

HYDROELECTRIC PLANT DISCHARGE EMERGENCY SYSTEM: TECHNICAL ISSUES AND EXPERIMENTAL RESULTS.

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Abstract: In many power plants designed to turbine large discharges, the effectiveness of emergency dissipating system plays a key role in case of cut off. The paper deals with the results of laboratory tests carried out on the scale model of the Power House Discharge System of the EEPKO Project in Beles (Ethiopia). The emergency discharge system was completed in 2010 and actually is fully operating; it consists in a dissipating system realized by a penstock connected to a Howell Bunger valve issuing in an armoured chamber and, at its end, a steel lining pipe.

The design of the lab scale model of the emergency discharge system and of the experimental campaign was developed jointly by the research staff of Technical University of Bari (Italy) and of ATB Riva Calzoni SpA, and carried out at the hydraulic laboratory of Technical University of Bari (Italy). In the paper, some technical requirements are analysed, as the need to line with steel plates the conventional grouted wall of the adit receiving the high velocity issuing jet. The data collected during the experimental test on the lab model are summarized, analysed and commented

Keywords: Emergency discharge system, geometrical scale model, dissipation efficiency, cavitation, Howell Bunger valve.

INTRODUCTION

In many power plants designed for turbinning large discharges, the effectiveness of emergency dissipating system has a key role in case of cut off. In order to assure safety of operations, and also to accomplish with the minimum biological discharge requirements, a water release penstock has to be designed to dewater the high pressure headrace tunnel. In case of underground plants, a ceiling-sloping tailrace tunnel can represent the most effective solution, provided that it is settled sufficiently upward the power house and equipped with proper outlet valves. Anyway,

notwithstanding high performance valves are surely available, the hydrodynamic thrusts caused by the issuing jet cannot be sustained in terms of scour by a grouted tunnel structure, which, in addition to a steel lining for covering the tunnel faces, needs an optimization of the efficiency of the dissipation device.

The paper deals with the results of a laboratory test carried out on the geometrical scale model of the Power House Discharge System of the EEPKO Project in Beles at the north-central Ethiopia (figure 1), jointly designed by the research staff of Technical University of Bari, ATB Riva Calzoni SpA and Studio Ing. G. Pietrangeli srl. The Beles Multipurpose Project is a large trans-basin 460 MW hydroelectric plant and it consists in an inlet channel whose origin is in Lake Tana, a 11 km headrace tunnel, an underground penstock and a powerhouse equipped by four turbines featuring 115 Mw each. The release system is realized by a 7.3 km tailrace tunnel and outlet regulation works into the Beles river. All the civil and mechanical works were completed in 2010 and actually the entire system is fully operating.

