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VERY HIGH RISE NAVIGATION LOCKS

- Feasibility Study of a 113 m Rise Lock for the Three Gorges Site -

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Abstract

This paper deals with the problems of using navigation locks when the rise is very important (70 to 113 m or even more) and when the traffic is very heavy. In this situation which can occur for energy or navigation purposes, the mechanical devices as shiplifts and inclined planes come at once in mind. Nevertheless it is shown that the use of lateral basins built inside of the walls solve many of troublesome questions as saving of water, cavitation, surges. A feasibility study of a 113 m rise lock for the Three Gorges Site

The data of the Three Gorges project

In 1986 the P.R.China began the hydroelectric exploitation of the Gezhouba dam. With a total installed power of 2715 Mw, it is nowadays the most important water control project of the country. The Gezhouba site is located some 2700 km upstream of the city of Shanghaï. Some 40 km upstream of Gezhouba, the Yangtze river cuts through three majestic canyons named: Qutang Gorge, Wu Gorge and Xiling Gorge (the Three Gorges).

As soon as 1958, the site of Sandouping was selected as another major harnessing possibility of the river, in the middle of the Xiling Gorge.

At the dam site, with a rather wide valley and a sound and intact bedrock of granite, the topographic, the geologic and the construction conditions are known as excellent for building a high concrete dam.

The minimum expected power to be produced at Sandouping could be as high as 13000 Mw i.e. 400 Mw more than the Itaipu installation. The maximum planned could be 18720 Mw (highest value of hydroenergy of the world to-day). But as is well known, the Yangtze river is also the most important transportation artery of China and reaching Chongqing by navigation some 660 km upstream of Sandouping is also a purpose of the project.

So appears the problem of the sailing through the Sandouping dam. From a meeting due to the courtesy of the Yangtze River Scientific Institute in Wuhan in November 1988 we got the information that the discharge could vary between 3000 and 110000 m^3/s. At the dam, the upstream water level variations would be between 175 m and 145 m and downstream between 62 m to 74 m. The draught should be 5 m at the sill, the air clearance 15m.

A fleet of ships carrying 12000 tons (one pushtow and 9 barges) should be able to pass without dismantling. At Gezhouba where two large locks are currently used, the lock chambers have 280 m in length and 34 m in width.

Related to the Sandouping dam, the maximum rise of the navigation device could theoretically be 113 m and the minimum 71 m but apparently it should more surely vary between 101 m (175-74) and 83 m (145-62). In a search of safety, we will deal hereafter with the extreme rise of 113 m.

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Choice of navigation system

In the present situation due to the very important level variations (30 m upstream and 12 m downstream) it does not seem possible to use efficiently hydraulic floats or funicular shiplifts : they are suitable to artificial waterways where the levels encounter only a few centimeters of variations in the downstream and the upstream bays.

Inclined planes with counterweights of the Ronquières or Arzwiller type can't make the deal either. The inclined plane used at Krasnoiarsk in its principle of double slope and a revolving platform could theoretically suit. According to the same principle of an intermediate bay, a double slope lock might be studied. But in both cases, the compulsory dimensions of the 9 barges pushed convoy would prevent their construction. An interesting system of elevator has been realized in 1973 at Danjiangkou on the Hanshui river (Hubei province), some 500 km north of Gezhouba. It is a carrying bridge with a rigid grid which takes a ship, under the hull, lifts it up in the air, moves it upstream or downstream and immerses it in the other bay. It has been accommodated for a 150 tons barge. It is technically inconceivable to extrapolate the dimensions of the grid to 280 m x 34 m.

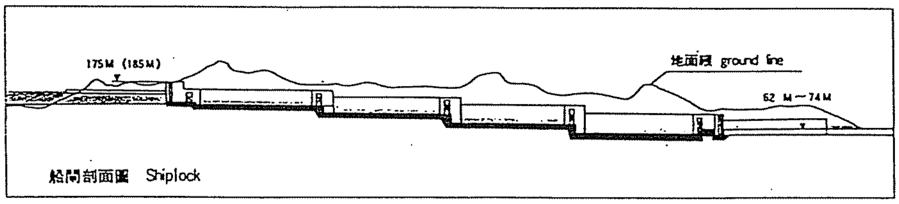


Fig.1 : The double flight locks.

Nowadays, the only valid solution which has been retained by the Yangtze River Scientific Institute is logically the one of the double flight of 4 or 5 locks (Fig. 1).

We develop hereafter the feasibility study of a single 113 m rise lock ([1],[2]). In fact, two locks should be foreseen according to the traffic requirements (see Figs 2 and 3).

