Current meters discharge measurements downstream the units

Test cases and general evaluations.

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Abstract

The current IEC 60041 standards do not recommend carrying out performance tests using current meters downstream the units. In many situations, however, this is the only possibility to carry out measurements and WEST had to face this type of test in many occasions.

These are certainly measures that need particular attention such as, for example, the choice of self-component current meters with detection of the direction of rotation from a hardware point of view, the qualitative identification of the speed fields through CFD and possibly the choice of the most appropriate measuring section and finally the comparison between different integration methods from a software perspective.

This paper describes the tests successfully carried out on three different plants with this methodology. These are low-head Kaplan units, even of considerable size, where other methods were unfeasible.

The conclusion that can be drawn is that these measures are feasible and that on the contrary it is recommended to avoid severely disturbed velocity fields characterized by high velocity gradients, regardless of the position in which these conditions occur and for this reason preliminary CFD evaluation may be useful.

Premises.

The need to get performance measurements in low-head machines pushed WEST to carry out flow measurements with current meters in the discharge channel. In fact, in many cases the measurement with current meters at the entrance or other methodologies are unfeasible or present even more important problems. Even if not recommended by the standards, this test methodology therefore represents the only realistic possibility and according to our experience it is able to provide reliable results.

This publication describes three different installations in which this test method has been successfully implemented:

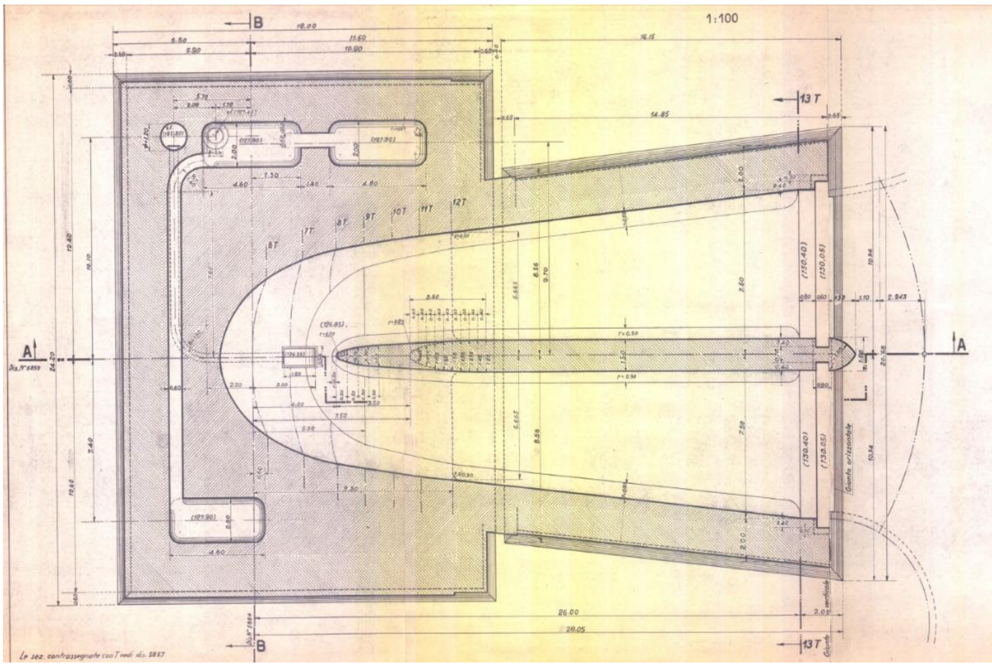
The first installation is a typical case, without specific problems, which is representative of many dozens of installations measured by WEST in the same way.

The following two installations represent particularly difficult cases which however led to excellent results thanks to the attention that was put into the preparation and implementation of the tests.

First case:

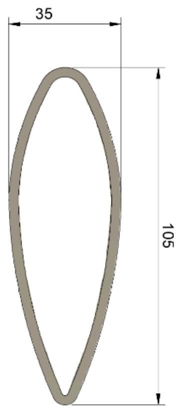
This is a vertical axis Kaplan turbine which exploits an average head of 9.4 m and provides, with a flow rate of approximately 130 m3/s, an axis power of 11 MW at a rotation speed of 200 rpm.

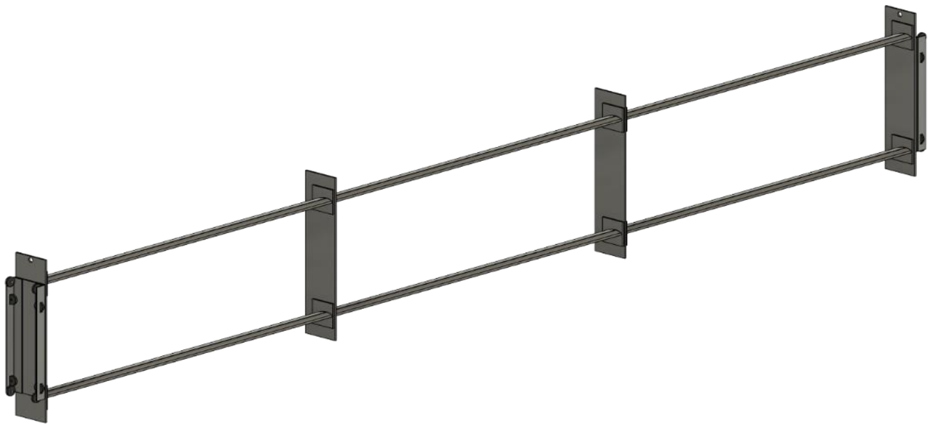
The performance tests were preceded by conjugation optimization tests through a joint analysis of index measurements through the differential pressure between Winter Kennedy type taps, vibration measurements and pressure pulsations. The unit has two discharge outlets 6.98 m wide and 7.4 meters high for approximately 50 m^2 for which the expected average speed at full load is 1.3 m/s.



The configuration of the outlet elbow is clearly visible in the previous drawing

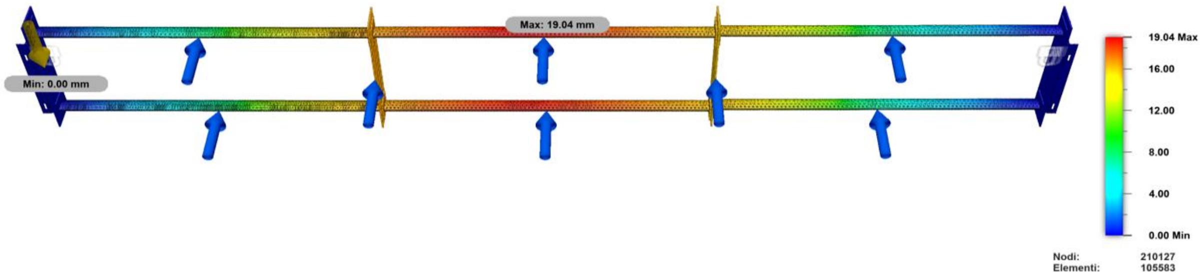
Two structures to be lowered into the valley benches were manufactred. Each structure has two 105 x 35 mm ovoidal rods on which 20 current meters (ten on each rod) were installed. The sketch of the stucture and of ovoidal rods is shown. The overall weight of each structure without current meters and relevant fixing clamps, is aprroximately 350 kg.