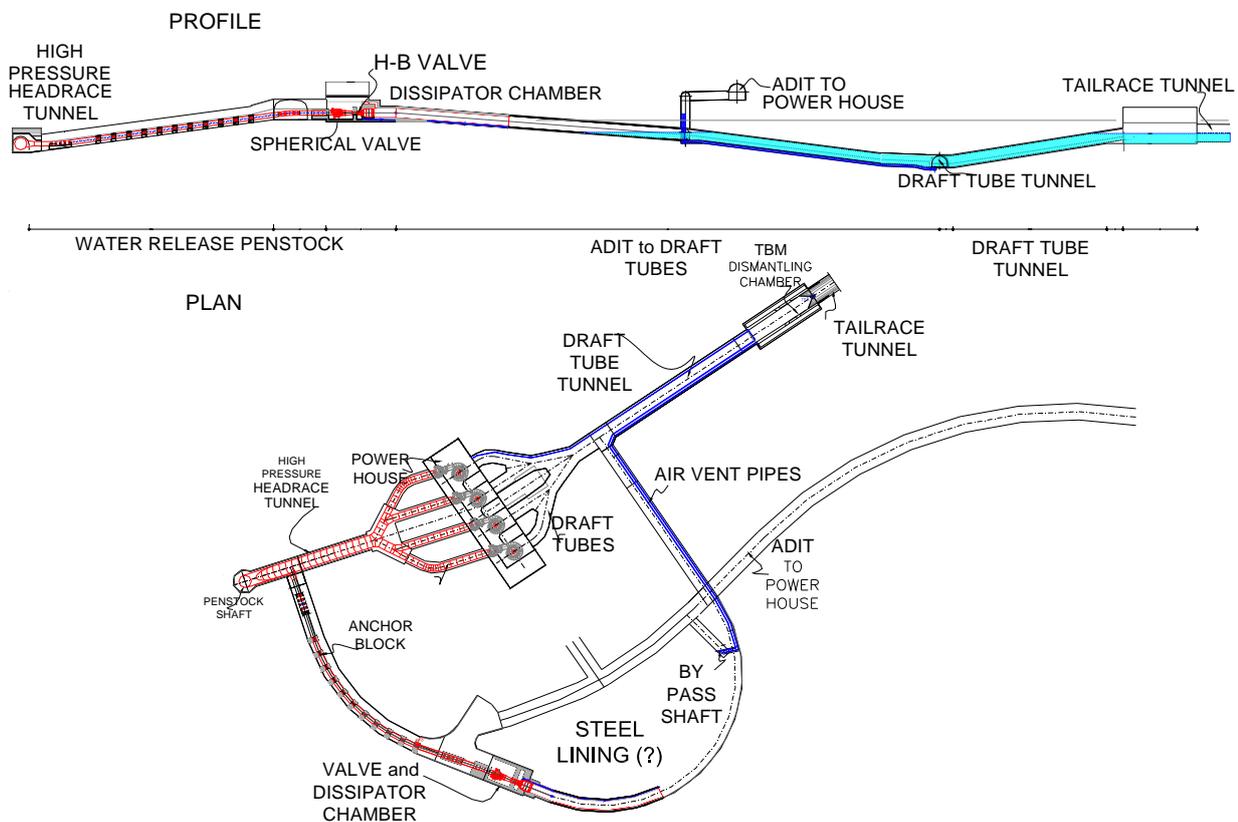


Fig. 1 – Beles Multipurpose Project: profile and plan view.

In order to ensure the environmental flow into the Beles river, besides to emergency or maintenance cases, a bypass system was realized. At the same time, it guarantees the irrigation water needs of a large agricultural area being designed for about one and half of the expected turbined discharge. The described bypass consists of a 100 m long, 2 m diameter water release penstock, a spherical guard valve, a 1500 mm Howell Bunger valve, an armoured chamber and a concrete tunnel with an initial steel lining protection approx. 85 m long. The HB valve is endowed with a hood, having an

annular orifice at the valve body junction: the hood is designed for enhancing the jet self-aeration process. The armoured chamber ventilation is ensured by an adit to the power house.

The jet issuing by the HB valve diffuses in a closed but aerated chamber: this occurrence, being the proposed device typically an outlet valve, yields to realize a laboratory modeling of the above described bypass for optimizing its hydraulic behavior and its geometry. Main goals of the designed laboratory tests were in confirming experimentally a) the geometry of the flow jet , b) the dissipation efficiency of the H-B valve and globally of the entire dissipation system; c) the evaluation of the pressures acting upon the lining pipe.

PHYSICAL MODELING REQUIREMENTS AND ANALYTICAL BASES

The laboratory scale model (Photo 1) was designed according to the Euler similitude, using a geometric scale λ_g equal to 1:20 whereas the pressure scale λ_p was set to 1: 10; consequently the velocity scale λ_v was equal to 1:3.16. The main geometrical and hydraulic data are in table 1.



Photo n. 1– Model at Technical University of Bari (Italy).

Table 1 – Prototype to laboratory model scale

	Upstream pipe diameter	HB Valve Diameter	Maximum working pressure	Discharge	Valve Velocity	Incipient cavitation index σ_i
	[m]	[m]	[bar]	[m ³ /s]	[m/s]	
Prototype	2	1.5	33	77	43.6	4.96
Model	0.1	0.075	3.3	0.06	13.8	2.94

It is worth to mention that Reynolds and Richardson scale effect were neglected since, in all tests, Reynolds number was greater than 10^7 and the expected change in water density was lower than 0.6%. On the other hand, Weber number could highly affect the results if the model data are directly scaled to the prototype size (Falvey, 1980), owing to the high air content and fragmentation of the

jet issuing from the valve. Ohnesorge (1937), as cited in Vischer and Hager (1995), introduced three different jet breaking mechanism types, each of them characterized by an increasing dissipating efficiency, which can be summarized as: (I) free surface vibration in axial direction, (II) jet breakdown due to symmetrical twisting shape vibration and (III) spray formation. At the same time, he defined a dimensionless parameter, known as Ohnesorge number, as follows :

$$Oh = \frac{\nu}{(\sigma D_o / \rho_o)^{1/2}} \quad (1)$$

in which ν , ρ_0 and σ are the kinematic viscosity, the fluid density and the surface tension respectively, whereas D_0 the valve diameter immediately upstream the fixed cone. In figure 2 is reported the Ohnesorge classification; it is evident as the dot, representing the design conditions for the tested HB valve, lies in the third region, the spray formation one, confirming as scale effects due to the surface tension are expected.

