Maximizing the benefits of Urra dam, Colombia

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The Fusegate system was used for the first time in Latin America to increase the reservoir storage capacity at the 73 m-high Urra multipurpose dam project in Colombia. Technical, environmental and economic benefits of this scheme are discussed here.

Although the principal purpose of the Urra I multipurpose scheme in Cordoba, Colombia, is power generation, it also helps to regulate the Sinu river. The dam is a rockfill embankment, with a maximum height of 73 m. It allows for the storage of 1740 × 10^6m^3 of water within a 7400 ha catchment area, 1200 × 10^6m^3 of which is live storage. The 660 m-long non-overspill section has a crest elevation of 137 m. It has a 600 m-long auxiliary dyke and a 182 m-long uncontrolled spillway. The powerhouse is equipped with four Francis turbines with a total installed capacity of 360 MW, and average annual production of 1491 GWh/year. The dam is owned and operated by Urra SA-ESP.

The current full supply level corresponds to the crest of the uncontrolled spillway at el. 128.5 m, which is 8.5 m below the crest of the dam.

Since its completion nine years ago, the spillway has operated three times during rainy seasons.

The sizing of the spillway was based on the Probable Maximum Flood (PMF) with a water level 1.1 m below the dam crest. The PMF was defined based on modelling precipitation-streaming, with extreme combinations of weather conditions and hydrological parameters. Its maximum peak flow of 14 906 m^3/s is three times greater than the peak for the 10 000 year flood. Based on these hydraulic studies, including a small-scale model, a 182 m-long ogee crested spillway was designed, which comprised 13 master bays of 14 m each, separated by intermediate piers.

Urra SA-ESP evaluated a number of options for increasing the storage capacity as well as flood mitigation, and in November 2008, awarded a contract to Hydroplus of France to design, manufacture and install a combined spillway control system consisting of Fusegates and flap gates to increase the reservoir elevation up to el. 130.5 m. This 2 m increase in reservoir level corresponds to an increase in storage capacity of 150 × 10^6m^3 without compromising the spillway discharge potential and safety of the dam during extreme flood evemts and up to the PMF.

View of the Urra spillway before the Fusegate installation.

The project is scheduled to be completed in October 2009.

An analysis of the major flood in June 2007 shows that if the project had been implemented before this event, the storage capacity at full supply level would have increased by 33 per cent within just one month, (that is, from 2994 × 10^6m^3 to 3990 ×10^6m^3).

It is important to note that Urra's reservoir plays an important role in regulating downstream flow conditions all the way to the Caribbean Sea. To minimize downstream flooding, Urra SA-ESP limits discharges to 700 m^3/s as much as possible. During the three seasons when the spillway operated, power generation was curtailed to avoid exceeding the downstream discharge targets.

From an early stage it was recognized that some form of gated spillway control system was required, rather than a fixed spillway heightening, with the associated extensive embankment crest works.

Urra SA-ESP's evaluatation eventually centred on two main options: inflatable weirs or Hydroplus Fusegates.

Among various constraints imposed on the scheme was that the spillway had to handle the PMF safely in all reasonable malfunctioning scenarios. Also, the system had to be able to operate automatically when required, and require minimal maintenance. In addition, it should be resistant to possible vandalism and represent an economically feasible soulution.

The Fusegate system was finally selected, as it met all the above criteria and offered a fail-safe solution which would also not be dependent on any electrical or mechanical systems for its operation during extreme flood events.

1. General considerations

1.1 Environmental and social aspects

An environmental and social impact study was carried out to ensure that the spillway would integrate within the existing framework after the improvement works had been completed, and that negative environmental impacts would be minimized during the construction activites.

An analysis of the environmental impact relating to the increase in storage capacity was carried out based on a study previously done for the dam. It consequently highlighted the impacts related to the installation of the Fusegates and the flap gates. This process allowed for a comprehensive identification and analysis of the various activities which could generate impacts, as well as components which could be modified; it concluded with the environmental changes associated with the project. All these changes were evaluated by a multicriteria system of notation, making it possible to identify and prioritize the impacts. The study was submitted to the ministries with relevant jurisdiction, namely Ambiente Vivenda y Desarollo Territorial, and Minas y Energias.

For each aspect, the methodology helped to identify impacts, define their characteristics (nature, intensity, frequency, remedies, and so on), and evaluate them (favourable/unfavourable, level of intensity, geographical area concerned, duration, and so on). The impact study was carried out for the actual site, but with an extended brief covering the whole area of the spillway, the reservoir, surrounding areas and downstream.