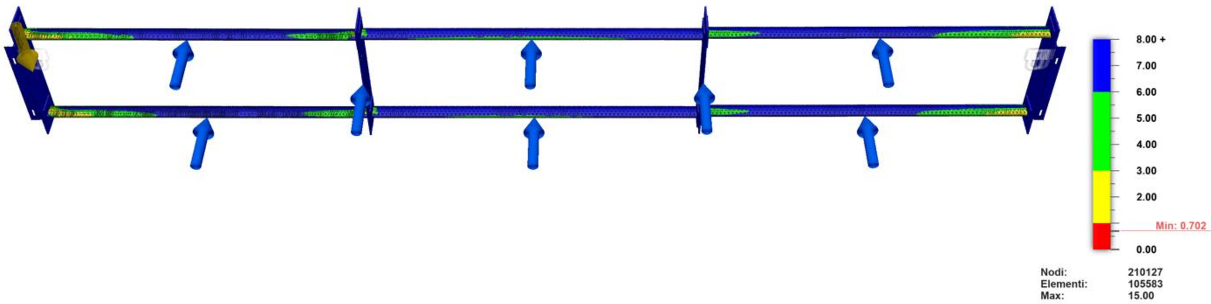


Five different sinkings of the structures were foreseen to obtain 100 velocity measurement points for each of the two discharge outlets. An initial CFD analysis showed a fairly good homogeneity of the two discharge outlets and in full load conditions (for which the structure is sized) a greater flow rate passing through the lower part of the left bay and on the contrary a greater flow rate passing through the upper part of the right bay. he presence of possible non-negligible recirculations on the surface but in general modest transversal components was observed. Due to this uneven distributon of the velocity the maximum local velocity should be around 2.4 m/s. A safety margin of 1.5 has been used so the FEM analisis of the structure has been performed for the calculation consider an homogeneous axial force based on 3.6 m/s flow velocity.

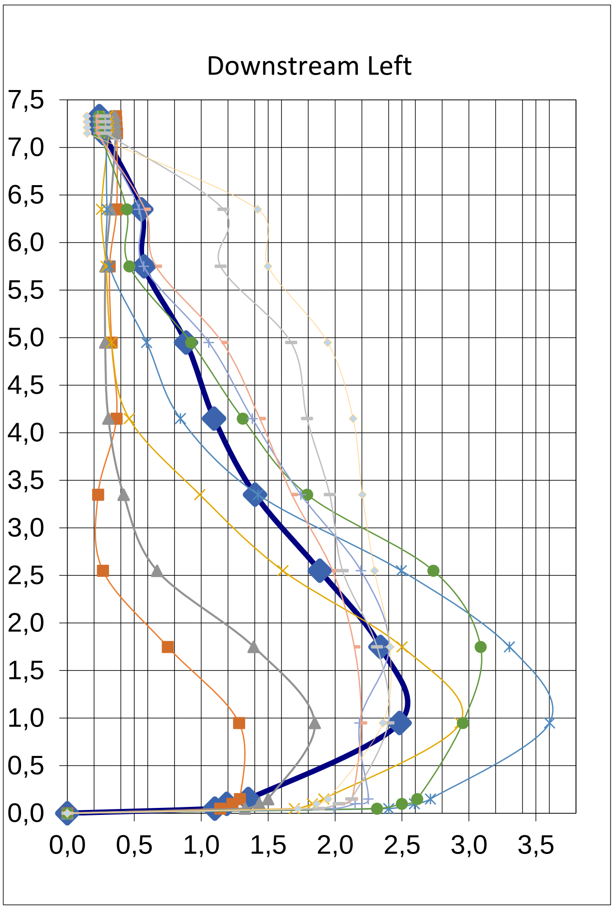
The results of the FEM in those extreme conditions show a maximum elastic deformation less than 20 mm values that were considered acceptable. No specific stress on the different components of the structure were observed. Here in after the results of FEM analysis regarding deformations.

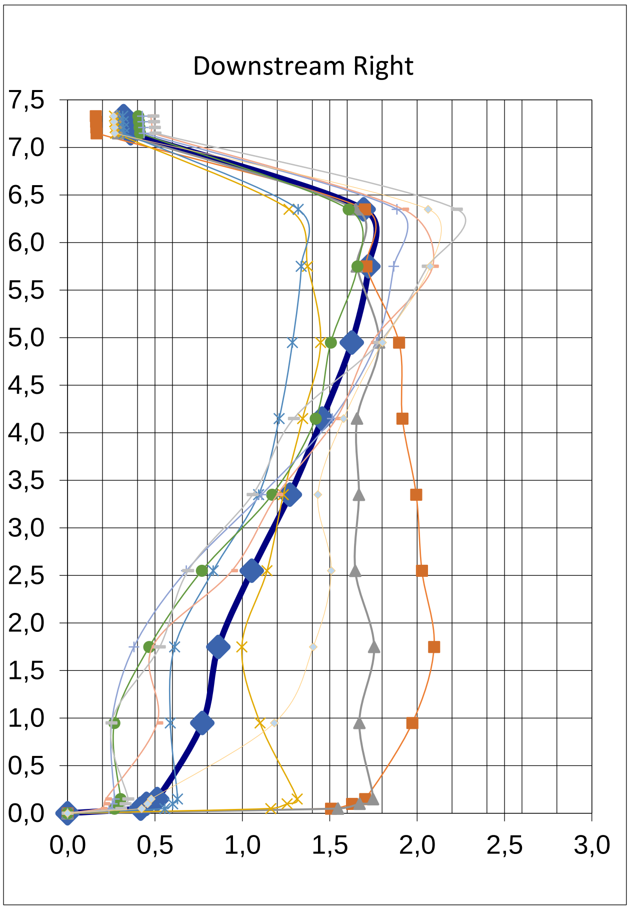


The reliability value of the system was also evaluated, presenting minimum values always adequate to the design condition in every sinking condition.



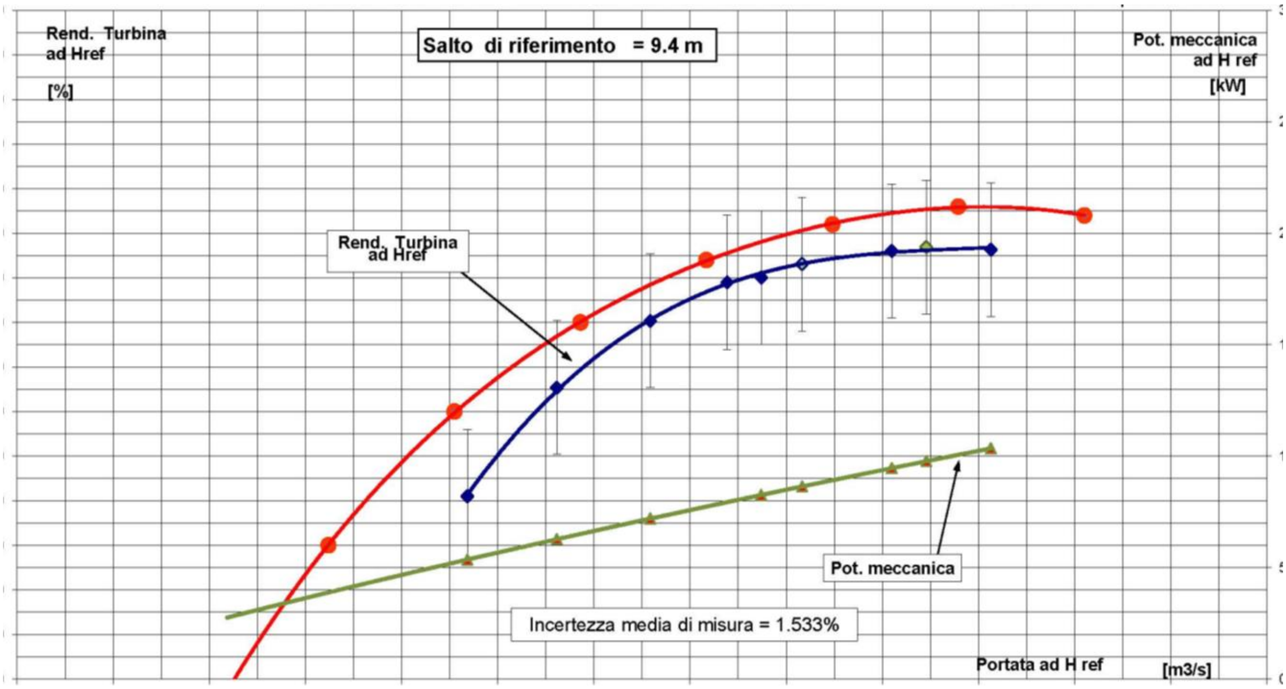
As expected, the tests did not show any particular problems and essentially confirmed the predictions.





