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Recent numerical models for engineering studies in open channels of power plants

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***Abstract*— In studies performed by EDF's Hydro Engineering Centre, Mascaret software is widely used to model the water waves in channels. This paper presents several recent models developed for Hermillon scheme, the "Grand Canal d'Alsace" and Line 4 of the Durance scheme, which totals 7 models and 15 branches. These models include a variety of areas, confluences, and pressurized galleries.**

The aims of these studies are to determine the maximum water level produced by a load rejection of the power plants, or to define the gradient of the increase in the water level, which is then used in protection alarms.

When it was possible, tests on site were realized and the results of the calculation were compared to the measurements. The paper also presents some numerical issues which occurred with Mascaret software.

I. HERMILLON SCHEME

A. Aim of the study

The aim of the study is to determine the hydraulic behaviour of Hermillon channel, operating at a flow 20 % greater than the design flow and to check that there is no overflow during load rejection of the power plant.

Fig. 1 Layout of the channel

B. Characteristics of the model

The scheme is modelled from the intake of Saint Martin la Porte dam to the entrance of the power plant tunnel, by a single branch.

Design flow (1974)	80 m^3/s
Design flow + 20%	96 m3/s
Fudaa-Mascaret version	3.5 (2015)
Calculation core	unsteady subcritical

C. Limits of the model

The pressurized flows that occur in the reinforced concrete tunnel (940 m), and in the siphon of the Rieu Sec (140 m), have been modelled using a Preissman slot, which is not a satisfactory representation, as the lengths of these tunnels are significant relative to the channel's length (2250 m). However, a comparison between computed and measured values shows that this assumption is acceptable in this particular configuration.

The model does not take the channel's bends into consideration. The head difference produced by the channel bend or lateral banking, however, is very slight, less than 1 cm, considering the channel's curvature.

D. Modelling parameters

The surface width being about 10 to 30 m, the spacing between the design profiles was set at 20 m.

The height of the water being around 4 to 6 m, the planimetric step in a profile section was set at 10 cm.

After checking its influence on the water level calculations, the calculation time step was set at 2 s.

As flow in the channel is subcritical, the unsteady subcritical core was chosen and a water level would usually be imposed downstream and a flow upstream. However, the transient state simulations were done with a flow downstream and a constant level upstream because there is some measurement of the flow at the downstream extremity of the channel.

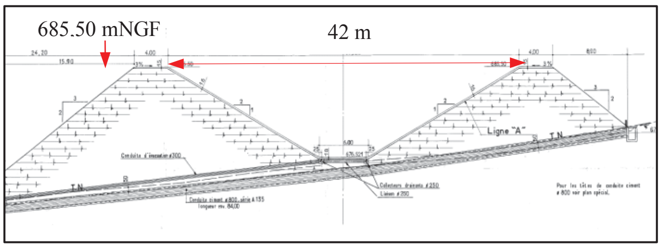

Fig. 2 Cross section of the channel

Fig. 3 Measuring flow and water level using a radar sensor at the downstream extremity of the channel

E. Main results

The values of the Strickler coefficients (Ks) were determined using two tests carried out on site in April 2015

TABLE 1: STRICKLER COEFFICIENTS (KS) FOR THE DIFFERENT PARTS OF THE CHANNEL

Parts of the channel	Ks
Reinforced concrete tunnel	81
Channel upstream	55
Rieu Sec siphon	75
Channel downstream	70

Fig. 4 Wave propagation going to the upstream, observed during the tests carried out in April 2015

The measurements gave a wave speed of 5 to 6 m/s.

The comparison between the model predictions and the measurements was satisfactory for the period of oscillation and the maximum water level values that occur in transients. However, the initial state or steady state showed a significant difference of 30 cm, which was one of the issues encountered in this study.

