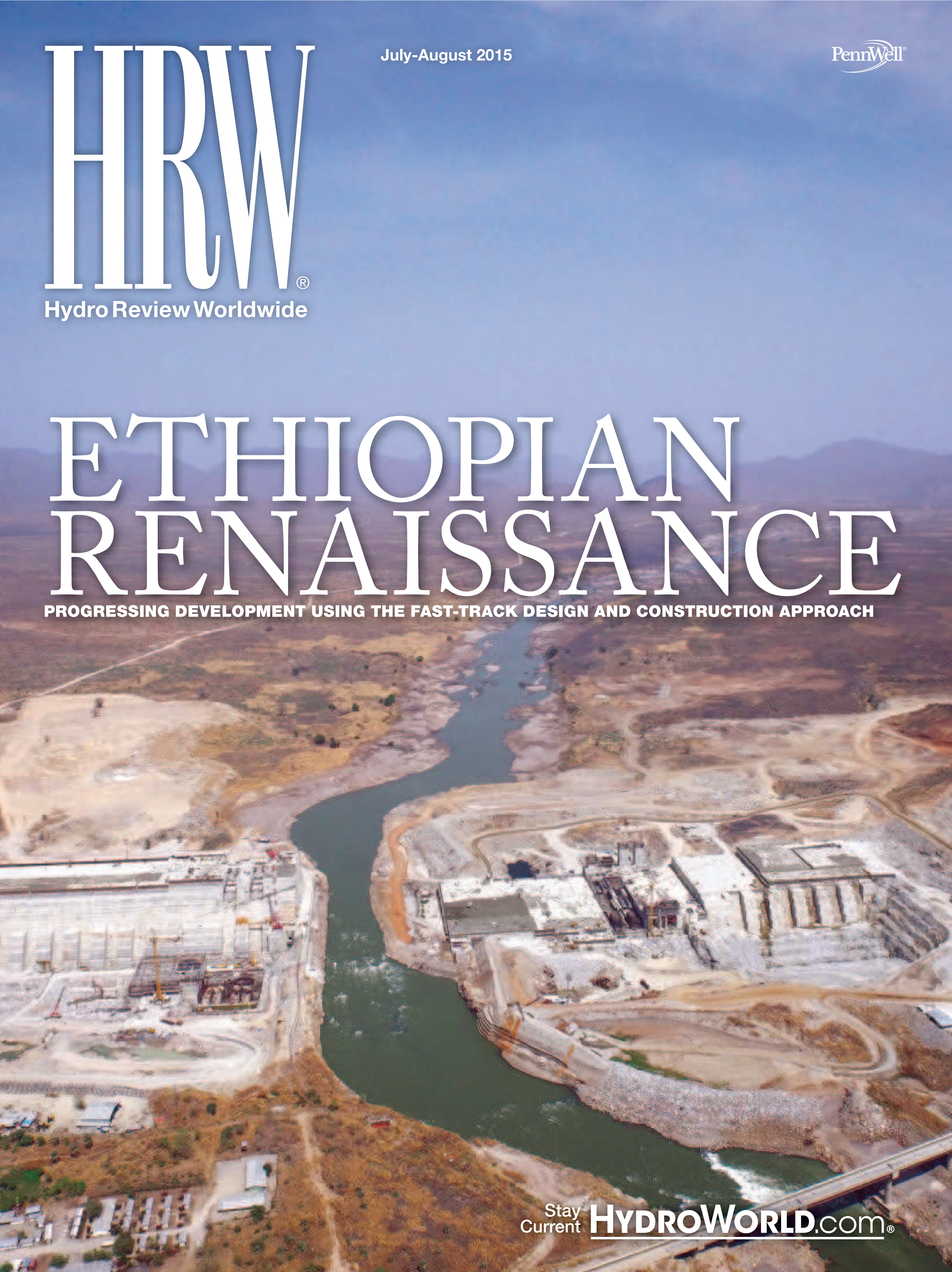

ETHIOPIAN RENAISSANCE

PROGRESSING DEVELOPMENT USING THE FAST-TRACK DESIGN AND CONSTRUCTION APPROACH

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Fast Track Approach to Design and Construction at Grand Ethiopian Renaissance Dam

Being constructed on the Nile River, Grand Ethiopian Renaissance Dam will feature the largest roller compacted concrete volume dam in the world at 10.2 Mm^3. Its reservoir of 70 km^3 will be comparable to those of Bennett (Canada) and Kraskoyarsk (Russia). This article reveals the approach allows a radical reduction – at least 50% – of total project implementation time and full control of project cost.