Differences between the three integration method adopted were negligeable.

Self-component current meters up to angles of ±45° capable to discriminate the direction of rotation were used, the recirculation effect at the surface was adeguately taken into account (by subtracting the small numbers of reverse rotations with appropriate weighting factor based on CM reverse calibration). The efficiency curve obtained was consistent with forecast. The efficiency curve at constant head was almost parallel to the expected with an average gap of -0.8% increasing by lowering discharge due to the larger clearance between the impeller and its spherical seat



A detailed examination of the measurement errors led on average to an overall error (which takes into account both the systematic and random components) of approximately ±1.53%.

Here in after photographs of the installation.

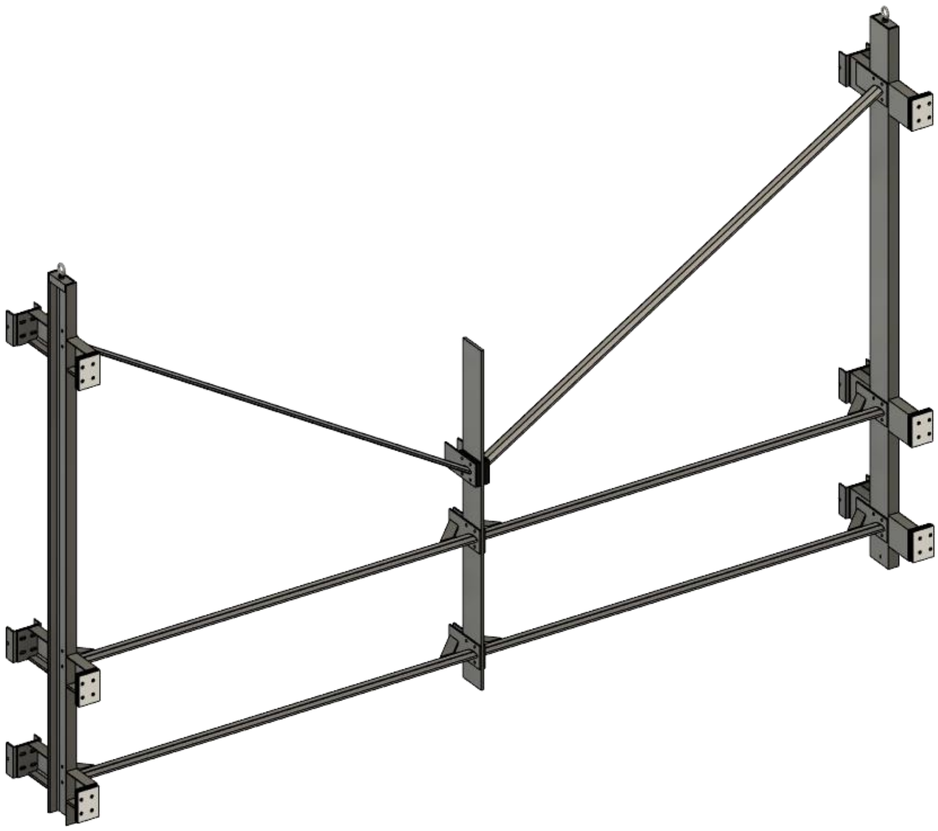
Second Case:

In this case too, it is a vertical axis Kaplan turbine which exploits an average head of 9.4 m and provides, with a flow rate of approximately 300 m3/s, a mechanical power of 26.5 MW at a rotation speed of 53.6 rpm.

The performance tests were preceded by conjugation optimization tests through a joint analysis of index measurements, through the measurement of the differential pressure between Winter Kennedy type taps, vibration and pressure pulsation measurements.

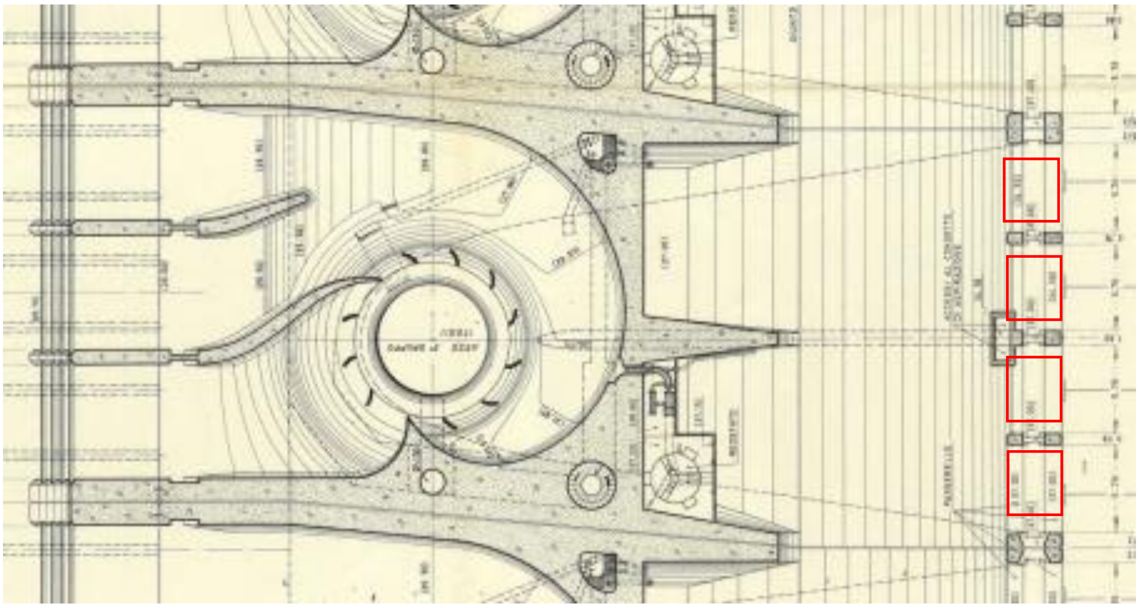
The unit has four free-surface discharge outlets 6.55 m wide and 10 meters high for approximately 65 m^2 for which the expected average speed at full load is 1.3 m/s. Four structures have been planned to be lowered into the four valley benches. Each structure is equipped with two horizontal ovoid rods 105x35 mm 750 mm apart. 10 hydrometric reels have been housed on each of the rods.

