The diversion works for the Cua Dat CFRD in Vietnam

Michel Ho Ta Khanh, Dinh Sy Quat, Prof Pham Hong Giang
VNCOLD
No 95/10 Chua Boc Street
Dong Da District
Hanoi
Vietnam

Abstract

The Cua Dat CFRD is constructed on the Chu River in Vietnam. In the initial design, the diversion works were foreseen by a traditional method with 2 large tunnels and a high upstream cofferdam. To minimize the cost and the delay of construction of the diversion works, it was decided to divert the flow during the most critical stage of the construction by only one small tunnel with a possible overtopping of the partially constructed dam. Different methods to protect the dam during the overflow were carried out in the hydraulic laboratory and finally a solution with a stepped downstream face protected by gabions was adopted. During the typhoon Lekima in October 2007, with an exceptional flood much higher than the "Construction flood", a portion of the dam collapsed. Several observations and lessons can be drawn from this incidence. The repair cost was 8.4 MUSD and the repair duration was 3 months. A cost saving of 12 MUSD and a reduction of construction delay of 21 months were then obtained by this method of diversion even in this unfavorable case. The comparison shows consequently that a diversion by means of submerged works, in place of the traditional method, may be the best solution and can be adopted for the construction of the next CFRDs in the same climatic conditions.

1. Main features of the Cua Dat scheme

The Cua Dat scheme is located in the middle of the basin of the Chu River, which is the biggest tributary of the Ma River, one of major rivers in the Northern Central Vietnam (Figure 1). The dam site is 230 km far from Hanoi.

The reservoir storage about 1450 hm^3 is designed with the main following purposes:
- flood control,
- irrigation of 87 000 ha,
- water supply for 2.5 million inhabitants, with a discharge of about 8 m^3/s to supply industry,
- hydropower generation with a capacity of 97 MW.

The main CFRD dam is 119 m high and 930 m long with a volume of 10 hm^3 (Figure 2).

Figure 1: The Cua Dat site

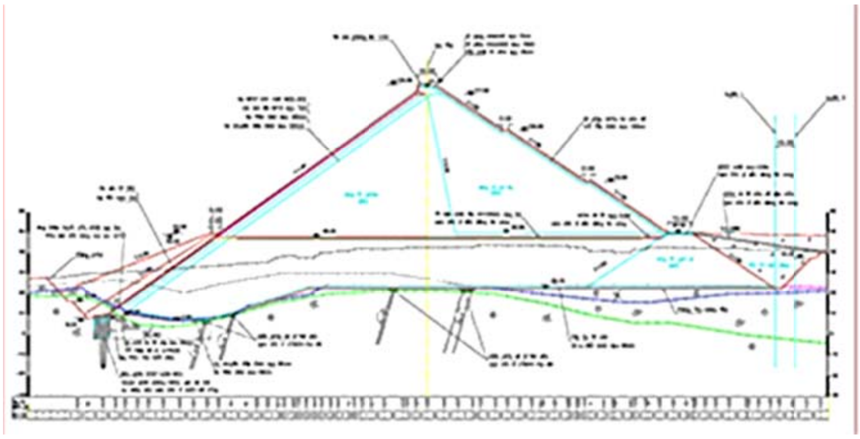

Figure 2: Cross section of the dam

Figure 3: General view of the Cua Dat project

The project includes (Figure 3):

- a reinforced concrete spillway, which consists of 5 gates with the dimension of 11m×17m, discharging the design flood of 13 200 m^3/s (frequency of 0.1%) and the check flood of 18 900 m^3/s (frequency of 0.01%),
- two tunnels with diameter of 9 m, one is 820 m long used as temporary diversion tunnel during construction period and for the entire reservoir discharge, the other 600 m long is to convey water into the hydropower plant,
- 2 saddle dams (20 m and 41 m high respectively),
- the irrigation canal system for 37 000 ha.

The construction duration is 5 years (2004 to 2009).

2. The river diversion

2.1 Methods of river diversion for the Cua Dat dam

Difficulties are met with the river diversion because of high peak flow discharge in flood season (about 3 months per year). The 20 year-flood, adopted as the "Construction flood', has a peak inflow discharge of 1230 m^3/s during the dry season and 5050 m^3/s during the wet season.