By Bruno Ferraro, Alberto Bezzi, Claudio Rossini and Paolo Mastrofini

The Grand Ethiopian Renaissance Dam (GERD) and hydroelectric project is located 700 km northeast of the capital city Addis Abeba, in the Benishangul–Gumaz region of Ethiopia, along the Blue Nile River. When it is completed, with its concrete volume of 10.2 million m^3, GERD will feature the largest dam in Africa.

State-owned Ethiopian Electric Power (EEP) hired Salini-Impregilo SpA as the Engineering, Procurement and Construction (EPC) Contractor. Studio Ing. G. Pietrangeli, based out of Italy, is the civil works designer.

GERD's water retaining structures include the following: the Main Dam, a roller compacted concrete (RCC) structure that is 1,800 m long and 175 m high, and a Saddle Dam, a concrete faced rock fill (CFRD) structure, 5,000 m long and 60 m high, with embankment volume of 17 million m^3. See Figure 1 for more details.

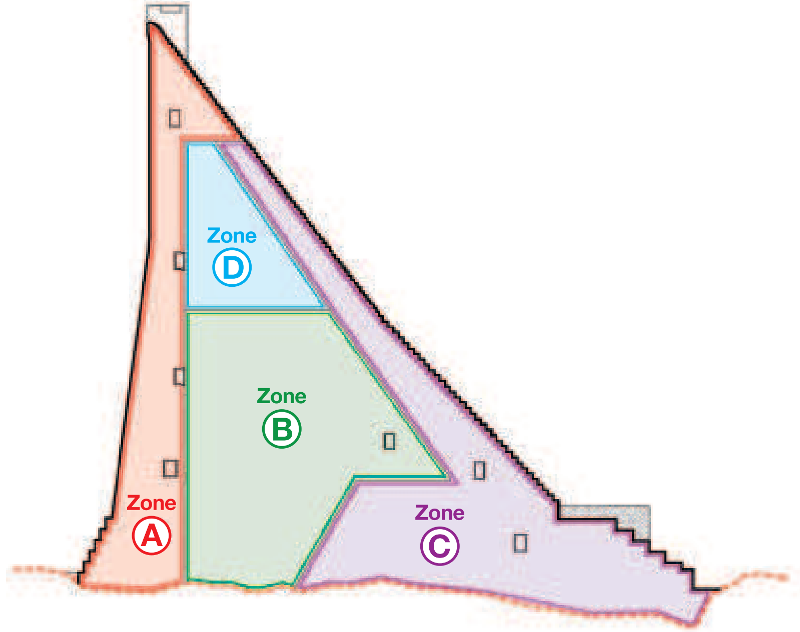
Two powerhouses located at the toe of the Main Dam will house 16 Francis units at 375 MW each, totaling 6,000 MW in capacity, for an expected annual generation of 15 TWh. The Project also includes a gated spillway, two non-gated emergency spillways, one 500 kV substation and switchyard, a 240 km transmission line and 120 km of access roads.

In the 1960s, the United States Department of Interior's Bureau of Reclamation conceived the water resources development plan for the Upper Blue Nile River in Ethiopia, which featured a dam site named Border. Since then, the plans and studies remained as they were created until 2010, when Salini–Impregilo and Studio Pietrangeli resumed studies and site investigations.