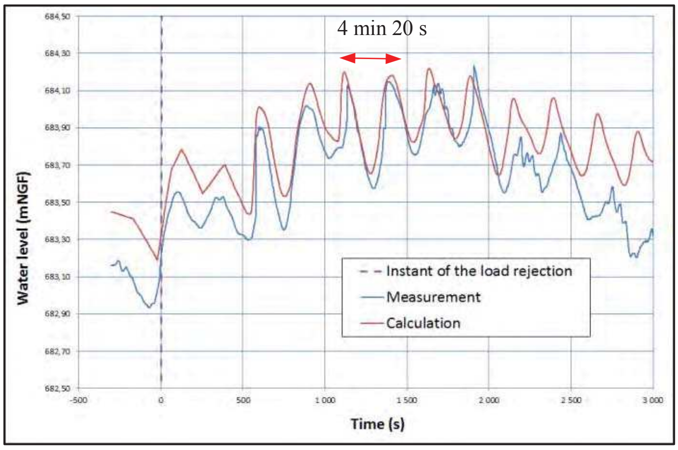

Fig. 5 Predicted and measured water level at the downstream extremity of the channel (test D5)

The simulation of a start up at the dam's high level, followed by a simultaneous load rejection of both units gives a maximum level that is reached at the downstream extremity of the channel and which leaves a freeboard of 1.10 m relative to the bank crest.

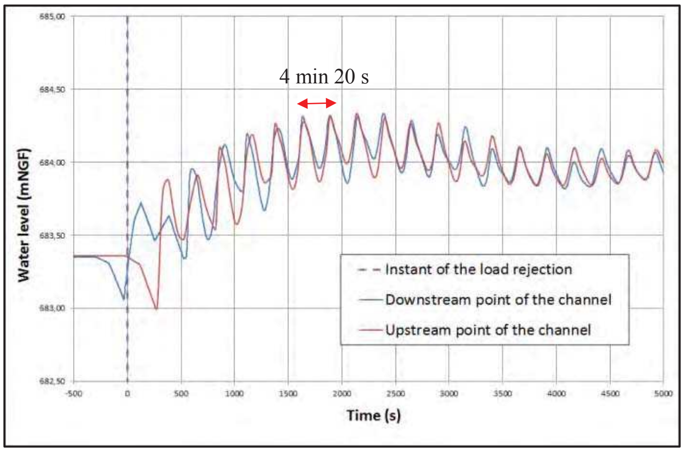

Fig.6 Result of a start up followed by a load rejection at the two extremities of the channel (calculation D6P)

The Mascaret code therefore fulfilled the aim of the study and the physical phenomena measured during the on-site tests were confirmed by calculations.

F. Difficulties encountered

It later appeared that, during the tests in steady state, the flow was stabilised but the water levels were not. The calibration of the Ks coefficients is therefore not optimum and can vary according to the simulations.

An analysis of the physical phenomena showed that the maximum water level in the channel is obtained not at the first group of oscillations, but after a rise of the water level towards the static level corresponding to the level in Saint Martin La Porte reservoir.

This maximum water level is therefore dominated in the first order by the filling of the channels (60 min period) and only in the second order by the amplitude of the wave propagation. Considering the filling phenomenon described above, we can deduce that the channel's load losses only have a slight influence on this maximum level.

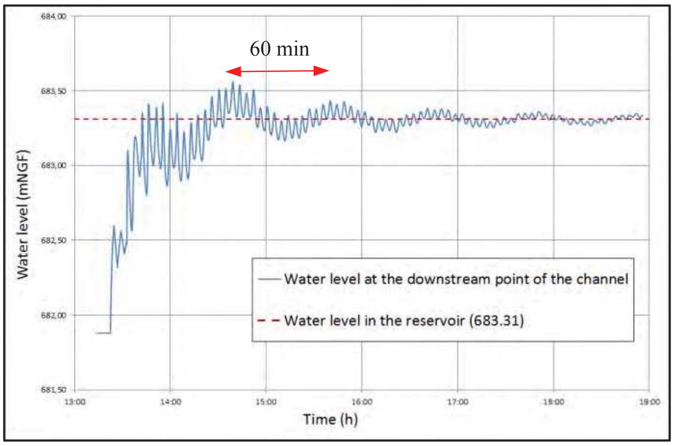

Fig. 7 Oscillations during the filling of the channel (D2)

II. "GRAND CANAL D'ALSACE"

A. *Aim of the study*

The aim of the study is to determine the variations in water levels produced by a load rejection in the headrace canals of Kembs, Ottmarsheim, Fessenheim and Vogelgrün power plants situated on the Grand Canal d'Alsace (GCA), without using the discharge elements.