To avoid bending of the central part of the structure, a vertical junction plate was provided between the two ovoid rods, supported by two diagonal stays also made with ovoid bar. The structure has an approximate weight of 680 kg and its handling was carried out using electric winches accompanied by 2 Tirfort systems attached to the UPN 200 profiles for fine positioning.



Six vertical sinkings of the structures were foreseen to obtain 120 velocity measurement points for each of the four discharge outlets. Such a number according to IEC code may lead to a quite accurate definition of the velocity distribution. The particular conformation of both the entrance and outlet with the presence of vertical and horizontal conveyor partitions highlighted in CFD analysis a notable asymmetry of the different outlets, with progressively different trends as the load varied.

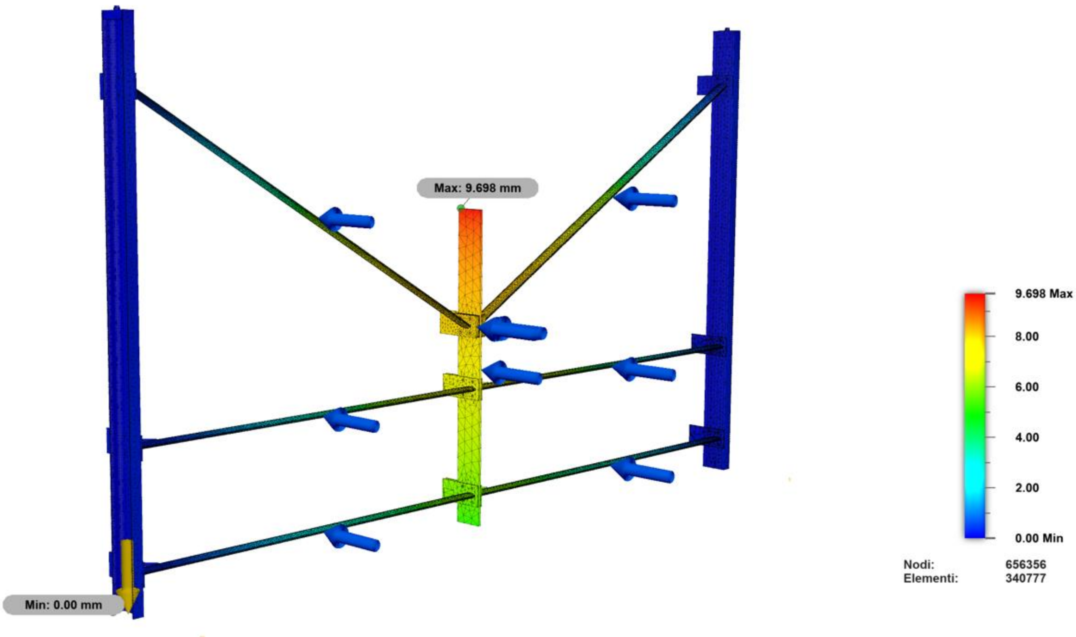
The horizontal section of the unit is shown in the following drawing



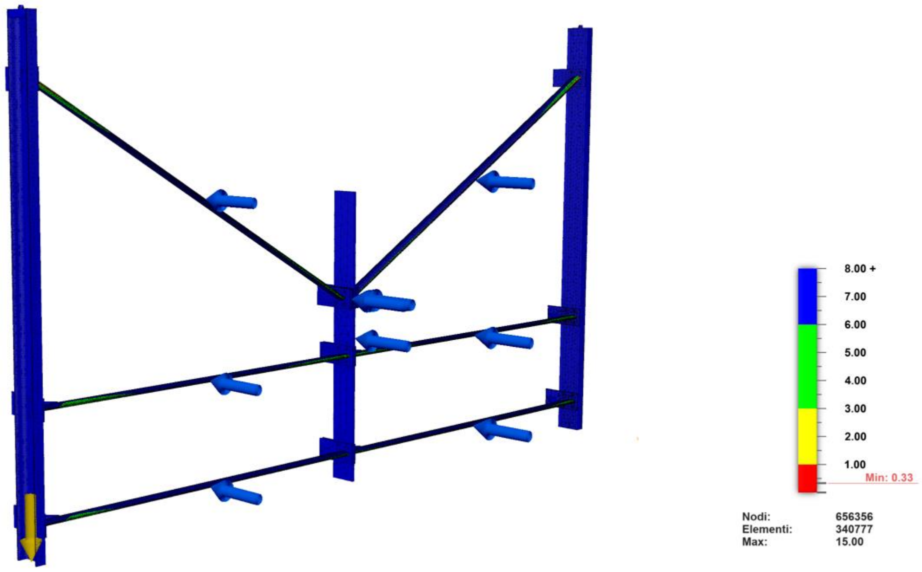
The depth of the draft tube elbow compared to the total height of the measuring section bays makes a greater flow rate passing through the lower part of the bays. In this case too, the presence of possible non-negligible recirculations on the surface is detected while the transverse components, although modest, lead to angles of the velocity vector lower than ±25° compared to the axial component. Despite the substantial similarity of the shapes of the velocity profiles of the individual bays, there are however notable differences between the different bays which lead to localized speeds of the order of 2.6 m/s.

A safety margin of 1.5 has been used for the FEM analysis of the structure has been performed so the calculation consider an homogeneous axial force based on 4.0 m/s flow velocity.

The results of the FEM in those extreme conditions show a maximum elastic deformation less than 10 mm values that were considered acceptable. No specific stress on the different components of the structure were observed. Here in after the results of FEM analysis regarding deformations.



The reliability value of the system was also evaluated, presenting minimum values always adequate to the design condition in every sinking condition.



The measurement section was not visible and therefore the dimensioning of the structure was carried out only using the construction drawings.

During the sinking phase, a narrowing of the bay was detected which forced to an immediate small modification of the structures to allow the passage of the current meters.

The measurement was particularly challenging both due to the number of current meters to be acquired synchronously and for having to move the four structures vertically at the same time.

Six measurements were carried out by using current meters interspersed with six index tests at the intermediate points to explore the entire operating range and approximately 12 hours of tests were needed to complete the measurements.

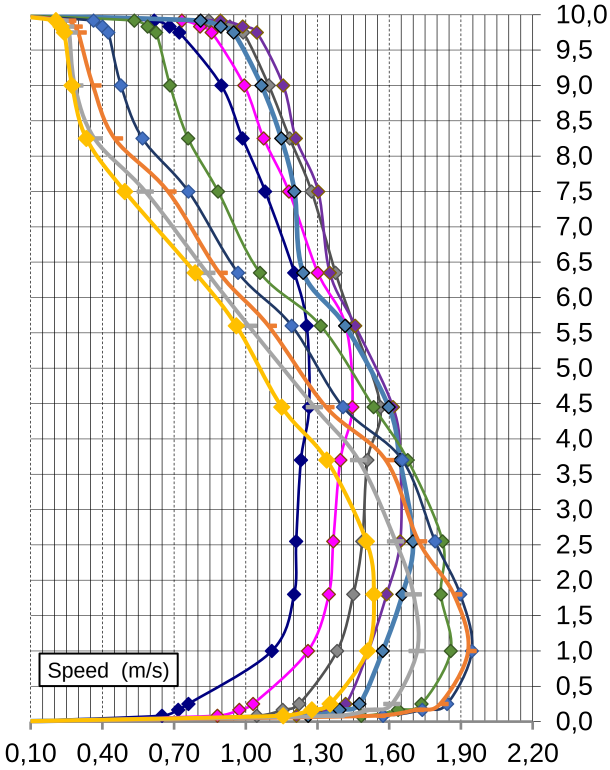
Despite the difficulties, however, the tests did not reveal any particular problems and essentially confirmed the predictions. Also in this case it was deemed appropriate to use self-component reels up to angles of ±45° with the ability to discriminate the direction of rotation.

