PLUNGE POOL DESIGN AT GEBIDEM DAM (SWITZERLAND)

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Gebidem Dam is a 122 m high double curvatured arch dam situated in the canton of Wallis, Switzerland. The dam reservoir collects glacier water of the longest glacier in Europe, i.e. the Aletsch glacier (25 km length). The water is very rich in sediment. This results in huge amounts of fine sediments depositing into the reservoir. The 55 m^3/s turbined by the Bitsch power station contain between 10 and 13 kg of sand, or an average of almost 40 tons per hour.

Hence, a yearly flushing is organized allowing to release about 400’000 m^3 of solid material from the bottom outlets of the dam towards downstream. Moreover, the crest spillway of the dam is frequently used during summer months to release water from the reservoir, resulting in high-velocity jets impacting the downstream plunge pool. The latter consists of a series of flat concrete plates tied together by means of steel anchors and supported by a layer of underlying mass concrete.

Intensive jet impact on this concrete apron within the last 40 years has led to severe damage and, as such, replacement of the apron becomes necessary. The present paper describes the methodology applied for design of a new concrete apron. Especially the interaction between the hydrodynamic pressures exerted by overtopping jets and the steel anchorage necessary to prevent uplift of the new concrete apron is pointed out..

Key Words : *scour, concrete apron design, anchorage*

1. INTRODUCTION

Gebidem Dam is a 122 m high double curvatured arch dam with plunge pool concrete apron situated in the canton of Wallis, Switzerland (Figure 1). The dam reservoir collects glacier water of the longest glacier in Europe, i.e. the Aletsch glacier (25 km length), which is very rich in sediment. This results in huge amounts of fine sediments depositing into the reservoir. The 55 m^3/s turbined by the Bitsch power station contain between 10 and 13 kg of sand, or an average of almost 40 tons per hour.

Hence, a yearly flushing is organized allowing to release about 400’000 m^3 of solid material from the bottom outlets of the dam towards downstream. Moreover, the crest spillway of the dam is frequently used during summer months to release water from the reservoir, resulting in high-velocity jets impacting the downstream plunge pool. The latter consists of a series of flat concrete plates tied together by means of steel anchors and supported by a layer of underlying mass concrete.

Intensive jet impact on this concrete apron within the last 40 years has led to severe damage and, as such, replacement of the apron becomes necessary (Figure 2).

2. NUMERICAL MODEL FOR CONCRETE APRON DESIGN

The model used for design of the concrete apron is the Comprehensive Scour Model (CSM)[1),2)].