These level variations have been drawn for a few specific points of the channels, corresponding to the locations of water level measurements and security weirs. They allow to determine the gradients of the rising water levels, to set the automatic operation system so that it does not deactivate them in case of the discharge elements stay closed (feedback on the incident at Marckolsheim scheme). They were also used to calculate the arrival times of the wave at the different security weirs.

Only the Kembs and Ottmarsheim models are detailed in this article.

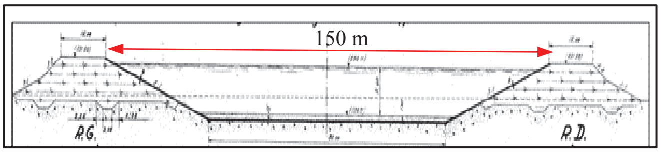

Fig.8 Cross section of the Grand Canal d'Alsace

B. *Characteristics of the models*

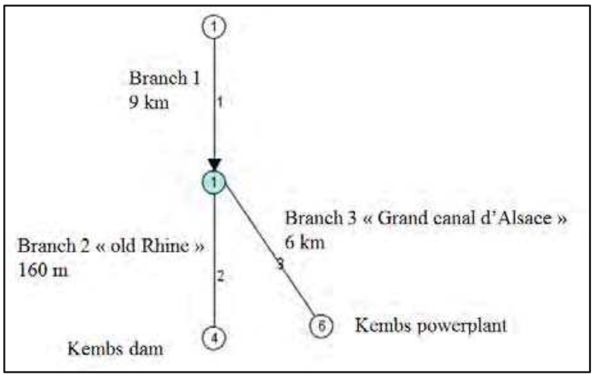

Fig. 9 Kembs model

TABLE 2: STRICKLER COEFFICIENTS (KS) IN THE DIFFERENT BRANCHES

Branch no.	Ks
1	25 - 40
2	39
3	49

Computation core unsteady subcritical

The transcritical core was used in that case, because the calculations are more complex with the diffluence.

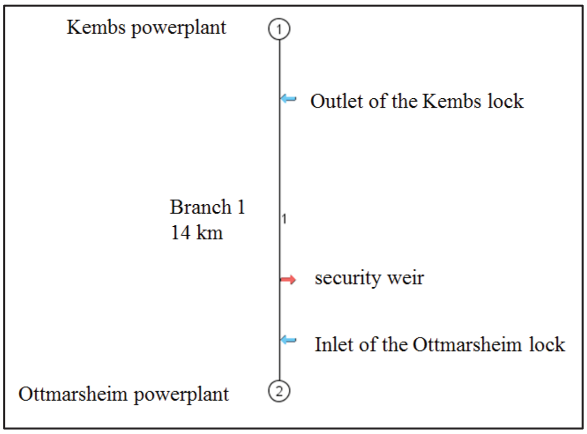

Fig. 10 Ottmarsheim model

Strickler coefficient	46
Computation core	transcritical
Use of non-hydrostatic terms	yes

These models were not calibrated and the Strickler coefficients are those used in the Mascaret models developed during earlier studies by EDF's Laboratoire National de l'Hydraulique et de l'Environnement (LNHE).

C. Modelling Parameters

For all simulations, the flow cutoff is triggered 5 min after the start of the simulation to check the model's stability in steady state.

A 0.25 s time step was used for Ottmarsheim, Fessenheim and Vogelgrün.

For Kembs, a 1 s time step was chosen to reduce the digital oscillations that only appeared for this model with 3 branches.

For the four models, a 10 m mesh size was chosen so that the sudden variations of the reservoir would be correctly reproduced by the model, although this size is much lower than the recommended rule of two to three times the width of the branch.

For the four models, a planimetric step value of 20 cm was chosen. 50 cm and 20 cm values were tested and the influence between these two values is negligible. This value of 20 cm respects the guideline of taking the elevation difference between the profile's lowest point and the water line's highest point, divided by 50.

Based on a water line initialised as steady state, the transient state uses the following limit conditions:

Upstream flow (1932) constant equal to 1400 m^3/s

Downstream flow cut from 1400 to 0 m^3/s in 10 s

D. Main results

The maximum level is not produced by the first intumescence since the channel continues to fill with a constant upstream flow, simulating a loss of the load rejection information from Kembs or Ottmarsheim power plants.