General result of the feasibility study

We have dealt with the questions of distribution of stresses on the foundation, the values of the stresses in the walls and the floor, the problem of the filling and emptying, the problem of cavitation to avoid it completely, the problem of the behavior of the barges in the chamber, and the question of the surges in the downstream reach.

The results are presented in the following figures : plan view of the locks (Fig.4), downstream head (Fig.5), upstream head (Fig.6) and cross-section with the hydraulic system (Fig.7).

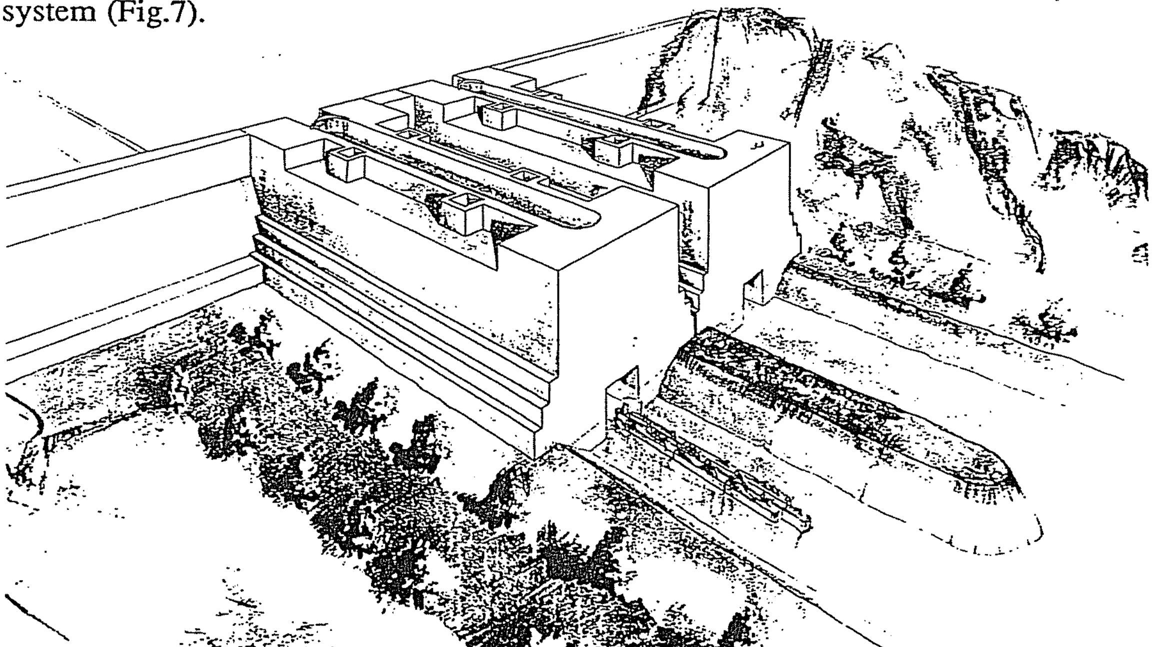


Fig.2 : Artist view of the double 113m rise lock (downstream side).

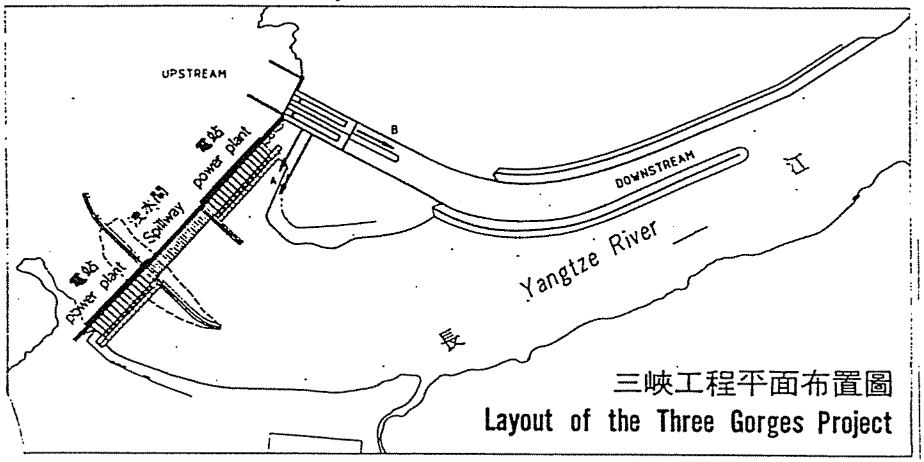


Fig.3 : The Sandouping dam with a double 113 m rise lock.

Study of the concrete structure

In order to reduce the earth removing works, the idea has been retained to build the aforementioned lock in the vicinity of the hydropower plant and to make use of a protection shield wall for the navigation. Moreover, this solution requires less excavation then the flight locks alternative.