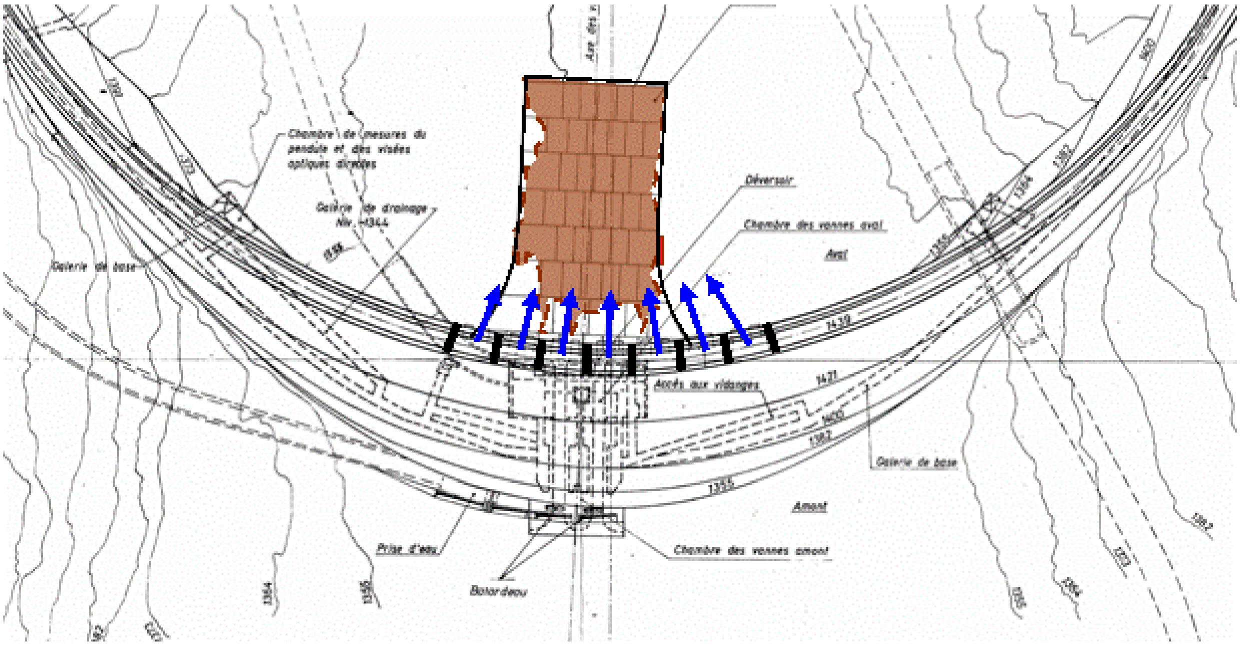

Fig. 1 Plan view of the plunge pool and the dam crest showing the damage to the concrete slabs

a) b)

Fig. 2 Photos of damaged concrete apron: a) overview; b) detailed view of damaged concrete slab.

The CSM basically represents a new method to evaluate scour formation in any type of brittle material. Examples are fractured rock, strong clays, concrete layers, etc. The model is physically based and the parameters are defined such that they can be used for engineering practice.

The model consists of three modules: the falling jet, the plunge pool and the fractured rock or concrete. The modules for the falling jet and for the plunge pool define the hydrodynamic loading that is exerted by the jet on the concrete apron. The former determines the major characteristics of the jet from its point of issuance at the dam down to the point of impact into the plunge pool. The latter describes the diffusion of the jet through the pool and the resulting jet excitation at the water-concrete interface.

Besides the fracturing process as a function of time, the third module allows estimating potential dynamic uplift of concrete slabs by net uplift pressures that are transformed into a net uplift impulsion. A more detailed description of all modules can be found in Bollaert (2004)[2)].

Emphasis will be given here on the steel anchorage necessary to prevent uplift of the new concrete apron. In ordinary pages, the text must be placed within borders immediately below 19mm top margin. The other layout is same as the main text in the title page.