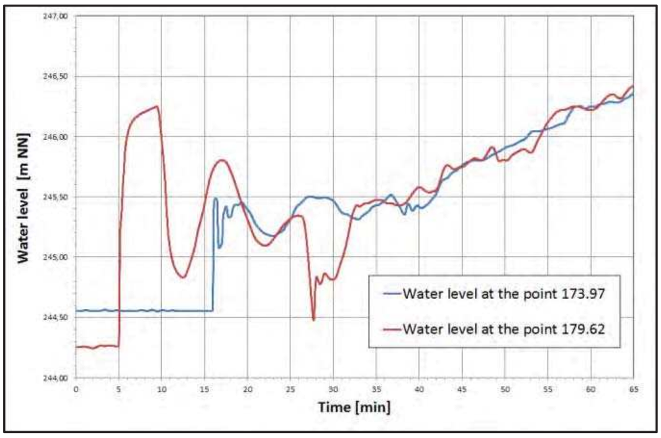

Fig. 11 Variation of water levels at Kembs in two different points

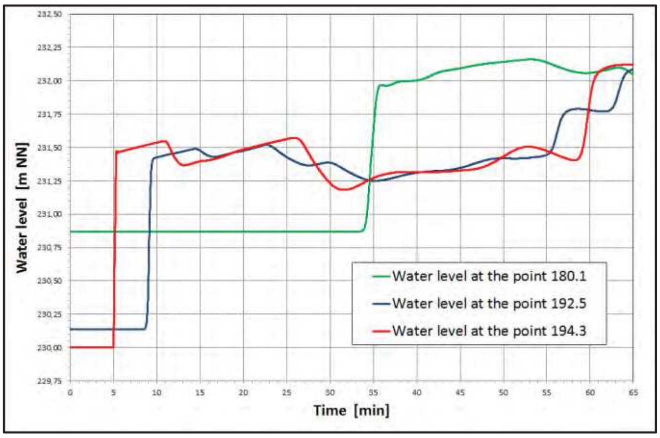

Fig. 12 Variation of water levels at Ottmarsheim in three different points

For Ottmarsheim (there is no security weir at Kembs) the time between load rejection and the start of overflow at the two extremities of the security weir is 11 min and 13 min. This corresponds to a speed of 8.5 m/s.

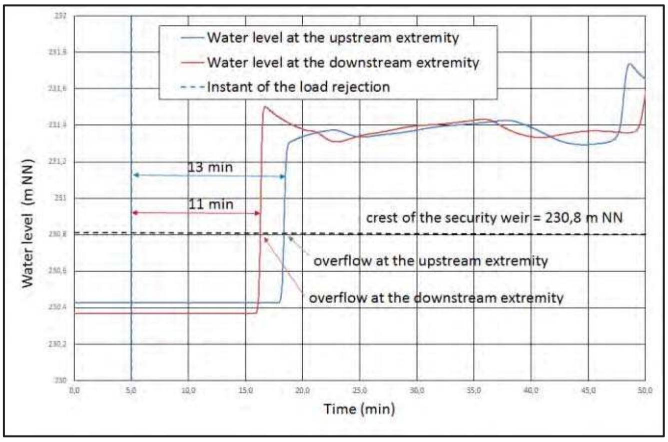

Fig. 13 Evolution of the level at Ottmarsheim security weir (D=5.6 km, L=1 km)

D = distance between the powerplant and the downstream extremity of the weir

L = length of the weir

The Mascaret code allowed the water level gradients and the transit time of the wave propagations required for the operation of the Rhine power plants to be predicted. These predictions avoided having to carry out on-site tests for each plant.

E. Difficulties encountered

Between two simulations carried out with mesh of 20 m and 10 m, the maximum level of the first oscillation shows a difference of 25 cm. The gradient of the rise in water level is unchanged, but this result is presently unexplained.