To minimize the cost of the diversion structures, it was admitted to divert the flow during the most critical stage of the construction (wet season of 2007) by only one tunnel (L=820 m, D=9 m) with a possible overtopping of the main dam 25 m higher than the river bed. The downstream face of the dam was protected by

several ranges of gabions, placed in steps of 1.5 m high and slightly anchored in the rockfill.
This innovative solution - in place of the traditional method with large tunnels and a rather high upstream cofferdam for a 20-year flood to a 100-year flood - was also adopted taking into account the following considerations:

- embankment dams (or their cofferdam) failed more frequently during construction than in operation,
- the cost and delay of construction of tunnels are high for large catchment areas and then high floods,
- high cofferdams built quickly in difficult conditions may not be totally safe and their failure may be dangerous due to the large stored water,

The traditional method - well adapted to most European countries for example - is probably not optimal for the sites with very high floods during few months of the wet season and low discharges during the rest of the year.
This method of diversion by overtopping requires however a precise program of the construction, with the placing of the rockfill only during the dry periods and a good selection of the crest level of the submerged dam, taking into account the hydrological characteristics and the constraints of the works. In the table here after the different stages of construction and diversion are given, for example, for the Cua Dat dam.

Construction Years	Construction Period	Closing Date	Exceedant Probabilities	Diversion discharge (m^3/s)	Closing Discharge (m^3/s)	Diversion Works
1st year	Dry season (Dec. to subsequent May)		5%	1230		Natural channel narrowed. Max WL +38.13m
	Flood season (June to Nov.)		5%	5050		Natural channel narrowed. Max WL +38.13m
2nd year	Dry season (Dec. to subsequent May)	1st decade Dec.	5%	1230	137	Tunnel 2 (TN2) Max U/S WL = 43.20m Max D/S WL = 30.50m
	Flood season (June to Nov.)		5%	5050		TN2 and main dam constructed to EL 50.00m U/S WL = 55.37m; D/S WL=38.02m
3rd year	Dry season (Dec to subsequent May)		5%	1230		TN2 U/S WL = 43.20m; D/S WL = 30.50m
	Flood season (June to Nov.)		5%	7520		TN2 and Spillway constructed to EL 83.50; U/S WL = 89.67m; D/S WL = 35.19m
4th year	Dry season (Dec to subsequent May)		5%	1230		TN2 U/S WL =43.20m; D/S WL =30.50m
	Flood season (June to Nov.)		0,1%	1230		TN 2 and Spillway constructed to El 97.00m

2.2 Alternatives for the protection of the dam during the overtopping

Various alternatives have been contemplated for the possible different protection system for the overtopped dam: protection by concrete slabs, gabions or downstream stepped rockfill and for different dam crest and water levels depending on the construction schedule and probability of floods.
Extensive laboratory tests (scale 1/40), taking into account the zoning and materials of the structures, have then been performed in order to check their stability and to measure the pressure and velocity of the flows at different parts of the structures.

More thoroughly, the laboratory tests were carried out in order:

- to determine the flow conditions over the cofferdams and the CFRD under construction for different flood discharges and dam crest levels,
- to explore water velocities field and depths along various profiles of the reach between U/S and D/S cofferdams,
- to explore water pulsation at critical locations,
- to research solutions to protect main dam as well as cofferdams,
- to examine eventual action of erosion,
- to adjust dimensions of diversion works, if necessary.

Three main alternatives were finally selected:

1) An alternative with a downstream slope face protection by concrete slabs or gabion mats when overtopping (Figure 4).

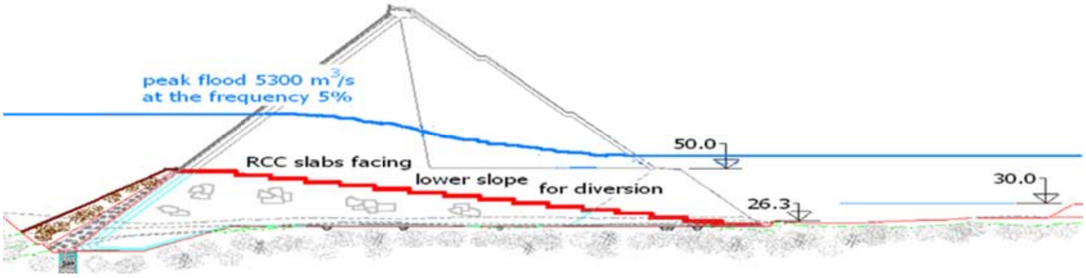

Figure 4: Cross section of the partial dam with a downstream slope face

Results of the tests: this first alternative would be safer with its more progressive dissipation of flood energy. However the third alternative was chosen because it can reduce a little the delay of construction with rather lower cost.

2) An alternative of rock fill without protection.

Results of the tests: creation of deep erosion on the dam and large scour at its toe.

3) An alternative with stepped gabions entirely on the downstream slope face of the dam (adopted alternative) (Figure 5).