3. HISTORIC DATA

Historic data are available for overtopping flow

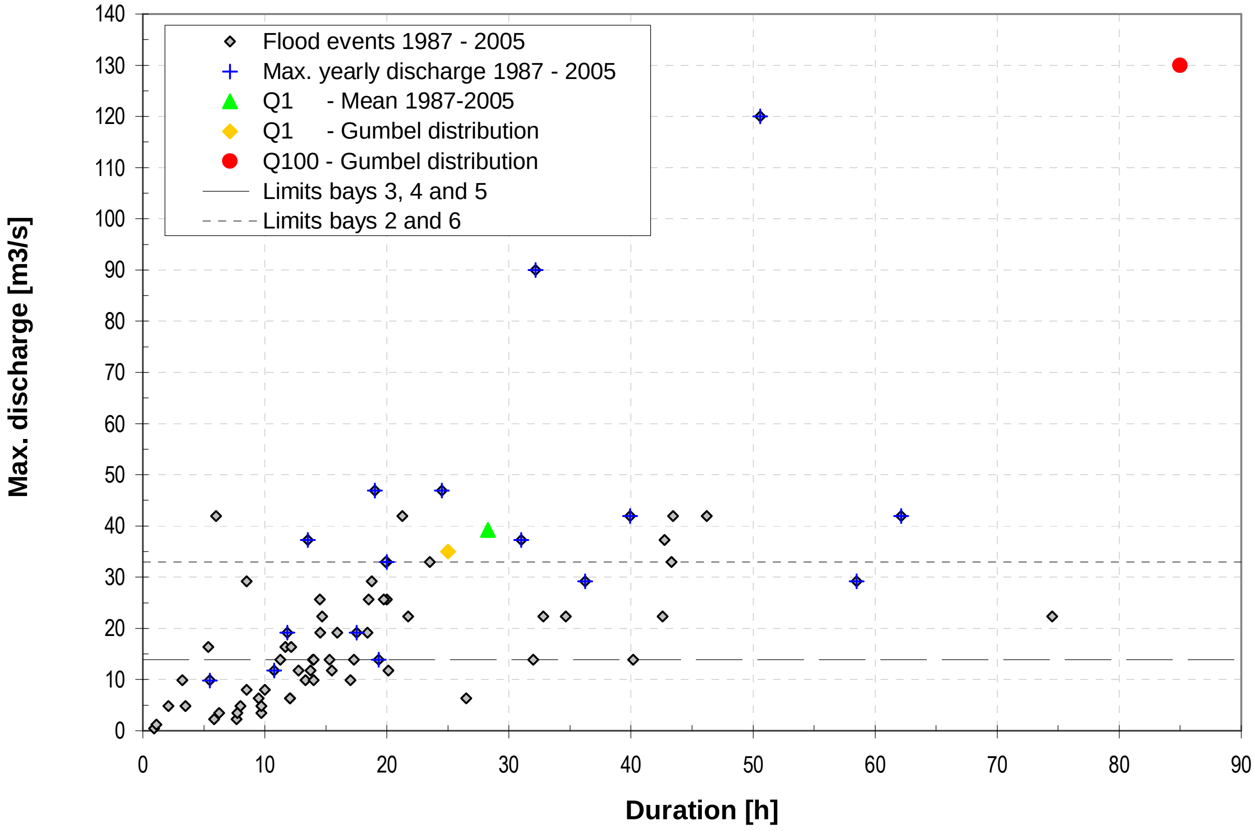

Fig. 3 Flow duration and intensity during overtopping of dam crest spillway.

discharge and flow durations since 1987. Figure 3 compares the measured values of the peak flow and duration of overtopping events with theoretical values for different flood return periods computed based on the Gumbel extreme distribution. In this way, the statistical yearly overtopping event has an average discharge of about 35 m^3/s, for a total duration of about 24h, while the 100-year overtopping event has a peak discharge of 120-130 m^3/s, for a total duration of almost 4 days.

4. FALLING JET AND PUNGE POOL

The detailed flow conditions over the dam crest spillway are illustrated in Figure 4 for the 100-year flood. At issuance from the crest, the flow velocity is 7-8 m/s for a flow depth of about 0.5 m.

The flow conditions at issuance from the crest form the basis for the jet trajectory calculations, which account for gravitational contraction of the jet core, jet diffusion, air drag and eventual break-up of the jet. The results are presented in Figure 5a for the 100-year flood. The jet impacts the concrete apron almost perpendicularly, with an average velocity of about 46 m/s. The jet is considered broken up.

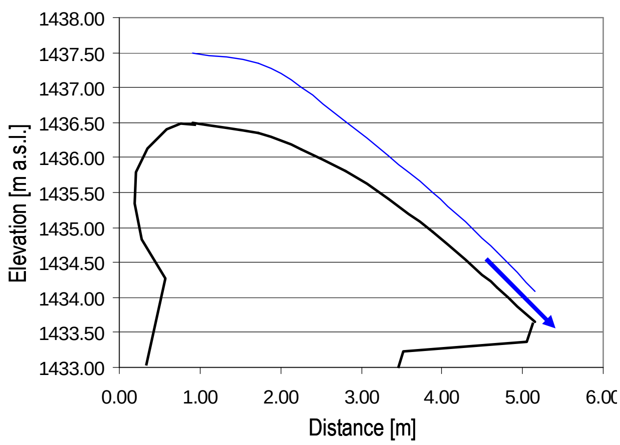

Fig. 4 Detailed flow conditions over the dam crest spillway for the 100-year flood.