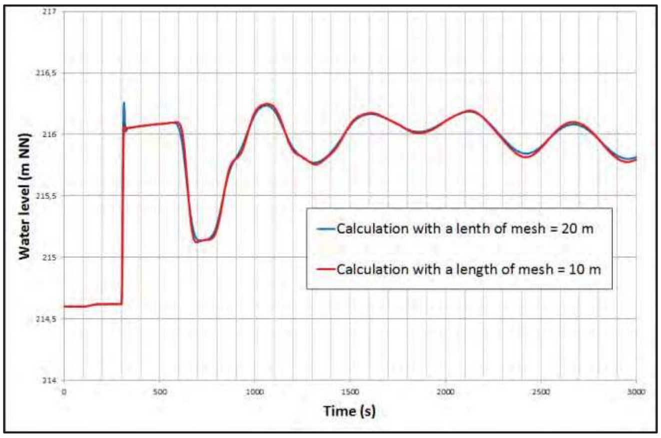

Fig. 14 Influence of the mesh

III. LINE 4 OF THE DURANCE SCHEME - MANOSQUE POWERPLANT

The studied Line 4 is made up of six hydropower plants linked by 8 EDF channels parallel to the Durance river. To calculate the wave propagation, the line was separated into two parts, to refocus on the headrace canals of Manosque and Sainte Tulle 2 power plants.

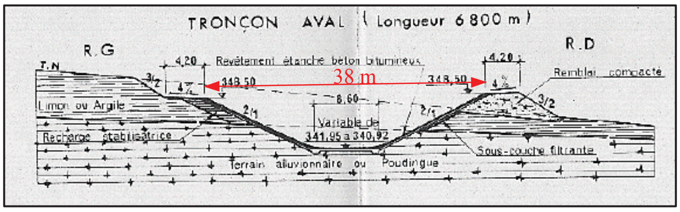

Fig. 15 Cross-section of Manosque headrace canal

A. *Aim of the study*

The aim of the study was to check the impact of an increase in flow from 140 to 168 m^3/s at Manosque power plant on the safety of the scheme's channels. The main check was that the water level variations produced by the plant's load rejection did not produce any overflow or loading of the bridges crossing the channel.

B. *Characteristics of the model of Manosque*

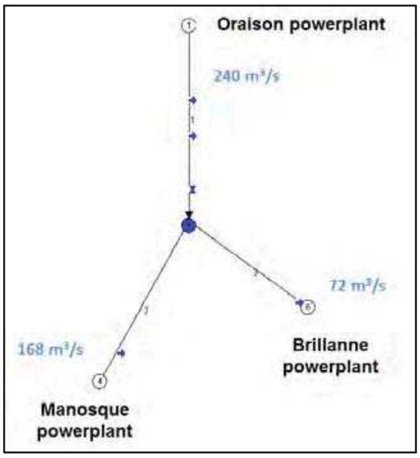

Fig. 16 Model of Manosque

The model is made up of three branches and three power plants: Oraison, Manosque and La Brillanne, linked by a junction called the Saint Saturnin diffluence.

Design flow (1969)	140 m^3/s
Design flow + 20 %	168 m^3/s
Fudaa-Mascaret version	3.5 (2015)
Calculation core	unsteady subcritical

Fig. 17 Saint Saturnin diffluence (view from upstream with a drone)

C. *Tests realized in October 2017*

The water level and flow measurements taken during the tests in October 2017 were done with a discharge of 140 m^3/s. They showed that the Favre waves observed on site did not produce maximum level in Manosque headrace canal.

For this reason, the "transcritical" core which allows the option "considering the non-hydrostatic terms" to be used, was not used.

Fig. 18 Wavefront and Favre waves in Manosque headrace canal (test D6)

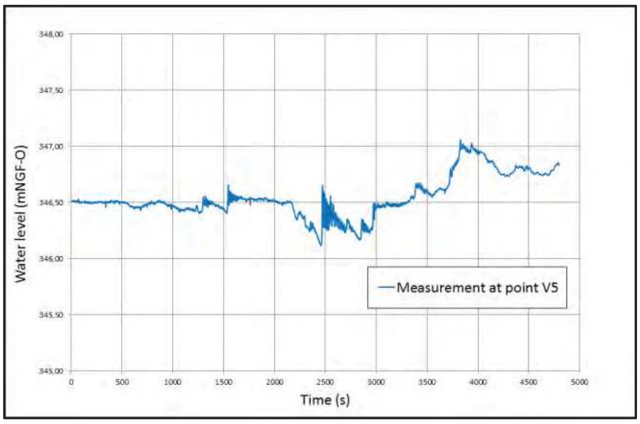

Fig. 19 Measurement in Manosque headrace canal (sensor V5 - test D6)

D. Calculations parameters

The numerical simulations have to be carried out at the highest level in the power plant's headrace canal, as well as with the highest flow. The operating constraints in steady states must therefore be considered, to avoid overflow at the security weirs and to respect the level laws set by the power plants controllers.

