GIBE III: A ZIGZAG GEOMEMBRANE CORE FOR A 50 M HIGH ROCKFILL COFFERDAM IN ETHIOPIA

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Abstract: The third phase of the Gibe cascade, known as Gibe III HPP, with an installed power of about 1870 MW will be one of the largest hydropower plants in Africa. The plant inlcudes a 240 m high RCC dam and a 50 m high rockfill cofferdam on the Omo river. Studio Ing. G. Pietrangeli S.r.l. is the designer. The cofferdam body is made with river gravel, basalt and trachyte. The impervious core of the cofferdam is made with a flexible 3.5 mm thick PVC geomembrane sandwiched between two layers of 1200 g/m^2 geotextile that protect it against puncturing by the fill materials. The geomembrane core solution was adopted in light of the necessity to finalize the approximately 500,000 m^3 embankment during the short, six-month span of the dry season when the average river flow is 200 m^3/s, since during the rainy season the average flow is between 1000 and 1500 m^3/s with peak floods that can reach 5200 m^3/s, in a return period of Tr=30 years. The geomembrane waterproofing system, which has been designed to follow step by step the construction of the rockfill cofferdam, will create a continuous impervious barrier running all along the longitudinal axis of the dam from the bottom cut-off up to the crest. The geomembrane and its protection geotextiles have been placed in a zigzag pattern. To achieve this result the body of the dam has been constructed in alternated sections which start from the centre line defined by the longitudinal axis and are upstream and downstream directed. The face of each section toward the centre of the dam is finished with a 1V:1H slope on which the waterproofing system has been placed. The first section of the dam body has a height of 6 m, the next sections have a height of 12 m. The paper describes the rationale and details of the design, and the various steps of construction and geomembrane installation.

Key words: rockfill dam, cofferdam, internal waterproofing system, zigzag geomembrane.

1 Background

The third phase of the Gibe cascade, known as Gibe III, with an installed power of about 1870 MW will be one of the largest hydropower plants in Africa. The plant, including a 240 m high RCC dam on the Omo river, is owned by Ethiopian Electric and Power Corporation. The Contractor is Salini Costruttori S.p.A. (Italy) while Studio Ing. G. Pietrangeli S.r.l. (Italy) is the Designer and ELC-COB JV (Electroconsult-Coyne et Bellier Joint Venture) is the Employer’s Representant in the construction works supervision.

Gibe III Hydroelectric Project includes an approximately 50 m high rockfill cofferdam for the main RCC dam. The cofferdam body is made with river gravel, basalt and trachyte. Inclination of the slopes is 1V:1.8H on the upstream side and 1V:1.6H on the downstream side, crest elevation is 720 m, minimum elevation of foundation is 665 m.