The footprints of the different jets issuing from the different crest spillway bays are illustrated in Figure 5b. These are defined by assuming that the shape of the jet deforms during its fall. At issuance from the dam crest, the jets are of very flat shape, with a width to height ratio of about 5. Due to gravitational contraction and minimization of energy losses, jets deform during their fall. As such, rectangular shaped

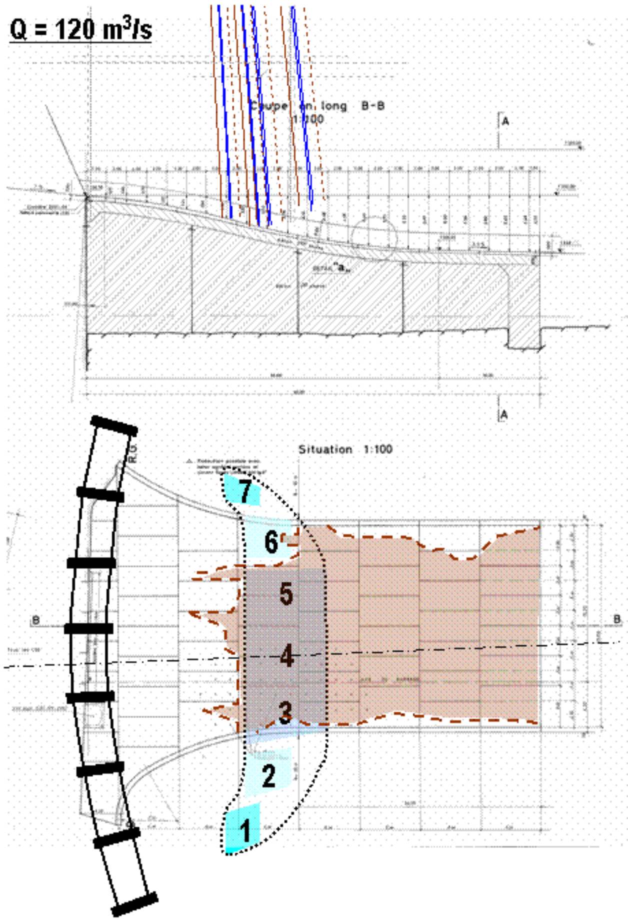

Fig. 5 100-year flood: a) Jet trajectories; b) Footprints of jets.

jets progressively change into circular or at least elliptical (= more compact) jets. This process, nevertheless, may take significant depth of fall to fully establish.

At Gebidem, based on videos and photographic evidence during past overtopping events, it has been considered plausible to adopt an elliptical shape for the jets upon impact. The disintegration is considered almost complete. Based on theoretical considerations, jet disintegration occurs after only about 10 m of jet fall for low discharges and after 75 m of jet fall for the 100-year flood. Nevertheless, for sake of safe design considerations, and based on actual lack of knowledge considering hydrodynamic pressures of broken up jets, the macroscopic dense clumps of water that still remain after jet break-up are still considered to be able to excite the concrete apron with severe hydrodynamic pressures. Their diameter is estimated at 0.80 m for the 100-year flood, assuming a purely circular shape.

The design of the concrete apron has been performed for both rectangular and circular shaped jets, representing the extreme situations (Figure 6). As no water cushion forms in the pool during overtopping, the jets directly impact the apron.