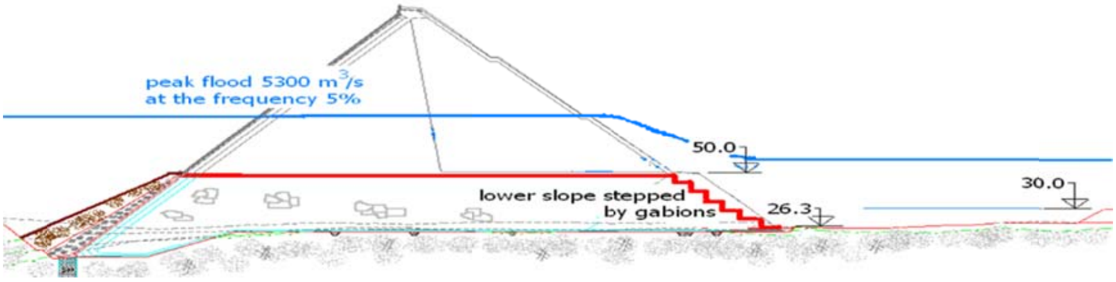

Figure 5: Cross section of the partial dam with stepped gabions on the downstream face

Figures 6

Figure 7

The Figure 6 shows the downstream steps of the partial dam and the Figure 7 shows the commencement of the degradation of the fill under the gabions for the high discharges.

Results of the tests: available alternative for the tested specific discharges, but this type of protection requires the use of steel bars in place of wire mesh, a filter layer between the rockfill and the gabions and a reliable protection at the toe of the dam.

4) A safer alternative with a downstream slope protection by RCC - as adopted for the Xingo CFRD in Brazil, taking also into account the good experience of RCC dam's overtopping - was also envisaged by some experts, but it was not finally retained since it slows down the construction program and it is also a priori more expensive.

Figure 8

Figure 9

The Figures 8 & 9 show the safe downstream face of the Chinese Hankou RCC cofferdam after an overflow depth of 8m (the RCC contains only 80 kg/m^3 of cement and fly ash with reuse of alluvial aggregates excavated from the river bed).

3. The failure (4th October 2007)

In October 2007, just at the end of the wet season, a very high flood during the typhoon Lekima centered on the site, came unfortunately with the discharge of more than 7000 m^3/s. It's higher 37% than the designed one. The flood lasted 48 hours. The erosion begun when the discharge was over 2200 m^3/s, with an overflow depth of 1.5 m. A part of the dam collapsed with a maximum overflow depth of 4 m. The destruction lasted 24 hours, with the opening of a breach from D/S to U/S (L= 70 m, i.e. one third of the dam portion in the channel and with about 350 000 m^3 of displaced rockfill).
As no scour in the bed-rock was observed just after the failure and the existence of an important erosion in the right bank was the consequence and not the cause of the breach, it seems that the initial failure is the destruction of the gabions, with different possible hypotheses (not really proved):

- insufficient resistance of the gabions (which were not well represented in the model by the used wire mesh),
- loss of stability of the gabions (by piping?),
- destruction of the gabion mesh by the floating debris and logs carried by the flood.

Figure 10

Figure 11

The Figures 10 & 11 show the commencement of the overflow.

Figure 12 *Figure 13*

The Figure 12 shows the breach in the dam and the right bank and the Figure 13 shows the partial clogging of the diversion tunnel.

Figure 14 *Figure 15*

The Figure 14 shows the failure of the dam (only on the right bank) and the Figure 15 shows the channel in the river bed after the incident.

Figure 16 *Figure 17*

The Figures 16 &17 show the gabions after the incident with the floating debris hooked in the wire mesh

The portion of the dam on the left bank was not destroyed probably because the formation of the breach on the right bank has significantly lowered the overflow depth on the remaining part of the dam.
The unlined diversion tunnel, with a 9m diameter, was partially clogged during the flood. It is to note that with the traditional method of diversion, where the total discharge is evacuated only by the tunnels, even with a larger diameter, this risk cannot be completely avoided as observed on other examples in the world.
It is also interesting to observe that the downstream maximum water level, after the dam failure, was not significantly higher than the natural water level for this flood (negligible incremental effect). With the traditional method, the U/S cofferdam crest would be higher (El.72.00 m in place of El. 45.50 m) and in case of its failure, the released flood and the river level would be higher, with probably much more damages downstream.

4. Comparison of costs and delays of construction for the 2 alternatives

The table here after shows a comparison concerning the costs (in MUSD) of the diversion works and the delay of construction (in months) for the dam with the initial design (A1) - utilizing the traditional method with a high upstream cofferdam and 2 large diversion tunnels - and these values for the constructed dam, including its repair (A2+REPAIR) following the incident. The cost saving is 36% and the construction delay saving is 21 months compared with the initial design.