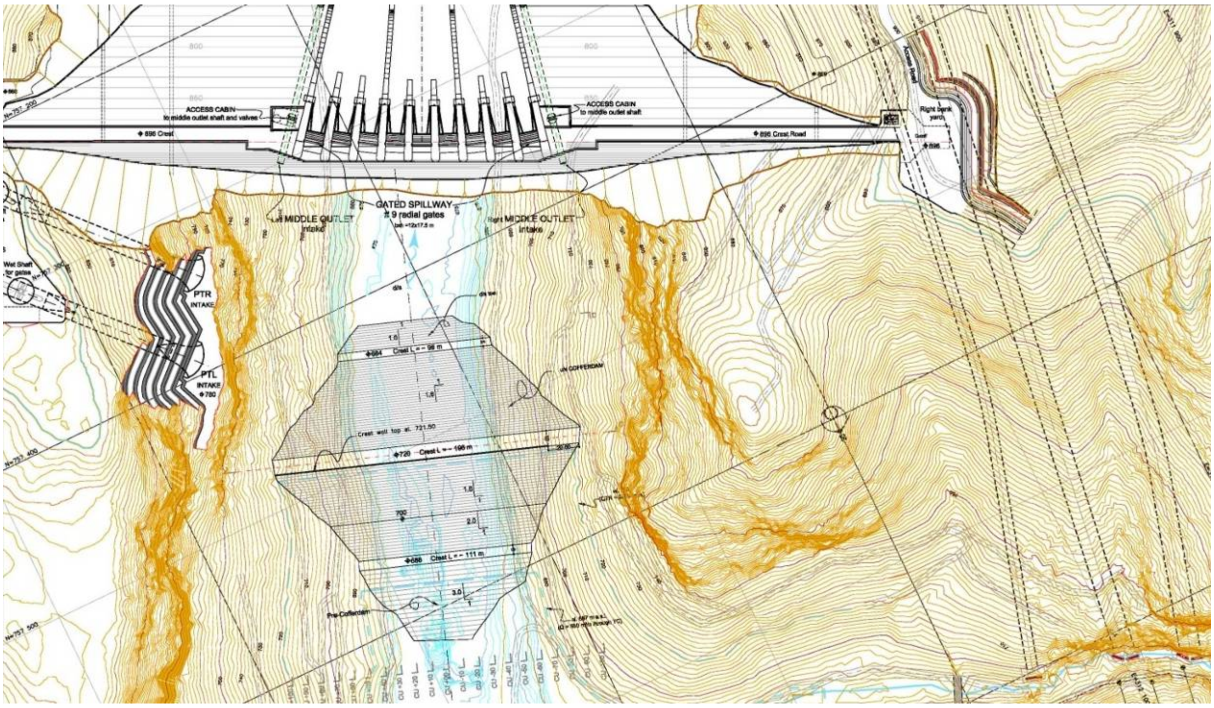

Figure 1. General plan of Gibe III cofferdam and main dam

The embankment has a fill volume of approximately 500,000 m^3. The construction of the embankment and of its waterproofing system had to be completed during the short, six-month span of the dry season when the average river flow is 200 m^3/s, since during the rainy season the average flow increases between 1000 and 1500 m^3/s, with peak floods that can reach 5200 m^3/s, in a return period of Tr=30 years.

A central geomembrane core was adopted because:

- TIMING: it would allow complying the construction within the very short construction period
- SIMPLICITY: it would allow the realization of an embankment of homogeneous rockfill, with optimization in construction times and costs.
- NO CLAY: lack of availability in the zone of material suitable for an impervious-core.
- SAFETY: With such layout the impervious layer is embedded in the embankment, safer than any impermeable layer (BFRD or CFRD).
  Settlement is not a problem.
  Permeability tests done during construction provide a guarantee unusual for this kind of structure

In the following chapters a detailed description of the adopted waterproofing system is provided.

2 The waterproofing system

The waterproofing system is placed as an impervious core, constructed during construction of the cofferdam.

2.1 General layout

The impervious core, installed and supplied by Carpi Tech, consists of a flexible Polyvinylchloride (PVC) geomembrane sandwiched between two anti-puncture layers that protect it against possible damage by the construction materials.
Two filter layers are placed respectively at the upstream and downstream side.
The geomembrane has been installed from the bottom cut-off up to the crest, in a zigzag pattern so as to follow the step by step the construction of the embankment and to be more flexible against possible settlements of the embankment. The waterproofing system thus creates a continuous impervious barrier running all along the longitudinal axis of the dam from the bottom cut-off up to the crest.
To achieve this result the body of the dam is constructed in alternate sections which start from the centre line defined by the longitudinal axis of the cofferdam and are upstream and downstream directed. The face of each section of the fill towards the centre of the dam has a 1H:1V slope, on which the waterproofing system is placed. The first section of the cofferdam body is downstream directed and has a height of 6 m. The next sections follow one upstream and one downstream directed and have a constant height of 12 m.
The construction of the cofferdam was preceded by the construction of an approximately 20 m high pre-cofferdam (which is incorporated into the final cofferdam) to divert the Omo river into the diversion tunnels and to dry out the cofferdam foundation. In this way the cut-off could be realized in clay (on which the geomembrane is encased), which waterproofs the riverbed alluvium and the shoulders colluvium.