The main simulations are either a load rejection, or start up followed by a load rejection.

In steady state, as the flow regimes are subcritical, the simulations are done using the limit conditions upstream flow – downstream elevation.

In transient state, the simulations are done using the limit conditions upstream flow - downstream flow, based on the water lines in the channels determined by the steady state.

Since the watch officer of the Hydro Control Centre (CCH) can control the plants' operation, it was decided to use the flow variations measured during the on-site tests in October 2017 and adapted for the simulations at 168 m^3/s.

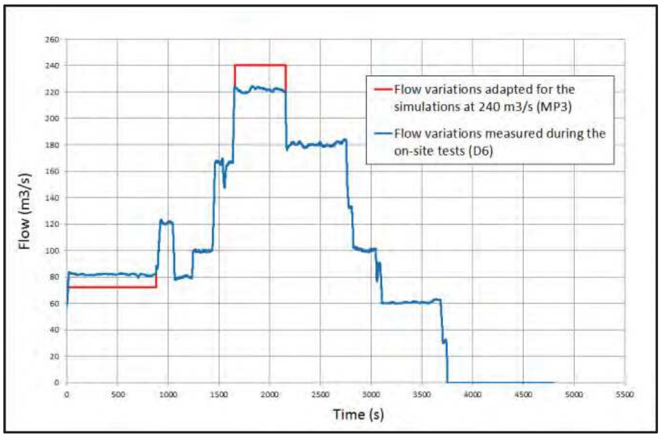

Fig. 20 Oraison flow laws

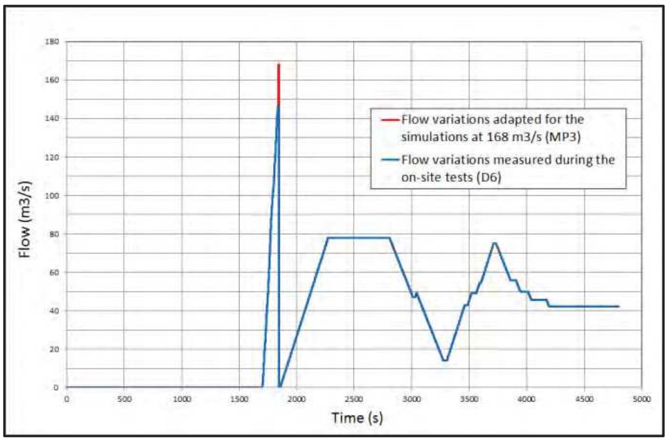

Fig. 21 Manosque flow laws (turbine + unloader)

E. Main results

The calibration of the model was based on tests carried out in 2012 to determine the Strickler coefficient values

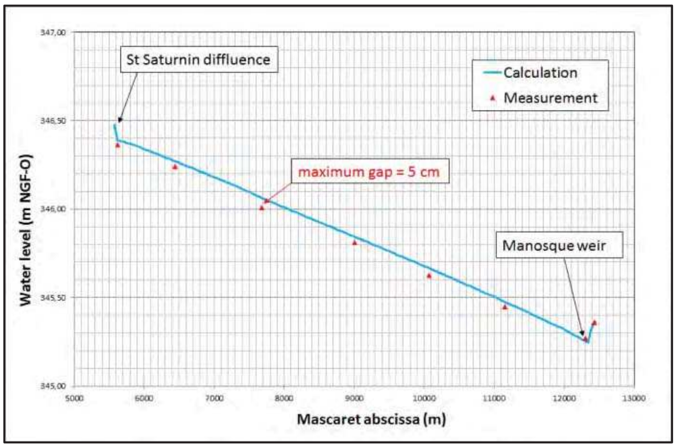

Fig. 22 Calibration of the Strickler coefficients

TABLE 3: STRICKLER COEFFICIENTS (KS) FOR THE DIFFERENT BRANCHES

Branch number	Abscissa of branches	Ks
1	0 – 403	60
1	403 – 2 220	62
1	2 220 – 3 899	70
1	3 899 – 4 257	68
1	4 257 – 4 292	60
1	4 292 – 5 527	65
2	5 566 – 12 448	65
3	12 603 – 14 205	52
3	14 205 – 15 054	54

The head losses that are specific to Saint Saturnin diffluence were not modelled. In steady state, they are included in the regular head losses by the Strickler coefficients.