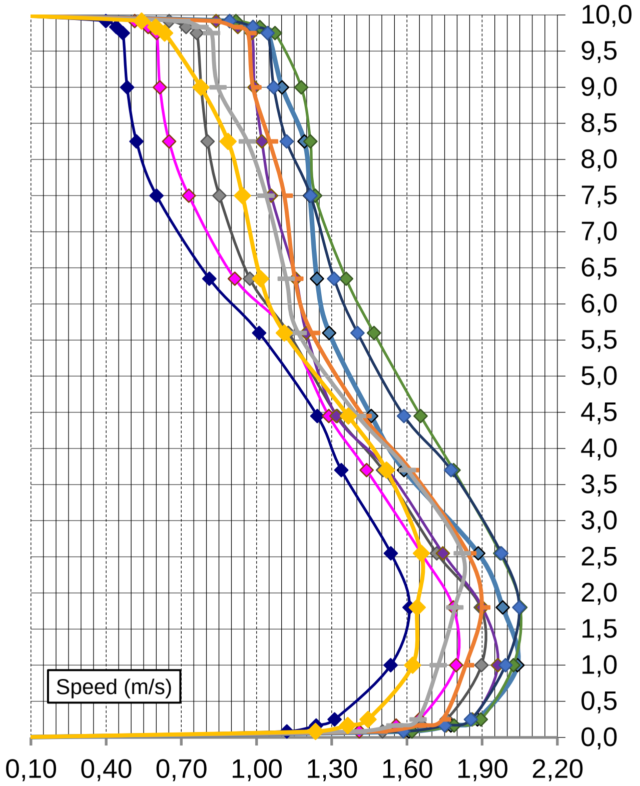
The recirculation effect at the surface was present and adequately taken into account (by subtracting the numbers of reverse rotations with appropriate weighting factor based on CM reverse calibration).

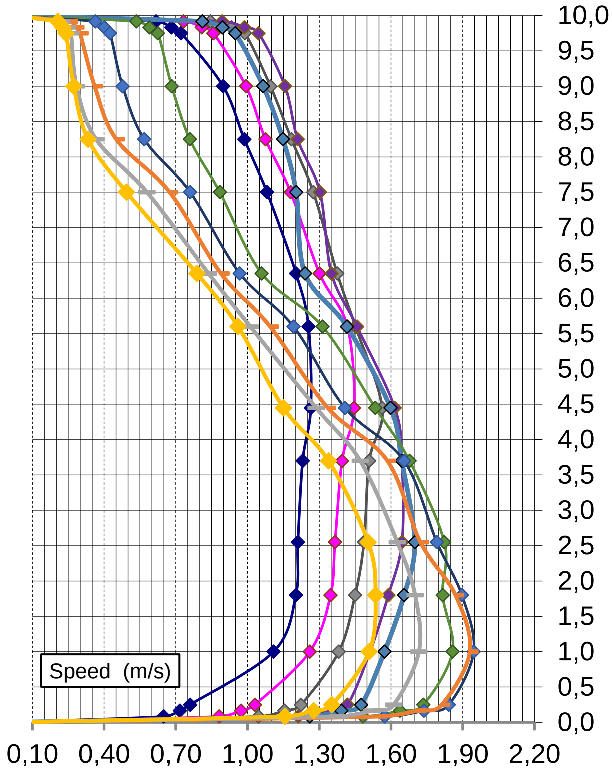
The following graphs show the velocity profiles of the individual discharge outlets as a function of sinking, in the maximum efficiency flow rate condition of the machine. The velocity profiles of the bays are shown in sequence starting from Bay 1 closest to the right to Bay 4 closest to the left.

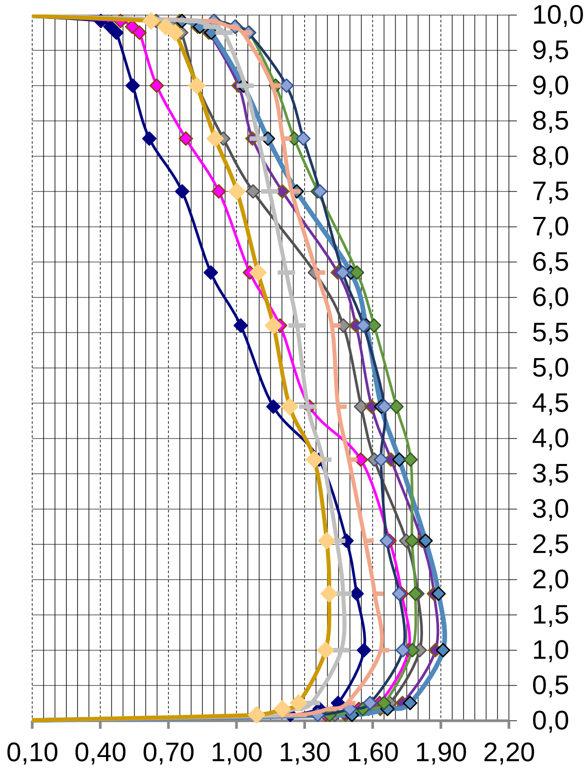
As already highlighted by the CFD analysis the measurements confirm that all bays show higher speed modules in the bottom zone and generally lower velocity at the surface where some recirculation was also detected.

The distribution of the discharge between the different bays was not homogeneous but maximum efficiency reperesent the condition were the differences are smaller. , in general Bay 3 always show lower discharge.