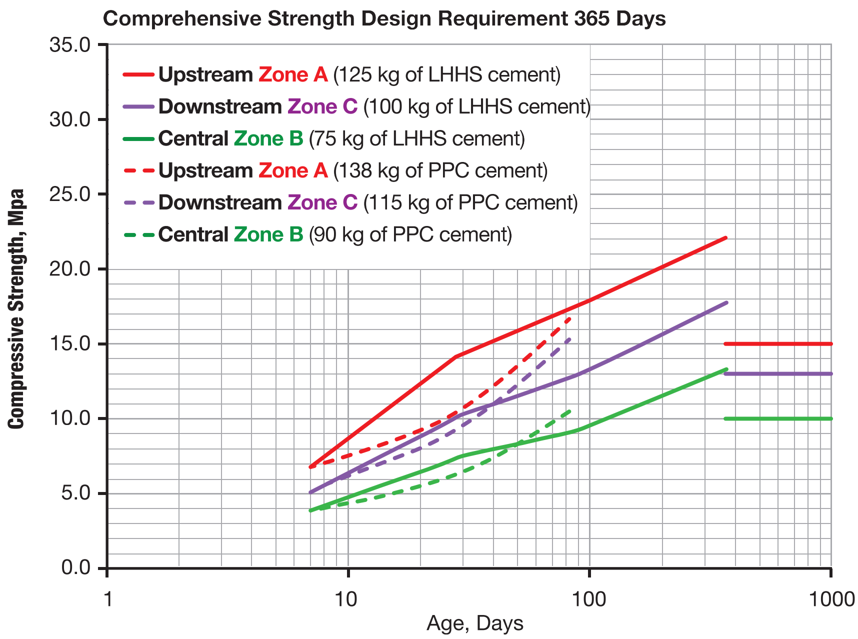
GERD is the first storage dam being built on the mainstream Blue Nile, upstream of Roseires Reservoir (located in Sudan), very close to the USBR's border site.

In 2011, construction was in full swing. GERD represents the most daring challenge, in terms of "fast-track project," being undertaken by Salini-Impregilo.

Figure 1 — RCC Average Compressive Strength (85th Percentile Guaranteed)



Note: Zone D has design specifications similar to or less stringent than Zone B.
Construction has not yet reached Zone D, whose detailed composition is under optimization.



Fast-track approach

The Fast Track Implementation method is based on the concurrent development of all relevant phases of a large hydroelectric project, investigations, studies, design and construction. Successful application in three Ethiopian projects, 420-MW Gibe II, 460-MW Beles Multipurpose and 1,870-MW Gibe III, reveals the approach allows a radical reduction — at least 50% — of total project implementation time and full control of project cost.

The main challenges for schedule control of GERD are the size of the related works, combined with its remote location. Neither of these two challenges is unique in the water infrastructure industry, but its combination is acute at GERD. The EPC is facing the task through a threefold approach: a two level design, continuous investigations during construction and adaptive management of construction methods.

Level 1 design represents the final definition of a section of works; it contains all the elements required to understand the technical solution, including studies and calculations. Level 2 represents the detailed construction/manufacturing design, e.g. construction drawings, detailed technical specifications, method statements, commissioning and testing procedures, etc. Experience has taught that the most effective measure for smooth construction progress is the adoption of reliable design and practicable construction solutions; in other words, solutions that are considered "as simple as possible, but not simpler than required."

EPC has extensive in-house capacity for site investigation and testing, and routinely applies such capacity, during construction, to supplement, integrate and update information provided by the initial campaign. Large availability of earthmoving and drilling equipment allows prompt access and execution of boreholes and in-situ tests over the entire project area. This, together with the availability of state-of-the-art and fully equipped laboratories at the site, enables quick and reliable characterization of foundation conditions of structures and construction materials available in potential quarries and borrow areas. The above allows preventive definition and management of geotechnical and construction risks.

Technological innovation

Adoption of the "as simple as possible" criterion did not hinder technological innovation, e.g. for topographic and geological surveys. With a zoom-in approach, different technologies are utilized in design investigation: satellites (200 km), airborne laser scanning (2 km), drone-aided photogrammetry (200 m) and "giraffe technique" (10 m).