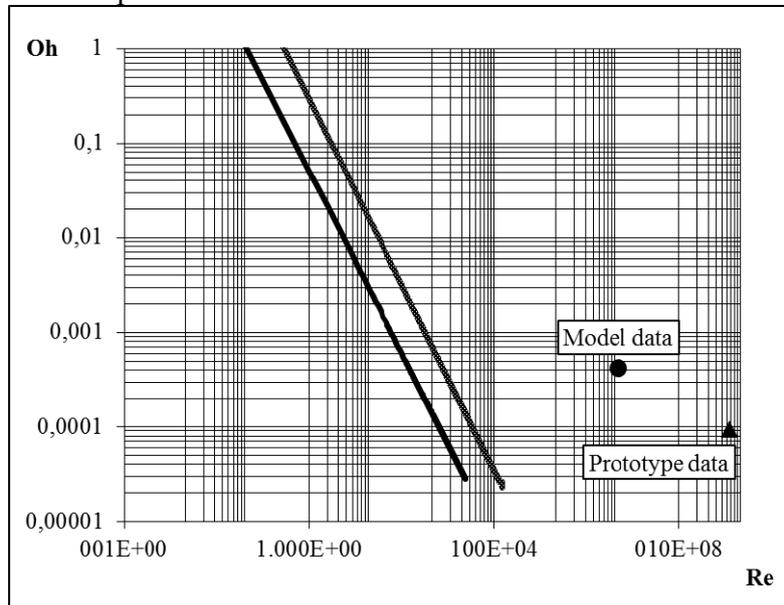


Fig. 2 – Ohnesorge classification of jet disintegration.

On this matter, Renna et al. (2006) and Fratino and Renna (2006), by means of experimental tests, demonstrated as an annular jet issuing from a fixed cone valve presents the over-crossing of the flow streamlines in a point located approximately 3 to 4 times the hood diameter; in reference to the tested model, the designed hood appears to be not long enough to generate a fully-mixed jet before it enters into the tunnel, as confirmed by the experimental evidences, too.

The dissipation efficiency of the HB valve and the cavitation tests were carried out according to the ANSI-ISA specifications (ANSI-ISA S75.02, 1988). According to the standards, the loss coefficient was defined as follows:

$$K = \frac{\Delta P}{\rho \frac{V^2}{2}} \quad (2)$$

whereas cavitation index was defined as:

$$\sigma = \frac{P_v - P_w}{\frac{1}{2}\rho V^2} \quad (3)$$

in which ΔP is the net pressure drop, ρ the water density, V the mean velocity in the pipe section just upstream the valve and P_v and P_w the downstream valve pressure and the vapour pressure at water reference temperature respectively.

Pressure and size scale effects was taken into account by means of two experimentally based coefficients named pressure scale effect (PSE) and size scale effect (SSE).respectively The PSE coefficient is defined as follows (Tullis, 1989, 1994):

$$PSE = \left[\frac{(P_d - P_w)}{(P_{d\ ref} - P_{w\ ref})} \right]^{0.265} \quad (4)$$

where P_d and P_w are the absolute pressure values at which the adjusted sigma is desired and P_{d_ref} and P_{w_ref} are the absolute pressure values at which the experimental tests were conducted. The exponent value was chosen analyzing an extensive available dataset (Tullis, 1994).

About the SSE coefficient, it was defined by the following equation (Tullis, 1989, 1994):

$$SSE = \left[\frac{D}{d} \right]^{0,3K^{-0,25}} \quad (5)$$

in which K is the loss coefficient, D is the valve diameter to which the cavitation data have to be scaled and d is the valve diameter of the reference cavitation data.

The relationship to be applied for obtaining a scaled-to-prototype cavitation index σ_{iprot} being known the model index σ_{imod} is:

$$\sigma_{iprot} = PSE * SSE * \sigma_{imod} \quad (6)$$

The laboratory testing line was equipped by an electromagnetic flow meter (model IF6-3800/1A1AM by ASA S.p.A) located on the upstream pipe, which assures an accuracy equal to 0,25% full scale and by a couple of high precision Bourdon tube pressure gauges, manufactured by Salmoiraghi, for measuring the pressure values upstream and downstream the HB valve. The cavitation occurrence was detected measuring vibration and sound induced effects; in this particular instance, for measuring vibration data, two different accelerometers were used: a Brüel & Kjær piezoelectric accelerometer (model type 4384) and a Brüel & Kjær Delta Tron accelerometer (model type 4397) whereas noise was registered by means of a 1/2" diameter Brüel & Kjær condenser microphone (model type 4191). The vibration sampling frequency was settled to 25.6 kHz, whereas the sound sampling frequency was equal to 51.2 KHz.