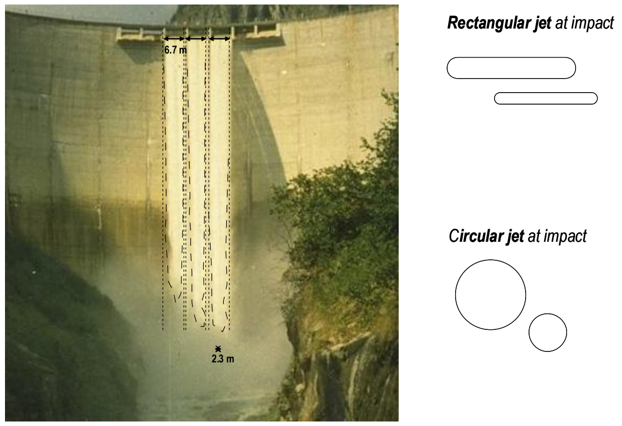

Fig. 6 Shape of jet impacting onto the concrete apron of the plunge pool.

5. DESIGN OF APRON AGAINST UPLIFT

Potential uplift of concrete slabs has been computed by determining the instantaneous net uplift pressure and impulsion.

Uplift pressures are defined by subtracting the positive pressure field over the slab surface from the negative pressure field that may install all under the slab surface (Figure 7). The latter pressures may typically be transferred to the underside of the slabs by means of construction joints and/or fissures in the concrete layer.

(1) Surface pressure field

The hydrodynamic pressure field at the surface of the slab is considered equal to the time-averaged mean pressure field. This approximation becomes valid only when the individual pressure spikes and peaks act on a very small surface compared to the total slab surface. As such, statistically a large number of spikes and peaks will cancel out each other. At Gebidem Dam, peaks and spikes act on surfaces with a diameter of typically 0.5-1.0 m, which is about one order of a magnitude smaller than the total slab surface lengths.

(2) Under pressure field

The pressures that are transferred to the underside of the concrete apron are determined based on the average surface pressures that act along the fissures responsible for the pressure transfer. The so defined pressures are multiplied by a factor of 1.20-1.35 to account for eventual transient effects and are adapted to the eventual presence of drainage galleries in the system.