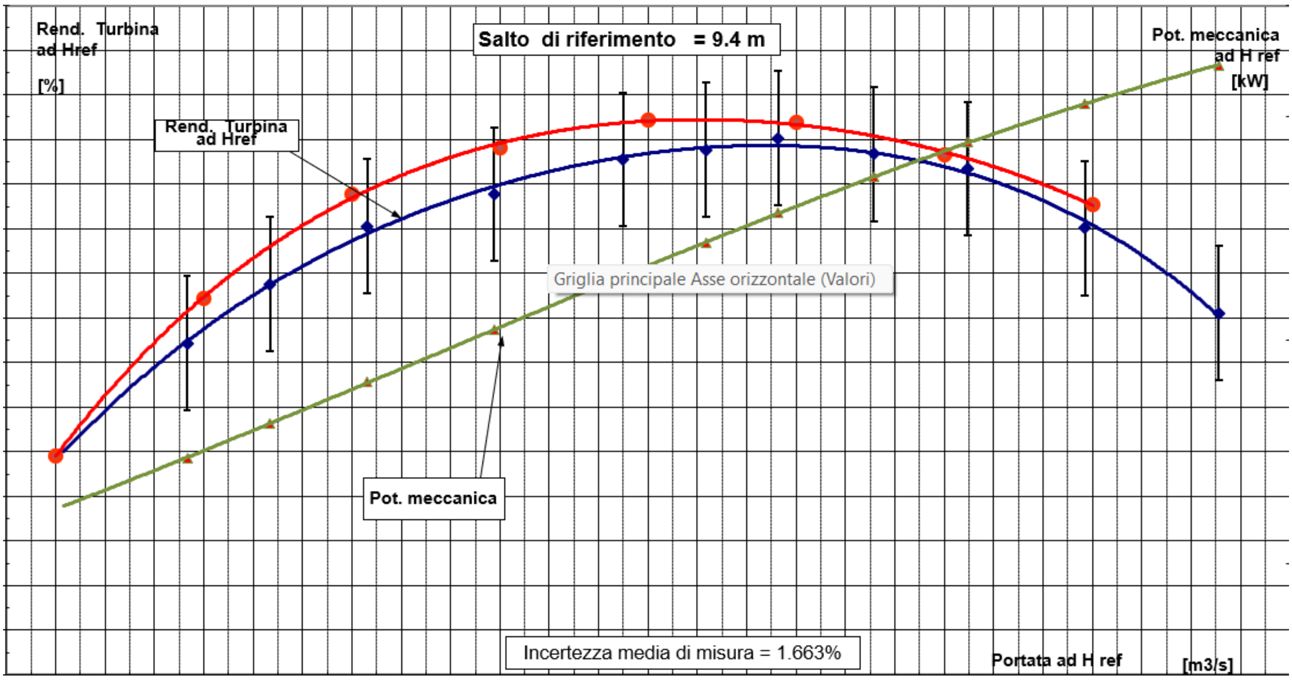








Differences between the three integration method adopted were negligeable.



The efficiency curve practically coincides with expectations both in the 4/10 and from 8/10 zones to full load, while between 5/10 and 7/10 the results show a modest deficit of the order of 0.50%. It is in fact an area in which the optimization of the conjugation that took into account both the efficiency and the dynamic phenomena was particularly complex.

A detailed examination of the measurement errors led on average to an overall error (which takes into account both the systematic and random components) of approximately ±1.67%.

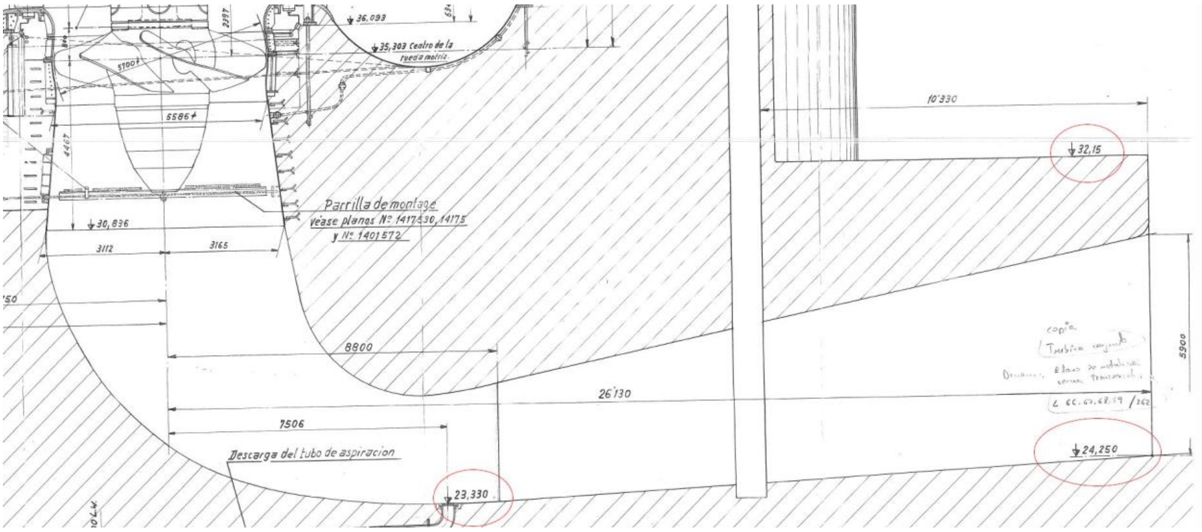
Here in after photographs of the installation.

Third Case:

This case also refers to a vertical axis Kaplan turbine which exploits an average head of 30 m and provides, with a flow rate of approximately 240 m^3/s, an axis power of 67 MW at a rotation speed of 125 rpm. The performance tests were preceded by conjugation optimization tests through a joint analysis of index measurements through the differential pressure between Winter Kennedy type taps, vibration measurements and pressure pulsations.

The unit has two discharge outlets and the slots for the downstream stop-gates are located approximately at 2/3 of the discharge elbow and therefore without a free surface. The section of each one of the mouths is slightly trapezoidal, 8 m wide, 4 meters high on average and corners connected with a radius of 400 mm for a total surface area of approximately 30 m^2. It follows that the expected average speed at full load is therefore 4.0 m/s.

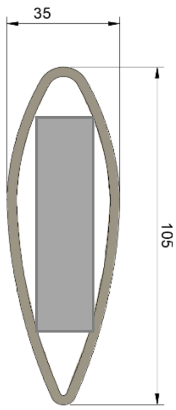
The vertical section of the unit is shown in the following drawing



Two structures have been foreseen to be lowered into these slots by using the guides of relevant stop-gates. Each structure has two horizontal and parallel ovoid rods with a 105x35 mm section on which 28 current meters are housed (14 for each rod). 4 vertical sinkings of the structures were foreseen to obtain 108 speed measurement points for each of the two discharge outlets. The measurement is particularly delicate because it is carried out in an area of the discharge elbow where high turbulence and asymmetries are conceivable.

To avoid having the flow hit parts with non-hydrodynamic profiles, the structure was built with an upper support crosspiece 4.20 meters from the base of the structure (therefore never hit by the flow) and the two measuring rods in the lower part at 200 and 900 mm respectively from the free base.

The structure therefore included a very rigid frame of UPN beams along upper and lateral sides and only the two measuring rods immersed in the flow, supported by two vertical plates fixed to the upper beam. The structure, during the lifting phase, had incorrect flexural deflections and therefore stiffening horizontal rods were provided at site. Those rods however were hit by the flow although in an area very far from the current meters and therefore practically irrelevant with respect to the measurements.



The CFD analysis highlighted a notable asymmetry between the two ports, with progressively different trends as the load varied: the right port was more affected by the flow at low flow rates while the left one was more affected by the flow at high loads. The velocity vector angles exceed at lower loads up to approximately ±30° compared to the axial component.

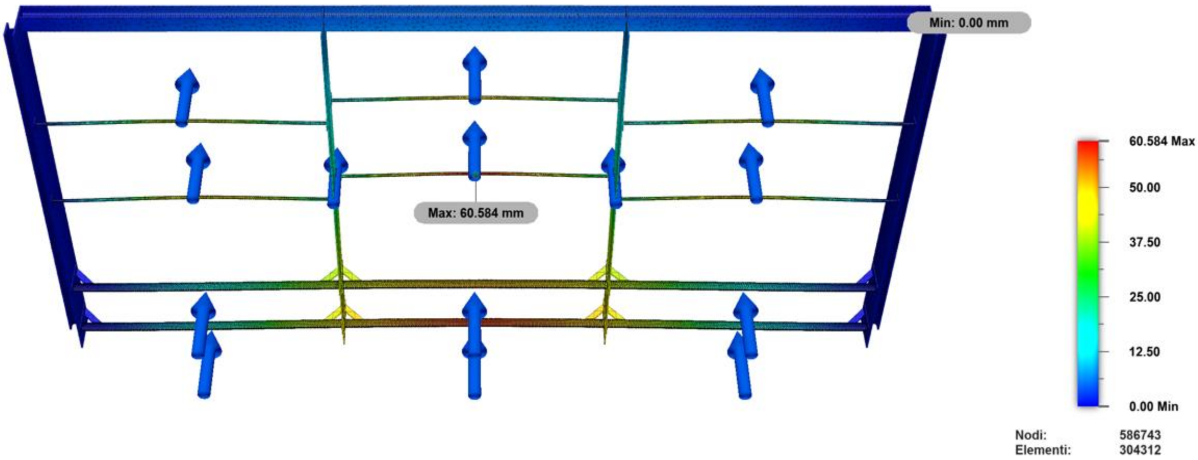
Using the usual safety margins while waiting for more detailed fluid dynamic information. The dimensioning of the structure was foreseen up to a speed of 6.0 m/s but the FEM realized predicted its failure.