Finally, the pressure values on the downstream tunnel were measured, settling the sampling frequency to 40 Hz, by means of Bourdon-Haenni protruding piezo-electric transducers.

DISCUSSION

In figure 3, the main data regarding the hydraulic behaviour of the tested HB valve are summarized. On the right graph is reported the flow discharge curve versus opening degree, from which it is easy

to detect as the design discharge, at the maximum working pressure, is reached when the valve is settled at an opening degree equal to 68%. The incipient cavitation curves, as for model as for prototype, at different valve opening degree, are plotted in the graph on the left of figure 3, combined together with system cavitation data, which are symbolized by green dots. From the graph, it is easy to see as the HB valve working point, at prototype scale, identifies a σ_i value slightly greater of the corresponding limit of the system.

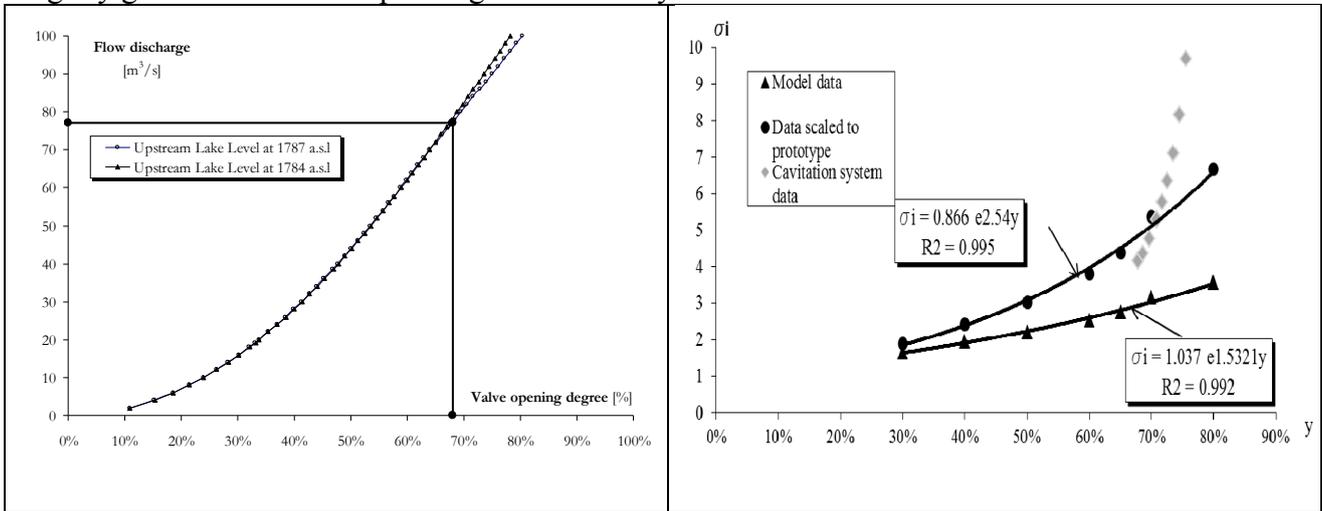


Fig. 3 – Right: flow discharge curve. Left: incipient cavitation curves vs. opening degree ψ .

The pressure values acting upon the downstream lining pipe were experimentally evaluated, at about 70% valve opening degree, when the design maximum flow condition occurs. The flow jet does not fill the entire pipe cross section (fig. 4 on the left), as visually confirmed by the laboratory tests (see photo 1). Local velocity measurements, performed, in different cross sections, by means of a Prándtl-Pitot tube and a differential pressure gauge, allowed to define clearly the cross sectional area filled by the air-water mixture; it presents a peculiar shape AKA “lunula”. (figure 4 on the right).