(3) Net uplift pressure field

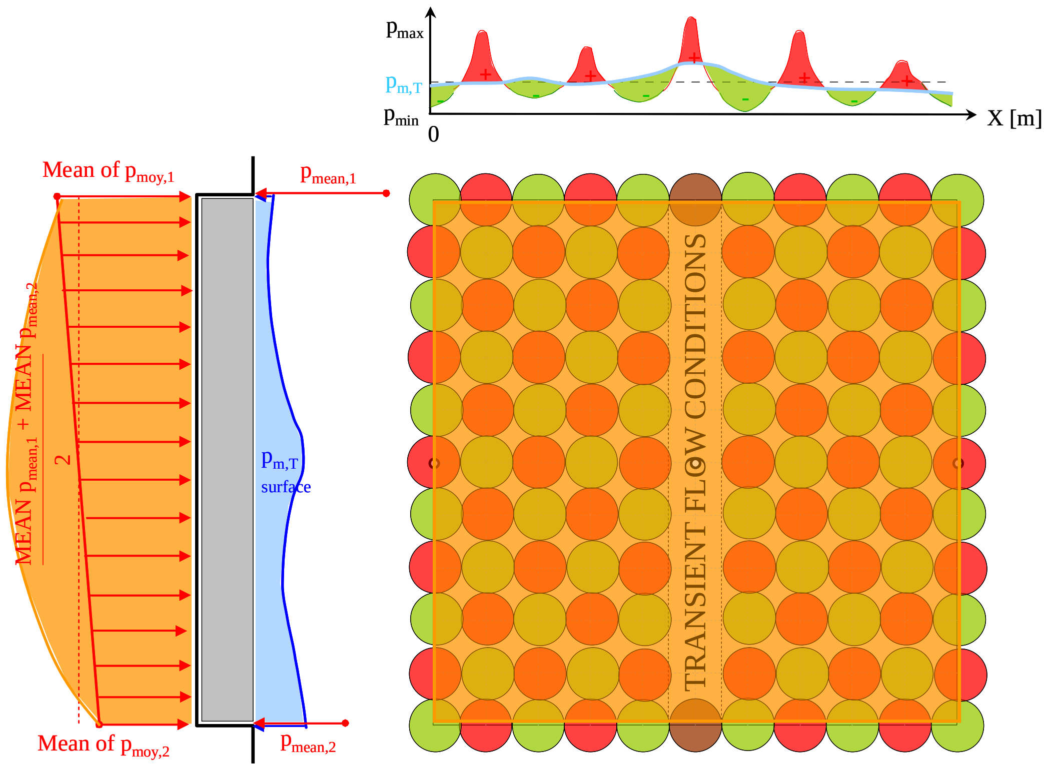

Fig. 7 Determination of net uplift pressure on concrete apron

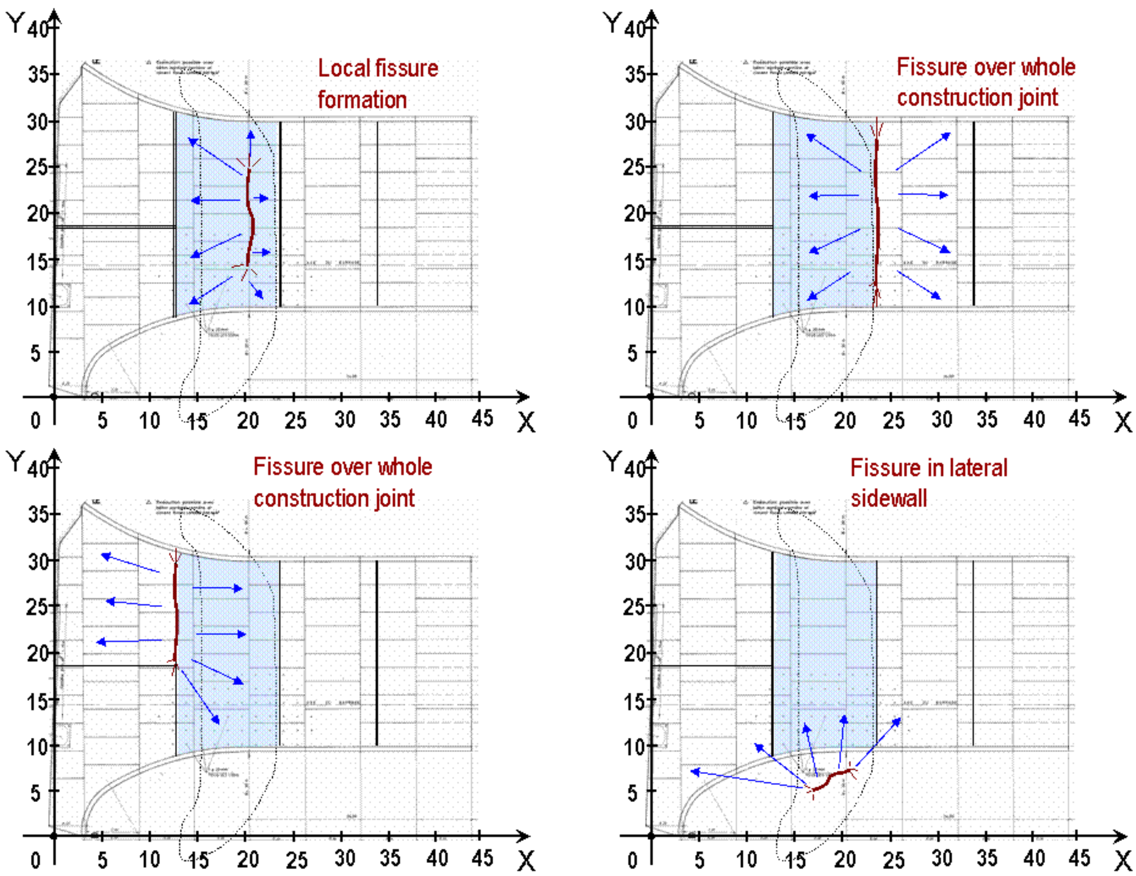

Fig. 8 Different fissure configurations tested by the numerical uplift model

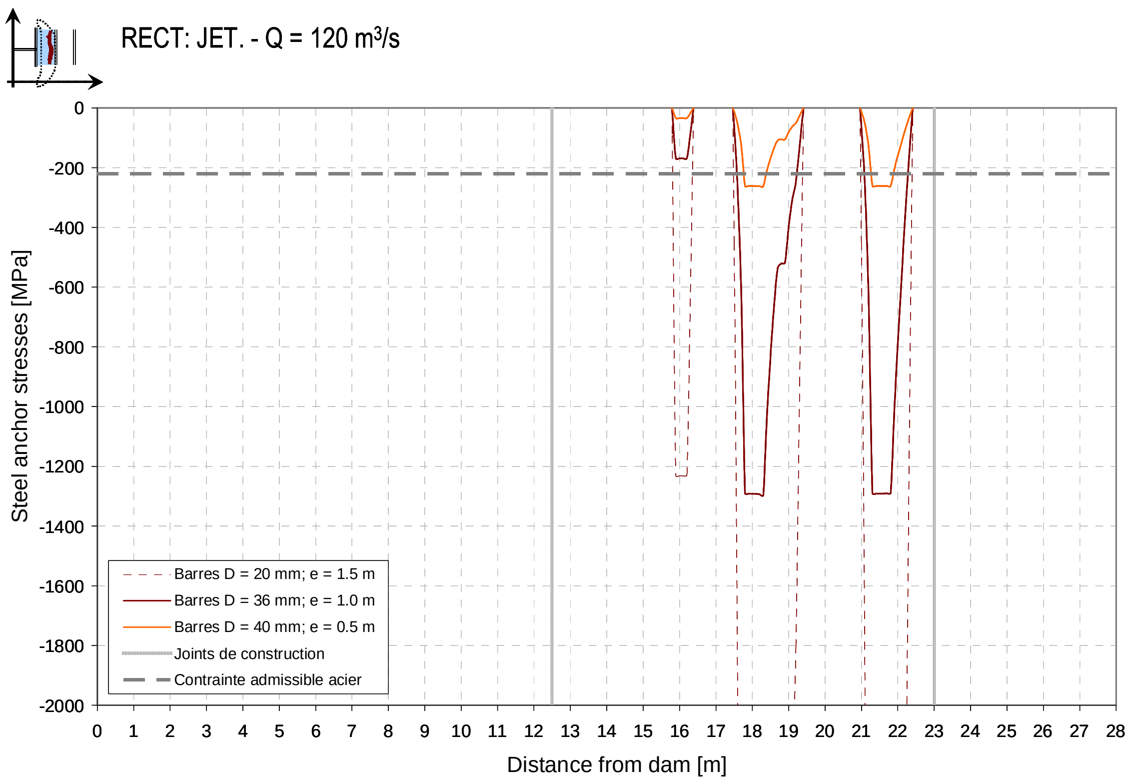

Fig. 9 Steel anchor stresses induced by the 100-year flood

By subtracting the spatially distributed surface pressure field from the under pressure field over a defined apron surface, the net uplift pressure field is obtained. The net uplift pressure field depends, however, on the assumptions regarding the type and extent of fissures that are responsible for their existence.

(4) Potential fissures in the concrete apron

Figure 8 presents some potential fissure formation in the new concrete apron of Gebidem Dam. The new apron is subdivided into distinct areas that are connected by construction joints. For each fissure configuration, the net uplift pressure field has been numerically computed. The results are presented at Figure 9 for the case of a fissure that extends over the whole lateral width of the new concrete apron. The apron is impacted by a rectangular shaped jet of 120 m3/s, i.e. the 100-year flood.