The action of the flow with this speed would in fact have determined high displacement values, localized in the central part with specific values exceeding 60 mm, considered unacceptable for the working conditions. Similar considerations were obtained by analysing the reliability parameters.

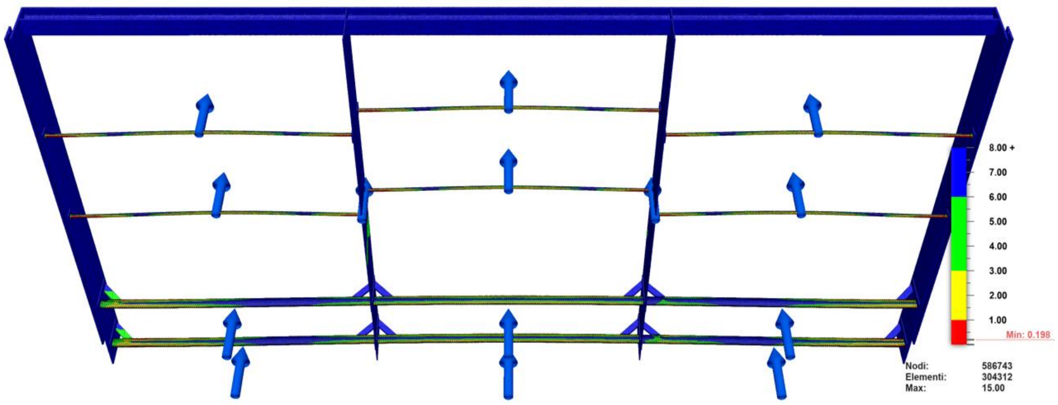
It was therefore decided to insert a rectangular core hot-keyed and welded at the ends inside each of the ovoid rods, in order to adequately reinforce it as visible in the section visible above.

The total weight of each of the structures finally exceeded 3700 kg.

Below are the FEM analyzes of the structure before modifications, such as deformations

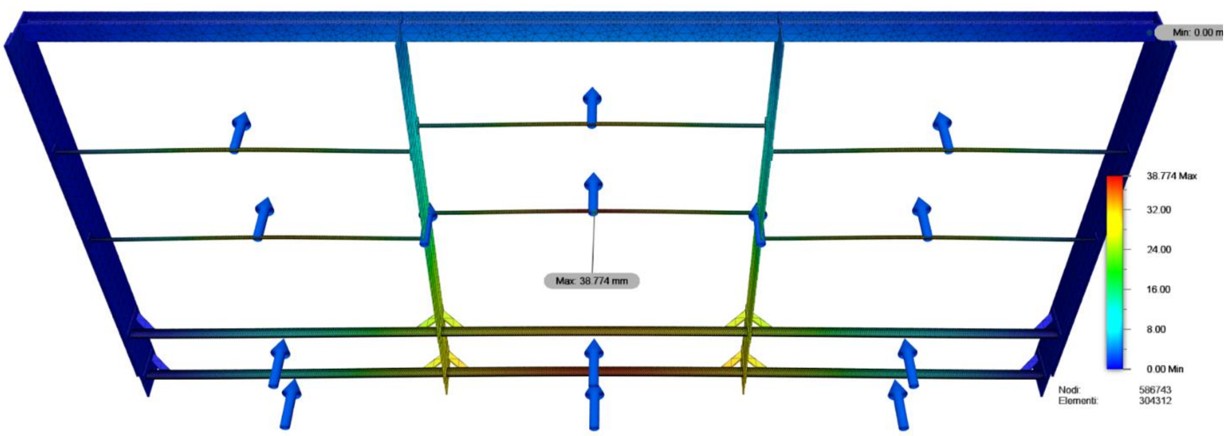


and as reliability

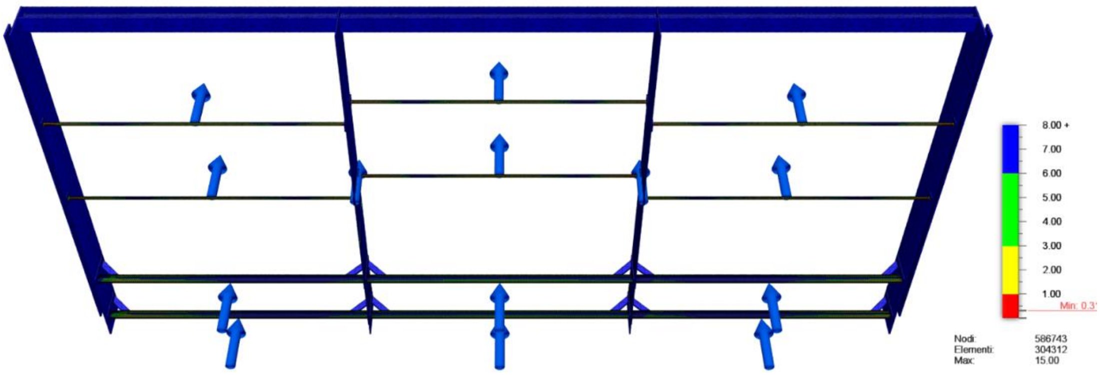


Further fluid dynamic analyses, however, highlighted that in full load conditions in the upper area of the left mouth a localized speed of 5.4 m/s would have been reached, therefore a precautionary evaluation with safety margin of 1.5 has been used. The final FEM analysis of the structure has been performed by considering an homogeneous axial force based on 8.0 m/s flow velocity.

The results of the FEM in those extreme conditions show a maximum elastic deformation around 30 mm that were considered still acceptable. No specific stress on the different components of the structure were observed. Here in after the results of FEM analysis regarding deformations.



The reliability value of the system was also evaluated, presenting minimum values still acceptable to the design condition in every sinking condition.