The drones, equipped with a digital 16 Megapixel camera, internal GPS and various sensors that include ground proximity, temperature, altitude, wind velocity and direction, were employed to prepare detailed geo-referenced ortho-photos, orthophotomosaics, Digital Terrain Models (DTM) and contour lines. Flight plans were preliminarily prepared taking into account the morphology of the sites and the extension of the area to be surveyed and the required survey accuracy; these were then uploaded into the drone controller.

During the survey, which is preceded by the selection of suitable starting and landing points as well as landing corridors, the drones are radio monitored up to a distance of about 3 km and work progress is displayed in real-time on a laptop. The self-piloting software allows the drone to adjust and adapt the flight plan in real time following the actual conditions of wind, battery level, presence of unforeseen obstacles and other parameters, thus reducing to a minimum the need for human intervention.

The geotechnical assessment of dam foundation has primary importance in the design process and during the construction phase; it is a prerequisite of the foundation treatment and supports post-construction monitoring. In order to speed up foundation mapping and to improve accuracy of the information acquired, an innovative technique has recently been tested during the foundation preparation works.

This image, taken on site in January 2015, shows the massive scope of the Grand Ethiopian Renaissance project's Main Dam, photographed from the right abutment.

Large areas of the foundation were photographed using a camera attached to a telescopic pole, nicknamed, Giraffe. The camera, remotely controlled using a tablet with a Wi-Fi connection, takes pictures of the foundation surface from a maximum height of 10 m, assuring the proper framing and overlap necessary for the photogrammetry processing. Ground control points, about 10 every 400 m^2, are topographically surveyed. Pictures are then processed by photogrammetric technique, obtaining a georeferenced three-dimensional model of the foundation surface that contains all the information on topography, main lithological limits and rock defects (i.e., length and orientation of discontinuities).

This procedure is faster and more accurate than a traditional geological/geotechnical survey. It has the added advantage of having geo-referenced images and a DTM that allow the survey to be documented for future reference/verification. The procedure also carries out specific measurements on the digital model itself. The speed of execution makes this method particularly suitable for large areas and situations in which concrete is being poured very shortly after mapping: a useful feature for the fast-track approach.

Maximum use of national resources

Maximizing the use of national resources for project implementation is an essential element for harvesting both direct and indirect economic impacts of the large investment associated with GERD. Direct economic impacts are those deriving from the construction of the project, such as electricity generation, employment, and other services provided by the structure. Indirect and induced impacts are those that stem from the linkages between the direct consequences of a project and

Drones were deployed equipped with a camera and various sensors to prepare detailed geo-referenced ortho photos, digital terrain models, contour lines and additional data.

the rest of the economy. Among them are impacts due to changes in output and input use in sectors other than those affected directly by the project, or changes in relative prices, employment and factory wages. Maximum use of national resources enhances indirect economic benefits.

At the same time, maximum use of national resources entails management issues that need to be addressed. Typical examples include: difficulty in securing adequate staffing due to the remoteness of the GERD site, sufficient and reliable provision of cement to meet the extremely high demand associated with the required RCC placement rates. Ethiopian cements proved initially unsuitable for RCC. The issue was solved with extensive laboratory and field tests that finally lead to the definition of suitable RCC mixes employing improved locally produced cements.

This experience, obtained in co-operation with the major Ethiopian cement producers, contributed to improve the cement manufacturing process and the quality of cement available on the local market resulting in beneficial effects for the overall Ethiopian economy.

River Diversion

The original river diversion scheme featured an initial phase when the river was flowing in its natural gorge while diversion culverts, together with the right and left portions of the Main Dam, were to be constructed on both banks. Upon completion of the diversion culverts, the river was to be diverted in the culverts, during one dry season (November-May).

The river diversion scheme changed with the introduction of 2.5 m3 rock excavation for an additional channel on the right bank, including appurtenant cofferdams and training walls.