For the current steel anchor configuration, i.e. with a diameter of 20 mm and a spacing of 1.5 m, the numerical computations result in anchor stresses of thousands of MPa. To reduce these stresses close the allowable stresses of about 220 MPa, anchor diameters of 40 mm and a spacing of about 0.5 m are required.

(5) Summary of computational results

The computations of the necessary anchorage of the concrete apron have been performed for different fissure configurations, jet impact shapes, drainage conduits, anchor diameters and anchor spacings. The results are summarized at Table 1 and show that the zone of intense jet impact needs significant steel anchorage. Zones of the concrete apron further away from the point of jet impact, and benefiting from the presence of large drainage conduits to reduce the under pressures.

6. DESIGN OF APRON AGAINST FRACTURING

Second, potential fracturing of the new concrete apron has been checked for by applying the fracture mechanics module of the CSM (Bollaert, 2004). This module determines the maximum possible stresses that may be induced in the concrete layer, at the tip of micro-fissures, and compares these stresses with the resistance of the concrete against crack propagation.

The computations are performed for different types of jets and as a function of the duration of jet impact and initial fissure extent. The outcome of a large series of numerical computations has shown that, for both rectangular and circular shaped jets, the new concrete apron needs a compressive strength of min. 60 MPa. Moreover, rectangular shaped jets ask for a tensile strength of min. 4 MPa, while circular shaped jets need a minimum tensile strength of 5 MPa.

					Fissure over total length		Fissure 5 m long	
					WITH DRAIN	W/O DRAIN	WITH DRAIN	W/O DRAIN
	Discharge cms	Thickness apron m	Bar diameter m	Bar spacing m	Contrainte MPa	Contrainte MPa	Contrainte MPa	Contrainte MPa
CIRCULAR JET	35	0.5	0.02	1.5	-	-	-	-
		0.5	0.036	1	-	-	-	-
		0.5	0.04	0.5	-	-	-	-
	120	0.5	0.02	1.5	>>>	>>>	>>>	>>>
		0.5	0.036	1	-730	-1600	-1200	-2200
		0.5	0.04	0.5	-150	-320	-250	-430
RECTANGULAR JET	35	0.5	0.02	1.5	>>>	>>>	-600	-1900
		0.5	0.032	1.5	-1600	-2100	-240	-720
		0.5	0.036	1	-580	-900	-90	-250
		0.5	0.04	0.5	-120	-180	-20	-60
	120	0.5	0.02	1.5	>>>	>>>	>>>	>>>
		0.5	0.032	1.5				
		0.5	0.04	0.5	-250	-350	-370	-460

Stresses

- extreme
- very high
- too high
- ~OK
- OK

Table 1 Steel anchor tensile stresses as a function of shape of jet, bar diameter and spacing, type of fissure in concrete apron and presence of drainage galleries.

7. CONCLUSIONS

Based on extensive numerical computations of potential uplift and fracturing of the concrete, a new design for the concrete apron of the plunge pool of Gebidem Dam has been developed. This new design requests the following basic elements:

1. HRC-concrete with a minimum compressive strength of 60 MPa and a minimum tensile strength of 5 MPa,
2. Construction joints outside of the zones of jet impact,
3. Steel anchorage with 40 mm diameter bars at a spacing of 0.5 m in the zone of jet impact,
4. Steel anchorage with 32 mm diameter bars at a spacing of 1.5 m in the zones out of jet impact,
5. Drainage galleries separating these differently anchored zones.

As such, the new concrete apron is actually under construction at the site. Its first functioning will be during next spring 2009, by flushing of the reservoir through the bottom outlet gates and during next summer 2009, based on jet overtopping during flood events.

8. CITATION AND REFERENCE LIST

1) Bollaert, E.F.R.: Transient water pressures in joints and formation of rock scour due to high-velocity jet impact, *PhD Thesis* EPFL, 2002.
2) Bollaert, E.F.R.: A comprehensive model to evaluate scour formation in plunge pools, *Int. Journal of Hydropower & Dams (1)*, pp. 94-101, 2004