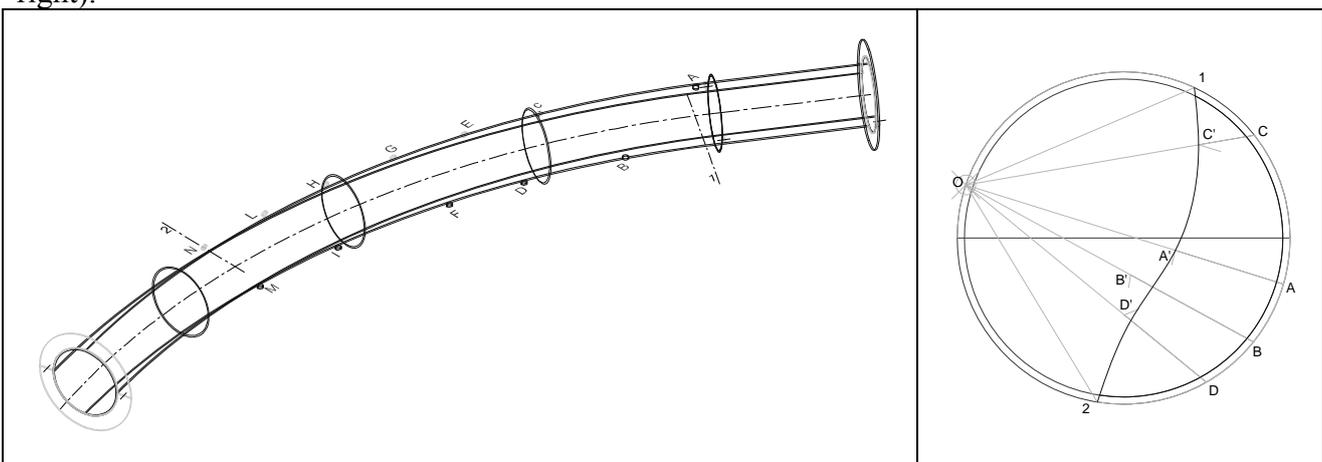


Fig. 4 – Lining pipe. Left: pressure transducers positions. Right: typical cross section jet surface.

About the pressure measurements, the higher mean values were recorded on the pipe lateral side (points C, E, G, H, L and N) and appear, as a whole, to be consistent with the analytical estimate

(0.054 barG), this last calculated applying the momentum equation. On the other hand, the pressure taps located at the pipe bottom (D, F, I and M) recorded mostly lower mean pressure values that appear to be consistent with the measured kinetic energy (fig. 4, right). In the third column of table 2 is reported the value of skewness of the temporal pressure data acquisition.

At the end, in the fourth and fifth columns of table 2 are reported the maximum and minimum value of the Euler number for any measurement point ; they can be used for qualitatively defining the expected pressure fluctuations, which appear to be relevant just close to the chamber outlet (i.e. A and B points), as, after all, expected (Rajaratnam, 1976, Falvey, 1980).

It is worth to mention as in the point A, located on the top of the lining pipe close to the section 1, negative pressure values and large pressure fluctuations were measured (see tab. 2), as a consequence of the streamline cross-over immediately outward the valve outflow (Renna et al., 2006).

Table 2 – Measured pressure data.

Location (fig.4, left)	Average Pressure [BarG]	Skewness	Cp _{max}	Cp _{min}
A top , s=0.037	-0.002	-0.148	4.535	-8.153
B down , s=0.167	0.002	-0.671	5.211	-3.674
C lateral , s=0.308	0.054	-0.034	1.508	0.513
D down , s=0.365	0.091	-0.609	1.094	0.898
E lateral , s=0.45	0.024	0.082	1.216	0.796
F down , s=0.51	0.009	0.129	1.328	0.786
G lateral , s=0.59	0.064	-0.112	1.257	0.759
H lateral , s=0.73	0.053	-0.220	1.162	0.817
I down , s=0.75	0.022	0.578	1.161	0.904
L lateral , s=0.86	0.055	-0.111	1.263	0.738
M down , s=0.93	0.022	0.613	1.853	0.539
N lateral , s=1	0.074	-0.035	1.146	0.889

CONCLUSIONS

The experimental results of the laboratory tests, carried out on a geometrical scale model of the Power House Discharge System of the EEPKO Project in Beles (Ethiopia), were used for evaluating the overall effectiveness of the designed system and allow some general comments. The H-B valves result to be very effective in dissipating energy when discharging into the atmosphere.

Nevertheless, in case of underground release in a tunnel, several concerns arise due to the impact of a high velocity jet on the tunnel walls. The average pressure force acting on the lining pipe in prototype is about $0.5 \cdot 10^5$ Pa and this value appears to be consistent with the experimental measurements performed on the scale model and with the theoretical assessment.

The study of pressure fields shows that the fluctuations are very low in the overall chamber except in those sections close to the valve hood, where a significant sub-atmospheric pressure and a wide fluctuation amplitude are recorded.

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