Among various findings from the impact study, the following turned out to be the most significant aspects:

- *Loss of vegetation as a result of the more frequent flooding of the shoreline zones.* The project has a minimal effect with relatively reduced intensity and involves medium-term recovery. It thus qualifies as "low impact".
- *Impact on the quality of water in the reservoir.* The impact is minimal compared with the remainder of the reservoir, and the operation of the dam limits harmful effects. It thus qualifies as "low impact".
- *Stability of the dam in relation to hydraulic saturation.* This risk would be localized and limited to some of the geographical sections which were already exposed at the time of the current development. The impact remains "low", but deserves more attention.
- Impact on the habitat caused by the existing infrastructure in the shoreline zone. The impact relates to the people living and working in this zone having to move. The zones concerned are very limited, and possibilities exist to convert this situation into a positive impact.
- *Increase in power production by increasing the hydraulic head.* There is a positive continuous and sustainable benefit categorized as 'medium'
- *Improved flood control downstream of the dam.* The possibility of storing a larger volume of water for flood attenuation together with improved operating characteristics of the spillway allows for the improvement of flood control relative to the downstream area. This positive effect is considered 'medium'.
- *Impact on vegetation in the region.* In the project area, vegetation is sporadic and permanent at elevations higher than 130.50m (low impact).
- *Submergence of small islands where a rescue operation would be required for terrestrial fauna.* This was not applicable.

1.2 Economic benefits

The incremental increase in storage capacity was defined, as well as the methods considered for achieving this, to optimize the costs of installation and the benefits of the additional water. Risk analyses were undertaken to derive probabilities of the potential additional water being available, taking into account the economic benefit of increased power generation capabilities together with associated social impacts.

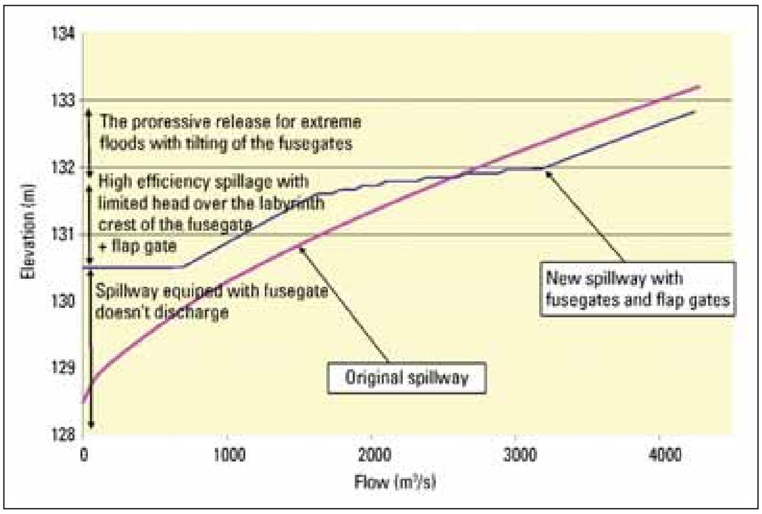


Fig. 1. Rating curve for the Urra spillway.

Even based on fairly conservative approaches, the project is estimated to have a tremendously beneficial return on investment with a break-even point of only 3.5 years, mainly as a result of the additional electricity generation of 78 GWh/year from the additional storage. (The additional amount of energy generated is estimated to be between 3 and 5 per cent per year).

Moreover, the permanent increase in head will represent additional power capacity during peak periods.

Finally, thanks to the additional storage volume, the owner is able to continue generating during flood periods, where previously generation would have been prevented, or at least reduced, to comply with the downstream flood mitigation targets. The surpluses which were previously discharged through the spillway will in future be used for power generation.

A retrospective analysis of the flood of June 2007 demonstrated that the project would have made it possible to increase by 33 per cent the volume of water for generation for one month (to 3990 × 10^6m^3 instead of 2994 × 10^6m^3).

1.3 Flood mitigation

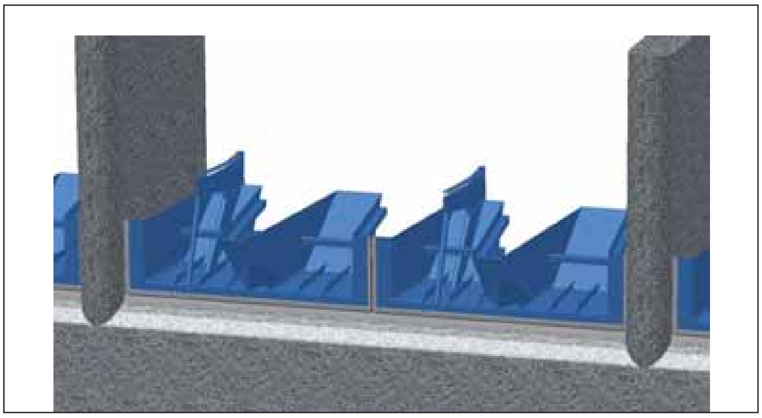
The increase in storage capacity also considerably reduces both the amount and frequency of flows through the spillway during small to medium floods. This aspect is particularly important in the area downstream of the dam, which is often inundated by floods.

2. Technology

2.1 Hydraulic and construction considerations

As mentioned previously, the original spillway was able to discharge the PMF at maximum water level,

Fusegate system on Urra dam upstream view.