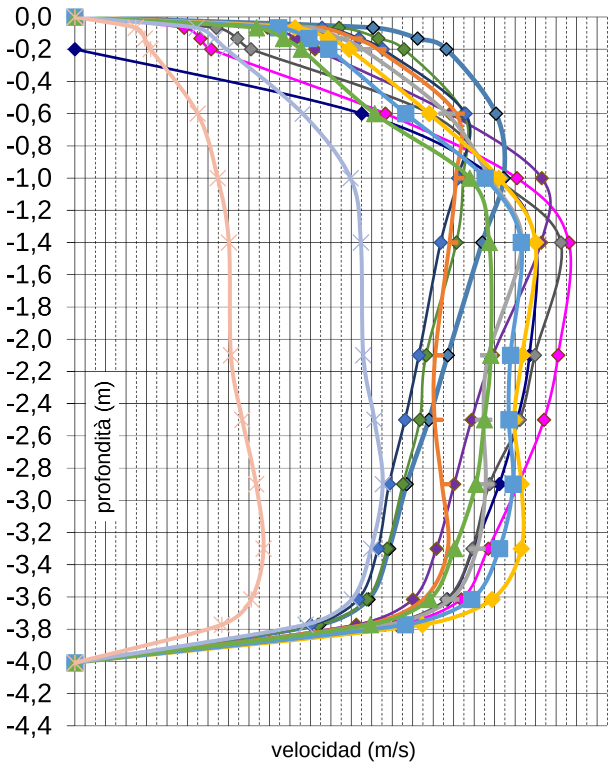


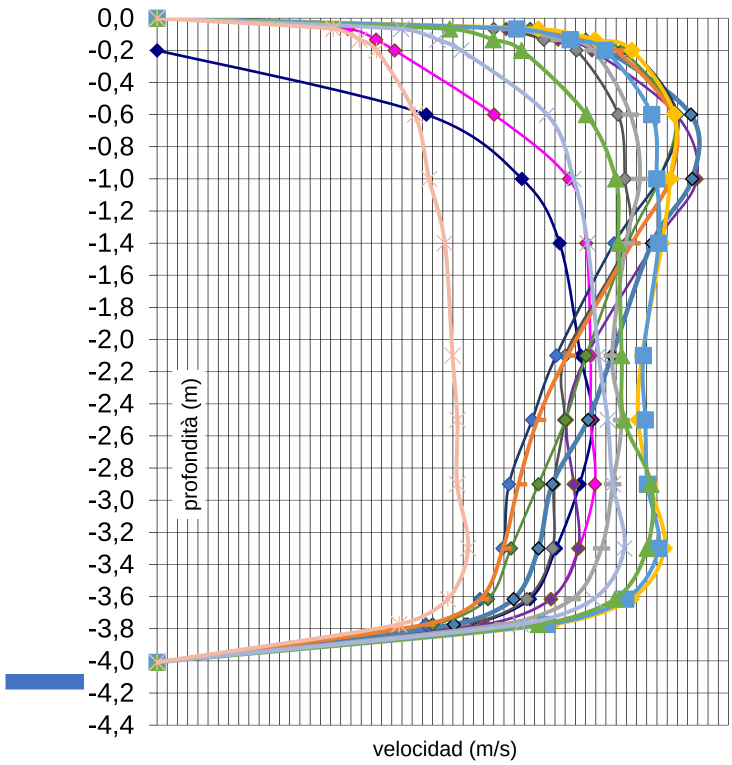
Also in this case the measurement section was not visible and therefore the dimensioning of the structure was carried out only using the construction drawings.

During the sinking phase, notable discrepancies were found (deformation of the guide rails, swelling of the concrete and a narrowing of the mouth) which made it necessary to adapt the structure and the intervention of divers for correct positioning. The measurement was particularly challenging both due to the number of current meters to be acquired synchronously and for having to vertically move the 2 extremely heavy structures with important dynamic phenomena at full load.

The handling was carried out mainly by 4 Tirfort systems for each structure attached to the UPN 400 and electric winches only for support.

Five measurements were carried out by using current meters, interspersed with six index tests at the intermediate points to explore the entire operating range and more than 10 hours of tests were needed to complete the measurements.The operating sequence was chosen with increasing loads, this choice proved to be correct because at the end of the full load tests the complete failure (probably due to fatigue) of the horizontal stiffening rods positioned in the upper left part of the left structure occurred (where the highest flow conditions were expected at full load).

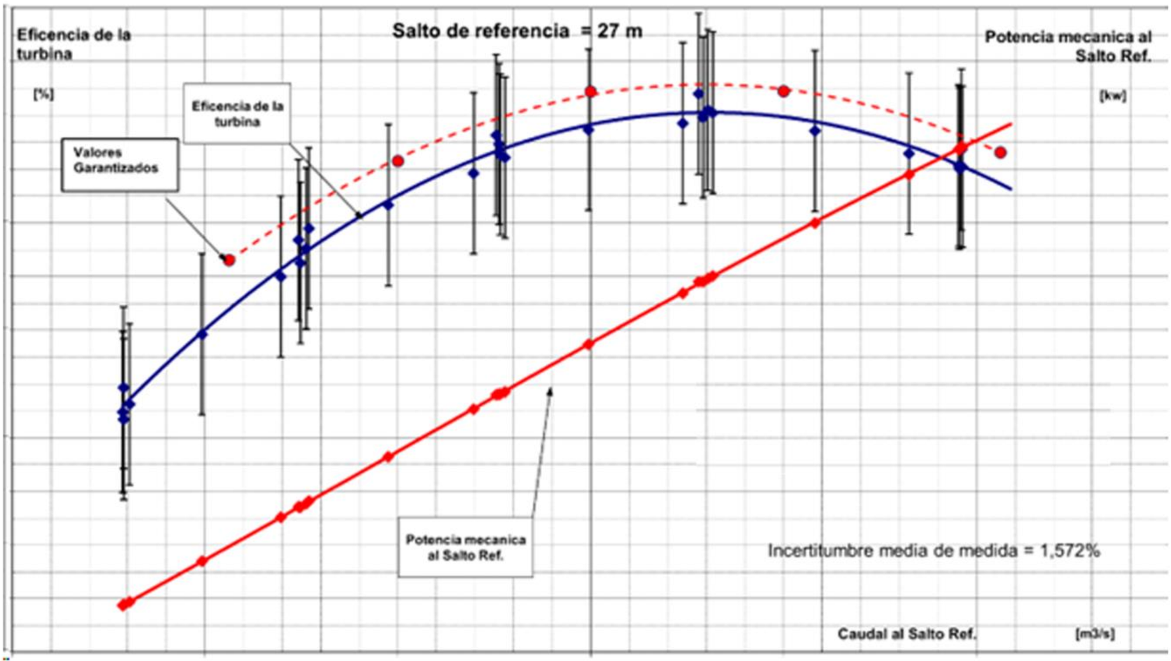




The graphs in the figure represent the speed profiles at the maximum efficiency load of the unit, from which a certain homogeneity of the velocity as the sinking varies can be deduced. Also in this case it was deemed appropriate to use self-component current meters up to angles of ±45°. No recirculations were detected.

Despite all mentioned difficulties and problems, however, the tests were completed satisfactorily, in this case particular care was necessary in the integration considering the disturbed flow fields and the presence of the connected corners but they essentially confirmed the predictions.

The efficiency curve obtained was congruent, showing a trend identical to expectations but with absolute values lower on average by -0.50%. A detailed examination of the measurement errors led on average to an overall error (which takes into account both the systematic and random components) of approximately ±1.57%.



Here in after photographs of the installation.

CONCLUSIONS

The reported experiences highlight that flow measurement with current meters at the outlet of the units is to be considered feasible and capable of providing reliable results and with acceptable margins of error. The cases reported range from very simple and calm situations to very complex cases both in terms of size and complexity. In any case, however, adequate preparation for the tests is important, which must always be preceded by a detailed analysis of the specific situations using all the necessary IT tools and in particular a CFD (even if not particularly advanced and with a simplified mesh) and a FEM for the sizing. of the structures. Furthermore, to avoid unpleasant unexpected events in the system, it is very important to have the possibility of visual feedback of the measurement areas in order to highlight any discrepancies with the drawings provided.