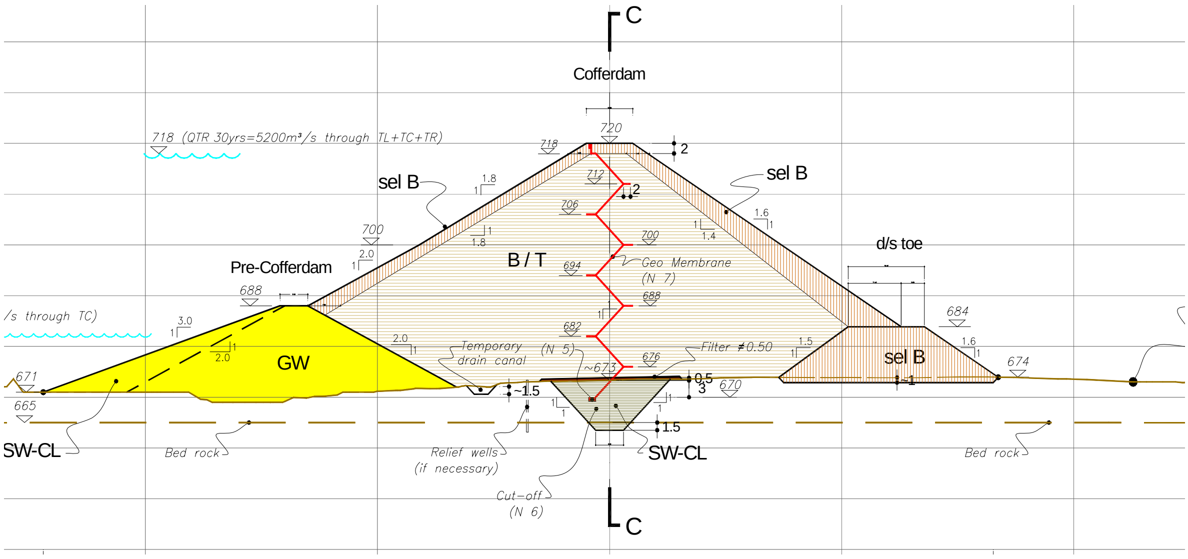

Figure 2. Typical cross section of Gibe III cofferdam

2.2 Impervious core

The geomembrane that constitutes the impervious core is Sibelon C 50 4550, a flexible impervious 3.5 mm thick PVC geomembrane, extruded in homogeneous mass from a flat die and made from virgin resin. The PVC geomembrane is resistant to ultraviolet attack, to deterioration under the alkali environment of damp concrete, and to degradation from organic and bacterial growth.
On both sides, the geomembrane is protected by an anti-puncture layer consisting of a high tenacity needle-punched geotextile, produced from 100% virgin polypropylene fibres and having a mass per unit area of 1200g/m^2. The filter layers placed on the upstream and downstream sides of the core are 5 cm thick sandy layers, maximum size 50 mm.
The zigzag path of the waterproofing system has been selected in order to provide sufficient material which can easily absorb any future deformation of the dam body caused by possible settlements. Furthermore the properties of the PVC geomembrane material, the anti-puncture properties of the geotextiles and the size of the aggregates composing the filter layers in contact with the waterproofing system will avoid any puncture or damage of the geomembrane.