River diversion featured construction of the central section of the Main Dam in the river gorge, which was to provide a temporary sill where the river could overflow during the wet season. For the success of this scheme, it was essential to complete the construction of the central section of the Main Dam during one dry season.

However, when foundation excavation revealed a much deeper river gorge and extensive sediments in the riverbed, the scheme had to be radically revised. The river diversion scheme changed with the introduction of 2.5 Mm^3 of rock excavation for an additional channel on the right bank, including appurtenant cofferdams and training walls.

The rapid adaptation of plans permitted limited impact to the river diversion schedule, a key milestone of any dam construction plan.

Hydrological Safety

With its 60-km^3 active capacity, the GERD reservoir will play an important role in attenuating large flood peaks with remarkable benefits for the hydrological safety of downstream countries.

A system of three spillways safeguards the project against the Probable Maximum Flood 30,200 m^3/s peak discharge. The different typology and location of the spillways introduces redundancy in the system, a key ingredient to guarantee the highest standard of hydrological safety.

The main service spillway of the Project is a gated structure, located on a saddle area to the immediate left of the main dam; its discharge capacity, at maximum reservoir level is about 15,000 m^3/s. A second spillway is located on the overflow section of the main dam. It is a free-crest type and can discharge up to 2,800 m^3/s.

The third spillway is located on the right abutment of the saddle dam; the excavation required for its realization is used for embankment construction. The saddle dam spillway is a side channel un-gated waterway. Its sill is set 2 m higher than the full storage level (FSL = 640 m asl). It is designated as an emergency spillway because it will come into operation when the combined discharge of the other two spillways equals the 1,000-year floods.

The peak discharge capacity is about 1500 m^3/s. The redundancy of the spillway system assure the capacity of discharging the PMF even in case of malfunctioning of one gate (N1-rule) and the 10,000 y flood in case of malfunctioning of two gates (N2- rule).

RCC Placement Rates

Extensive time has been devoted to the study and optimization of each RCC ingredient and of the most appropriate RCC mixes for different areas of the dam. RCC uses three classes of aggregates (crushed rock) from gneiss-granite quarry: 8mm (sand); 8-20 mm (grain size) and 20-50 mm (pea size).

Two types of cement are used:

CEM I 42,5 LHHS (Portland Low Heat of Hydration and High Sulfate resistance), and

CEM IV-A 32,5 R (Pozzolanic cement).

Cement contents vary, through the cross section of the dam. Equivalent values in the case of pozzolanic cement are: 138/90/100 kg/m3, in zone A, B and C respectively.

Comprehensive testing on plasticizer/retarder admixtures allowed such setting times to be attained to maintain warm joint conditions up to 12-16 hours after RCC spreading. Admixture dosages vary, at GERD, between 1.0% and 1.75% of cement weight. Achieving warm joint conditions guarantees design cohesion values for the lifts, while minimizing joint treatment time.

Tests during RCC production included: VeBe time, air content, fresh density, and in situ density. Quality control of placed RCC involved core drilling after three months from laying and include: density, compressive strength, direct tensile strength (on parent RCC and joints), joints cohesion, friction angle and permeability.

Large-scale RCC production started in December 2013, and monthly placement rates progressively increased from 75,000 to 235,000 m3 in December 2014, with peaks of 23,200 m3/day.

Production plants consist of a primary 2,000 t/hr crushing station and an auxiliary one of 400 t/hr. Coarse aggregates pass through an air pre-cooler plant which, together with an ice plant, yield RCC at 17 °C. Two batching plants feature eight mixers for a total capacity of 1,120 m^3/hour; delivery of mixes takes place by conveyors belts and 32/40 t dumpers.

RCC production process is continuously optimized. Since January 2015, the overall placement area has been about 50,000 m^2, subdivided in 6 working zones, each one of about 9,000 m^2. Eight RCC lifts, each one 0.4m thick, are placed in each zone before production moves to another zone. This translates in one cold joint and seven warm ones. The cold joint is Type 2 (above 72 hours after compaction) and coincides with the lowest/starting one on which construction returns after completing the eight lifts of the other five zones. This method allows mitigation of temperature rise by heat dissipation from the lift surface during the stop period, as well as maximizes the number of warm joints. Reduced dosage of admixture is used for the eighth lift, which allows anticipating the necessary treatment. RCC ramps (using sloping layer method with 6% gradient) ensure satisfactory connection between different areas of the dam.