ALTERNATIVE: A1 (traditional)	**ALTERNATIVE: A 2 (with overtopping)**	**REPAIR** (to restore the damaged structures)	**A2 + REPAIR**
1. Two tunnels (Diameter=11.0m, Total length = 1250m): 31.5 MUSD 2. Upstream cofferdam: 1 MUSD 3. Downstream cofferdam: 0.06 MUSD 4. Longitudinal dam: 0.42 MUSD **- Total: 33 MUSD** **- Construction period: 7 years.**	1. One tunnel of 9.0m diameter: 8.5 MUSD 2. Protection of the D/S face with stepped gabions: 2.3 MUSD. 3. Upstream cofferdam: 1.6 MUSD 4.Downstream cofferdam: 0.06 MUSD 5. Longitudinal dam: 0.42 MUSD **- Total: 12.85 MUSD (39% of A1)** **- Construction period: 5 years.**	1. Overflowed CFRD part : 7.9 MUSD 2.U/S and D/S cofferdams : 0.5 MUSD **- Total : 8.4 MUSD** **- Duration of the repair: 3 months**	**-Total cost: 21.25 MUSD** (64% of A1) **- Total delay saving: 21 months**

5. Return of experience of the Cua Dat dam diversion works

The incident of the Cua Dat dam diversion leads to the following questions and answers:

- Choice of the frequency for the "Construction flood" of this design?
Probably too high (1/20) for an important embankment dam with some uncertainties concerning the hydrological data. A probability of 1/100 should be more realistic.
- Choice of the type of diversion works with overtopped structures?
Certainly justified, if we compare the costs and delays of construction, even with this incident due to the exceptional flood of October 2007 (frequency 1/500?): in that unfavorable case, the expenditure to restore the eroded dam portion is only about 20% of the cost of a large diversion tunnel.

- Choice of the type of protection?
It is probable that, if the downstream slope of the dam were protected by a RCC layer - or much better by a small downstream FSHD (or a CSG dam) - in place of the gabions, the main dam and the RCC would have resisted to the flood or been only superficially damaged.
For the Cua Dat dam, the protection by the gabions was not sufficient for such a high overflow depth, with a flood duration larger than one day. The risk of collapse was augmented by the flood transporting a lot of floating debris and logs. This type of protection should require the use of strong steel bars in place

of a simple wire mesh, a filter layer between the rockfill and the gabions and a reliable protection at the toe of the dam: this protection won't be finally cheaper than a protection by a RCC layer.
The Cua Dat's breach, restricted to only a part of the dam length, shows that it could be economically advantageous to foresee - for a long embankment dam - a fuse portion of the crest in the central or the lowest parts of the dam partially constructed, to reduce the overflow depth on the rest of the structure in case of a very exceptional flood.

6. Conclusion

The failure of the Cua Dat CFRD must not lead to rule out the method of diversion with overtopped structures - which allows generally important cost and delay savings - but to adopt an adequate mode of protection of the downstream slope of the embankment and, if necessary, of its toe and abutments. So the downstream slope of the dam portion must be strengthened sufficiently to be safe in large flood overtopping.
If a dam is constructed on a site with low discharge during the dry season, but with very large floods during some months of the wet season, it is possible to reduce, by this mean, its delay and cost of construction. As more and more CFRD will be constructed in Asia in such condition (monsoon), this practice seems very promising.
It will be therefore interesting to collect in the future the experience of this method of construction to improve its economy and safety.

References

[1] "Feasibility Studies of Cua Dat Dam", Hydraulic Engineering Consultancy Company HEC1, Hanoi, Vietnam 2003.

[2] "Design of the Cua Dat CFRD in Vietnam and innovative river diversion system", M. Ho Ta Khanh & Pham Hong Giang, Int. Symp. "ASIA 2006 – Water Resources & Renewable Energy Development in Asia", Bangkok, Thailand, 2006.

The Authors

M. Ho Ta Khanh has 45 years of experience in the fields of design and construction of hydropower structures, in particular concerning dams and the associated hydraulic structures. He has participated in the studies and construction of more than 80 projects, both in France and abroad, and particularly in Africa and Asia. He participates in several ICOLD's Technical Committees and is a member of CFBR and VNCOLD.

Dinh Sy Quat was a Chief Engineer in the Hydraulic Engineering Consultants (HEC) of MARD and was an expert in VNCOLD.

Prof. Pham Hong Giang was the Vice-Minister of the Ministry of Agriculture and Rural Development of Vietnam (MARD) and he is presently the Chairman of the Vietnamese Committee on Large Dams and Water Resources Development (VNCOLD).