1.1 m below the dam crest. Since the maximum water level is not changed as a result of heightening the dam with Fusegates, there is no requirement to modify the non-overspill crest of the dam wall. However, to meet certain development approval constraints, it was decided that the intermediate flood levels would require adjustment. Accordingly, the 10 000 year flood must be able to be discharged below el. 132 m (that is, 3.5 m above the existing spillway crest).

The existing free overflow spillway has a reinforced concrete ogee weir. A bridge spans the entire spillway with piers every 14 m. The Fusegate solution will eliminate the need for any modifications to the existing bridge and minimize construction work on the spillway sill.

The hydrological data for the catchment has been analysed for two periods (between 1960 and 2007, and between 2001 and 2007). These data were used to establish statistical models to define the maximum probable flood for the design of the spillway. The new data were consistent with the original data, which confirmed that the spillway capacity did not need to be increased. The new flood data were used to develop the Fusegate solution.

The following project requirements were stipulated by the owner:

- No Fusegate should tip for floods of less than the 100 year return period.
- Tipping of the Fusegates should be progressive, and create minimal incremental outflows.
- The Fusegated spillway should have a rating curve limiting the maximum level reached for the 10 000 year flood, and be identical to that obtained by the existing spillway (at el. 132 m).
- The maximum water level should not exceed el. 135.90 m.

To meet these requirements, it is proposed to install a combined spillway control system comprising 22 Fusegates, to be located on 11 of the 13 bays of the spillway, and flap gates (5.5 m high and 12 m wide) on the remaining two bays.

To minimize the risk of faulty operation, the flap gates are designed to open by a float system in the event of a power outage. Similar systems have already been installed at many run-of-river projects. The use of flap gates in combination with Fusegates allows for many benefits for the operation of the dam, some of which are minimum control of the reservoir elevation, release of flows and the evacuation of floating debris. The flap gates have been designed under subcontract by B.P. Etudes. At this project, the flap gates are designed to operate in such a way as to optimize storage in the reservoir by opening gradually when there is overspilling above the crest of the Fusegates.

The technical challenges of the Fusegate design in this project have included the determination of an optimal coefficient for discharge over their crest, and the requirement that the Fusegates and mechanical gates be installed with minor modifications on the sill. There will be 22 Fusegates, each 7 m wide by 2 m high. Each Fusegate will have two buckets. Some interesting developments to the Fusegate system have been undertaken to meet various challenges associated with this project :

- *Fusegates with increased high discharge coefficients*: the specific constraints of the project leave little margin between the new full supply level, and the level reached by the reservoir at the 100 year return period flood. It is therefore necesary to have a high discharge coefficient to be able to optimize the operation. A customized Fusegate geometry with a labyrinth crest supplemented by an upstream cantilever extension was specifically designed for this purpose. Various model tests were carried out on this new geometric Fusegate shape at the Hydroplus plant in Marolles, France.
- *Fusegates on an existing ogee weir*: Fusegates are generally installed on broad-crested spillways, (except for one project in France, the Puylaurent dam, where the Fusegates were installed on an ogee crest). At the request of the dam owner, Hydroplus developed a new Fusegate design to enable them to be installed on top of two longitudinal steps created on either side of the existing ogee crest. These steps will ensure minimal construction activity on site. The Fusegates will contain lateral flanges which can be adapted to the geometry of the existing spillway.
- *Fusegates assembled on site without the requirement for in-situ welding*: to minimize transportation issues, the Fusegates were designed in carefully thought out components with the final assembly on site using pre-drilled holes and various bolting arrangements. Once assembled close to the dam site, they will be installed on the spillway using an overhead crane fixed on the bridge over the spillway.

Both Fusegates and flap gate metal structures will be manufactured in Colombia and only some specific parts will be imported.

Another interesting component of the project is the structural modification of two bays of the spillway, which will each house 12 m-wide by 5.5 m-high flap gates. In March 2009, Urra SA-ESP awarded the structural modification contract to Decotec Pty Ltd, an Australian specialist company for concrete removal. This involves the following methodology to isolate ogee sections into 20 t blocks for lifting out and removal.

For each of the two bays there will be :

- approximately 200 m of 50 mm diameter drilling to feed the diamond wire around the areas to be cut;
- three vertical wire cuts at approximatley 40 m^2 per cut;
- three horizontal wire cuts totalling 330 m^2; and,
- drilling of 110 mm-diameter holes for 125 tonne hydraulic bursting.

Conventional blasting techniques were not acceptable because of the proximity of the piers and bridge deck, and the accuracy of concrete removal which was required.

Conclusion

The Urra reservoir is the first scheme in Latin America where Fusegates have been applied, and this project has reaffirmed the versatility of the system which has been customized to meet specific unique project requirements. The additional storage capacity gained at Urra dam by this project offers the following benefits:

- a marginal capital cost per additional cubic metre of storage capacity achieved;
- additional storage capacity to increase power generation capacity, also providing increased flood protection downstream; and,
- no increase in the maximum water level during the most extreme flood conditions, and no major dam crest works. ◊

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