The adoption of a mixed system, including horizontal layers and sloping layers ramps, well reflects the “fast track” system and its added benefit of continuously studying and optimizing production processes during construction while achieving the required RCC characteristics.

RCC Temperature Control

Temperature control is one of the most important issues during the construction of a large RCC gravity dam, especially in the presence of volumes and production rates,

A world record for roller compacted concrete placement was set at the construction site in December 2014, with peaks of 23,200 Mm3/day.

such as those associated with the GER Main Dam. The cement dosage of each area of the dam is intended to meet design strength and permeability requirements based on the results of extensive RCC test campaigns.

The main measures to control temperature rise in the Grand Ethiopian Renaissance Dam are: pre-cooling of materials, mixes with low cement content, appropriate construction schedule, and solar radiation protection by continuous curing. Furthermore, a temperature monitoring and early warning procedure has been implemented in order to verify, during the progress of works, agreement between calculated and recorded temperatures. The early warning procedure includes the definition of threshold values and an indication of prompt actions to be taken in case anomalous temperatures are detected.

The temperature limits at different ages are portrayed in a graph indicating four zones with different safety factors against mass cracking, namely: safe, early warning, warning and risk of crack.

These temperature limits are defined on the basis of the mechanical characteristics of the RCC mixes. Particular attention was paid to the definition of tensile strain capacity; detailed analysis of direct tensile tests (providing both strength and modulus) and creep tests were carried out for the evaluation of this key parameter.

Thermal behavior during long-term construction of the dam is being analyzed by software developed by Studio Pietrangeli. The main purpose of the thermal study is to manage the risk of crack development by controlling the RCC temperature rise and it is accomplished by defining maximum allowable placing temperatures in relation to construction rate and environmental conditions.

The thermal model is based on the finite difference method, which considers several factors that include the following:

— Time-dependent ambient conditions: fluctuation of air temperature and solar radiation, heat transfer by convection from the external surface of RCC lift;

— Time variation of thermo-mechanical properties of the RCC/Grout Enriched-RCC mixes: adiabatic temperature rise, elastic modulus, creep, tensile strain capacity; and

— Production parameters: placing temperature, construction start, lift height and lift placement rate.

The thermal properties of the three mixes used in construction of the Grand Ethiopian Renaissance Dam, (i.e., specific heat, thermal diffusivity, thermal expansion coefficient, adiabatic temperature rise, etc.) were preliminarily estimated during laboratory testing and subsequently validated by back analysis of full-scale trial tests. Full-scale trials were conducted on an RCC dam block used in the river diversion scheme; the block, measuring approximately 130 x 14 x 20 m, was equipped with 31 thermocouples.

Back analysis was extremely useful to accurately define the adiabatic temperature rise. As of January 2015, with about 20% of the works completed (2.3 Mm^3 of RCC placed), temperature measurements in the dam body confirm the good match with the values predicted by the calibrated model. It can be noted that the peak temperature and the correspondent time predicted by the model are slightly higher than the measured values, which is on the safe side.

Conclusions

Salini-Impregilo's experience in Ethiopia, and teaming with Studio Pietrangeli, have demonstrated that large infrastructure projects can be efficiently implemented using a fast track approach.

Project management for scheduling and cost control are maintained by the following:

— Early start of activities because site investigations and feasibility design are carried out concurrently to produce the basic design on which risks are identified, discussed and agreed between the parties;

— Use of the Engineering Procurement and Construction form of contract that sets the obligations of the parties; and

— Salini-Impregilo's knowledge of the country and capability of fast response to changed conditions, during execution of the works.

For more information and up to date news about this dam and the associated hydropower projects, visit HydroWorld.com and search for renaissance. ■

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