In transient state, the maximum difference between the calculations and the measurements taken in October 2017 is 15 cm. It was decided to give the results with no uncertainty, because the numerical model tends to increase the levels measured during tests.

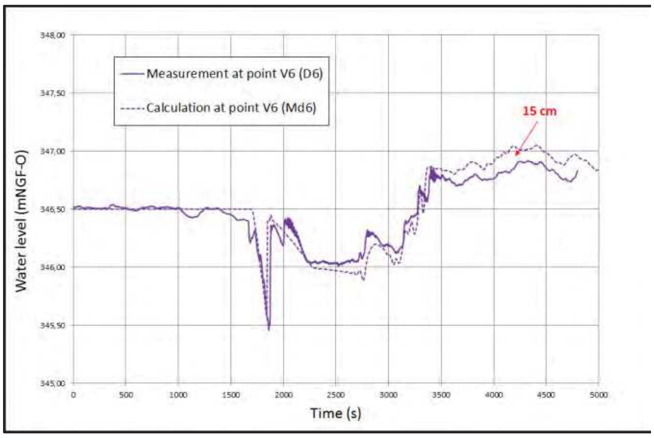

Fig. 23 Measurement calculation comparison for test D6

The maximum level reached for all the simulations at 168 m^3/s is at the upstream extremity of Manosque channel. The corresponding minimum freeboard is 1.10 m relative to the banks crest (348.50 m NGF-O) and no bridge is loaded.

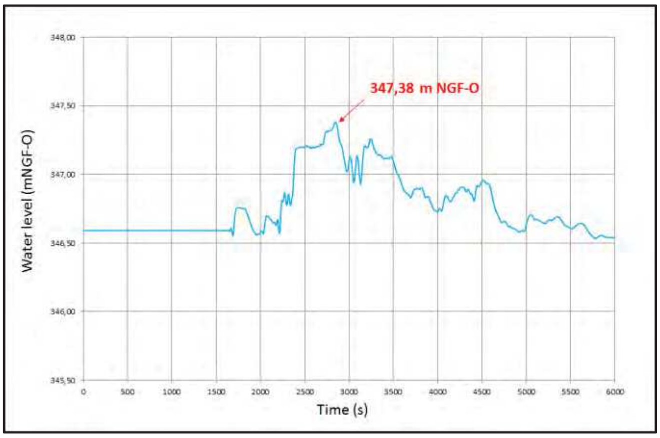

Fig. 24 Water level at the upstream extremity of Manosque channel during loading followed by a load rejection (MP3)

Thanks to Mascaret, it was possible to model this fairly complex scheme, after a number of simplifications, justified by the results of the tests of October 2017 and by the freeboard determined by the calculations, aim of the study.

F. Difficulties encountered

The calculation core used is "unsteady subcritical" because the initial water line calculations using the "transcritical" core do not converge easily and take too much calculation time, which was unsuitable for the time frame of this study.

Moreover, the initial water line calculated using the "unsteady subcritical" core is not compatible with a transient state calculation using the "transcritical" core.

Indeed, when we go back to the calculation, the "transcritical" core lacks information on the condition of the confluences, causing a systematic numerical instability at the start of the calculation.

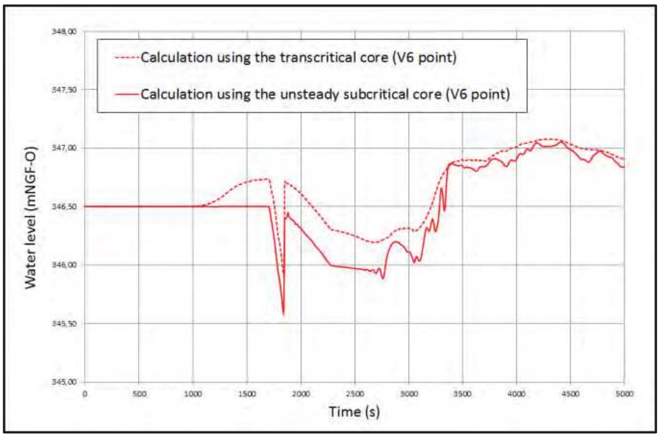

Fig. 25 Difference between the unsteady subcritical and transcritical cores

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