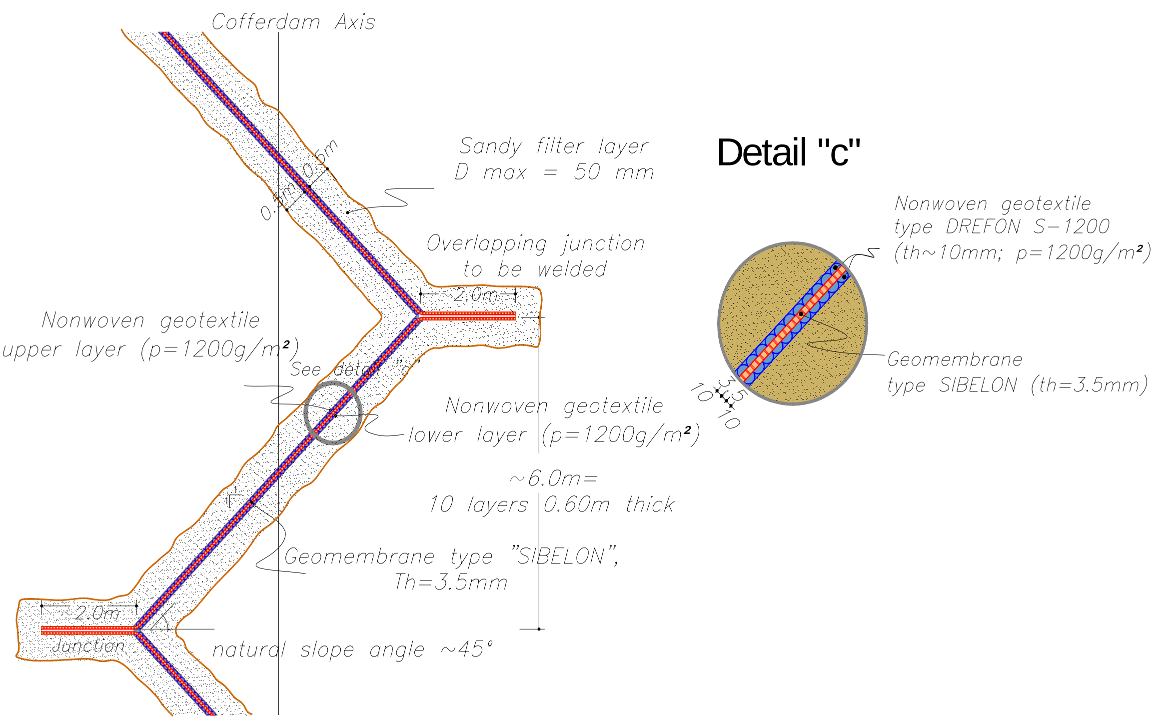

Figure 3. Detail of the impervious core of the cofferdam

2.2 Anchorage at boundaries

The anchorage at the bottom boundaries is made by embedding the geomembrane in the 6 to 8 m deep clay cut-off and by backfilling with the same impervious material. At the two abutments, due to the difficulty of excavating the cut-off with the same depth due to the presence of surfacing rocks in the river bed, the geometry was slightly modified during construction adapting the thickness of the clay layer below and above the geomembrane.

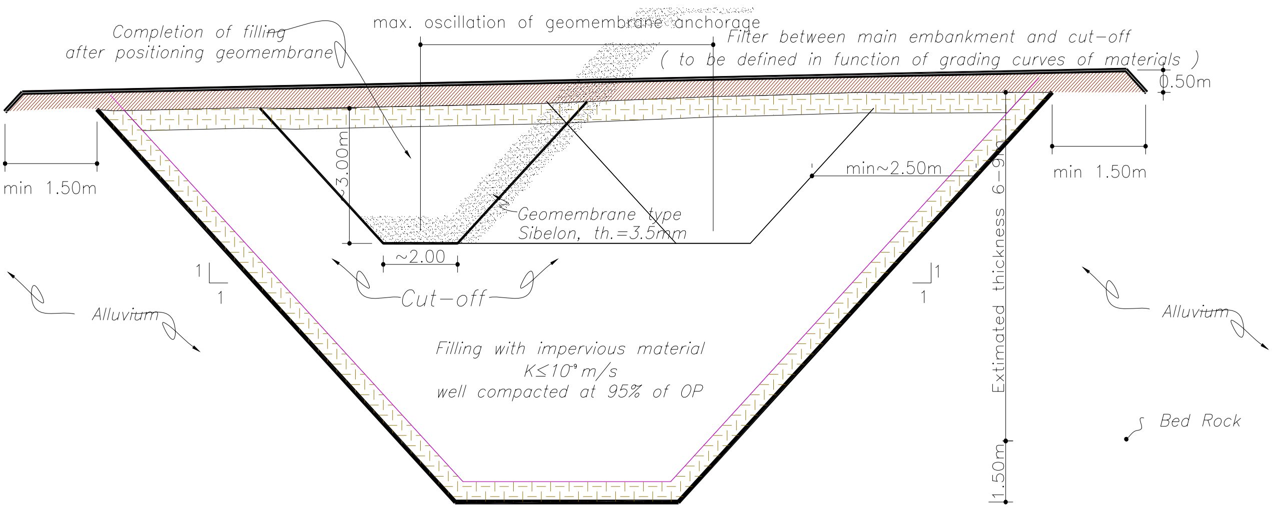

Figure 4. Anchorage of the impervious geomembrane core at cut-off

Upper anchorage of the geomembrane is made with steel anchor and plates fixed to the reinforced concrete crest wall.

3 Construction

A trial section of the geomembrane erection sequence was carried out before the actual installation started. The trial section had the same section and 1H:1V inclination of the cofferdam, total length of 20 m and total height 6 m.

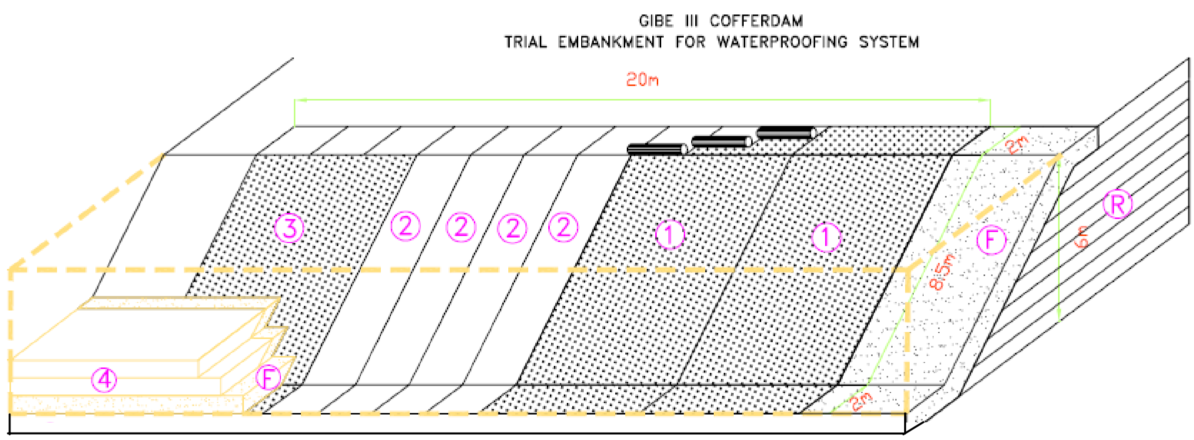

Figure 5. R = rockfill lifts simulating a section of the downstream embankment; F = filter layer; 1 = anti-puncture geotextile; 2 = waterproofing geomembrane; 3 = anti-puncture geotextile; 4 = rockfill lifts simulating a section of the upstream embankment

When the Contractor finished the inclined face and 5 m of the temporary crest of the first section of the cofferdam body where the waterproofing system was to be installed, Carpi proceeded to verify that the surface was fully compliant with the Technical Specifications (planarity, aggregate grading, compaction and stability of the slope etc.). Any deviation was immediately corrected by the Contractor so that the area could be handed over for placement of waterproofing system.

In the areas checked and handed over, Carpi immediately started placing the anti-puncture geotextile type Drefon S 1200 on the filter layer. Since the geotextile was supplied in rolls 5.9 m wide and 42 m long, the geotextile sheets were cut to the appropriate length to cover the entire inclined slope and extend 2 m on the flat temporary crest. Once cut, the geotextile sheets were placed vertically from the top to the bottom of the slope, with an overlapping of at least 15 cm between adjacent sheets. Along the overlapping the geotextile sheets were joined by manual thermo-fusion seaming. At the toe of the first slope, the geotextile was placed in the cut-off.

When the placement of anti-puncture geotextile was well advanced, Carpi started placing the waterproofing geomembrane. The geomembrane was supplied in rolls 2.10 m wide and 12.5 m long, so that each roll could easily cover the entire inclined slope and extend 2 m on the flat temporary crest and 2 m more at the bottom of the slope. The geomembrane rolls were placed along the temporary crest of the cofferdam, the edge of the geomembrane sheet was unrolled to cover 2 m on the flat crest, and after the verification of the correct alignment the sheet was completely unrolled down on the slope. The geomembrane sheets were temporarily ballasted on the temporary crest with sand bags.

Adjoining sheets overlapped at least 8 cm, and were joined by thermo-fusion seaming. The seams, continuous for the entire length of the sheets, were executed by an automatic machine performing a double track seam. The main characteristic of this type of seam is the presence of a small channel that allows performing a non destructive test with air in pressure. All the executed seams were 100 % tested. All tasks relevant to the watertightness of the geomembrane system were carried out by Carpi specialised technicians.

Due to the fact that the cofferdam body is constructed by horizontal lifts of fill material, the placement of the protective geotextile on top of the PVC geomembrane had to be done with sheets placed horizontally from the bottom toward crest following the placement of the lifts. The protective geotextile stops at top of the slope. The PVC geomembrane placed on the temporary flat crest section 2 m wide was protected with stronger material to avoid major potential damages during the construction of upper part of the new section.

In the areas where the waterproofing geomembrane had been installed, welded and checked, a final joint inspection was carried out to verify that no defects were present. The general contractor, after placing the second anti-puncture geotextile on top of the geomembrane, started constructing the second cofferdam body section, directed on the opposite side.

The construction of the dam body proceeded by alternate sections upstream and downstream directed. The crest of each section is thus also the bottom of the section above it, and in this flat area the PVC geomembrane lining the lower section is watertight connected to the PVC geomembrane lining the section above it.

Figures 6 and 7. At left the first section of the cofferdam is completed, the first anti-puncture geotextile (white) is placed on the sand layer, and the PVC geomembrane (gray) is placed over it. At right, construction of the second section starts after the second anti-puncture geotextile has been placed over the PVC geomembrane

In the flat area at the crest of each section, the PVC geomembrane lining the lower section overlaps the PVC geomembrane lining the section above it, for a width of about 2 m. In correspondence of this 2 m wide overlapping area, the connection of the two PVC geomembranes is made by means of a double track seam executed with automatic machine and tested with air in pressure, as already described. The execution of this horizontal longitudinal connection seam, parallel to the axis of the dam, is made at the same time of installation of the PVC geomembrane sheets over the inclined slope of the upper section. Before the execution of this seam the protection placed to avoid damages on the geomembrane is removed, the area is cleaned, the integrity of the geomembrane is checked and if needed damages are repaired.

Figures 8 and 9. At left, the PVC geomembrane installed over a completed dam section is watertight welded onto the PVC geomembrane protruding 2 m from the crest of the section below. At right, placement of the fill for the fourth Section of the cofferdam

All the procedures described were repeated for each step of the construction of the dam body sections from the very bottom of the cofferdam (El. 670) up to the crest (El. 720), where the upper edge of the upmost PVC geomembrane is mechanically fastened to the reinforced concrete crest wall.

Figure 10. Gibe 3 upstream cofferdam embankment construction completed (on the crest the realization of the crest wall is ongoing)

4 Conclusions

The design of the Gibe III 50 m high rockfill cofferdam with internal waterproofing zigzag geomembrane has been expressly conceived and tailored for the Gibe 3 cofferdam case, in the frame of the fast track project of the Gibe 3 Hydroelectric Project EPC Contract, taking into account the specific needs and site constraints of this project.

However this solution presents many aspects that can give answer to some problems commonly encountered during design and construction of dams and cofferdams, like:

- Tight construction time schedule (of environmental or contractual nature).
- Lack of availability of impervious material.
- Complication of construction sequences and differential settlements for embankment realized with impervious core material.
- Difficulties in managing settlements.
- Difficulties in assuring proper protection and safety of the impervious layer.

The scheme adopted for this Gibe 3 cofferdam can be profitably adopted also in rockfill dams' design, by the introduction of some simple implementations that can assure the performance of the work in the long term time also, like:

- some more redundancy (double waterproofing system);
- inspection gallery for inspection, monitoring and repair intervention;
- instruments for any water pressure or leakages monitoring displaced at the geomembrane construction joints;
- drainages for any leakages control and discharge.