The upstream head of such a lock has to be studied as a dam as far as the sliding stability and the elastic stability are concerned. With the dimensions shown on Fig.4 to Fig.7, the stresses transmitted to the foundation under the upstream head are smaller that 50 dN/cm^2. The downstream head feasibility study leads to a maximum stress to the foundation of 32 dN/cm^2.

The computation of the stresses and the displacements in the chamber itself, leads to the drawing of Fig.7. The longitudinal walls should be established with inner basins as indicated and with partition walls inside of the basins. A finite elements method study (323 elements) has given the main following results :

Basins full of water and chamber empty

- Maximum displacement at the top of the walls - 36 mm (2 x 18 mm) of decrease of the chamber span
- Maximum stress transmitted to the foundation - 26 dN/cm^2
- Maximum vertical stress - 50 dN/ cm^2
- Maximum horizontal stress - 8 dN/ cm^2.

Lock chamber full of water and basins empty

- Maximum displacement at the top of the walls - 38 mm of increase of the chamber span
- Maximum stress transmitted to the foundation - 17 dN/ cm^2
- Maximum vertical stress-currently smaller than 60 dN/ cm^2 , a very small zone of 90 dN/ cm^2 excepted.
- Maximum horizontal stress - 25 dN/ cm^2.

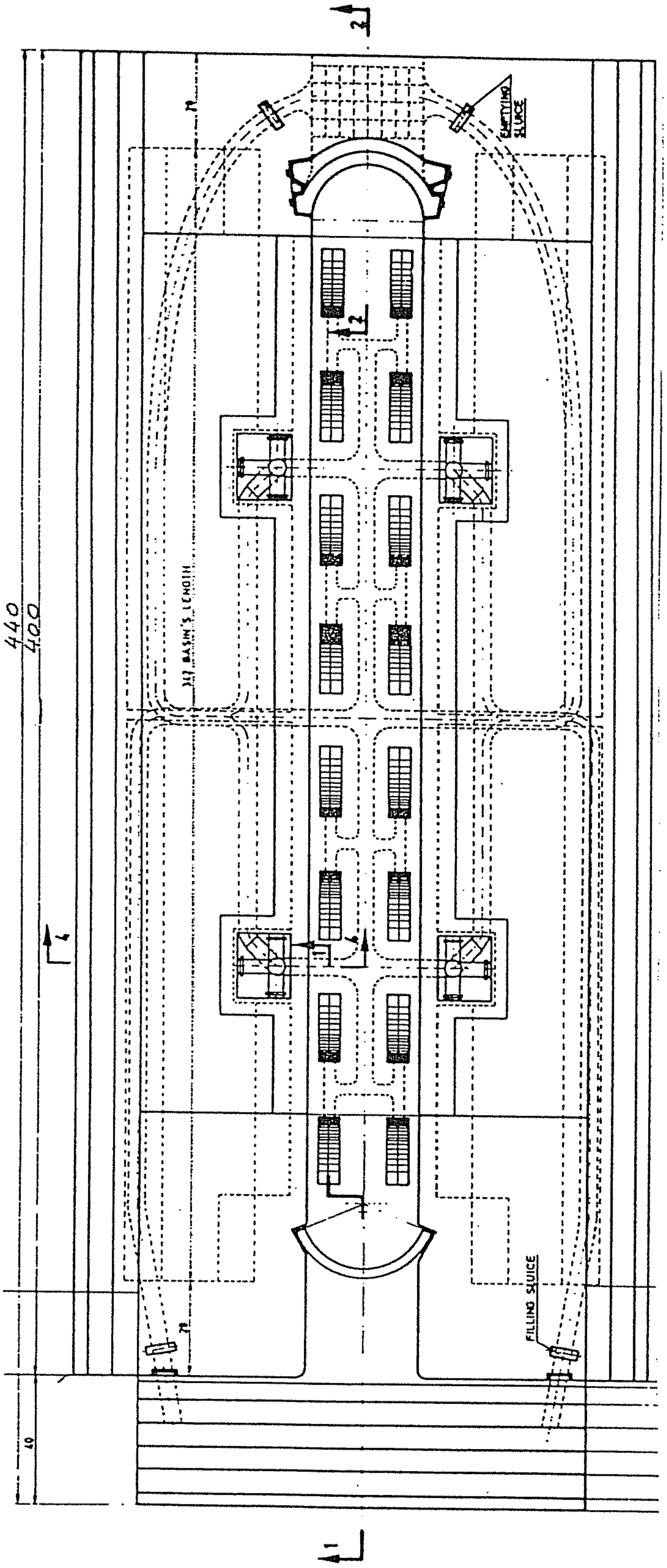
These results show that never the allowable stresses and displacements are exceeded.

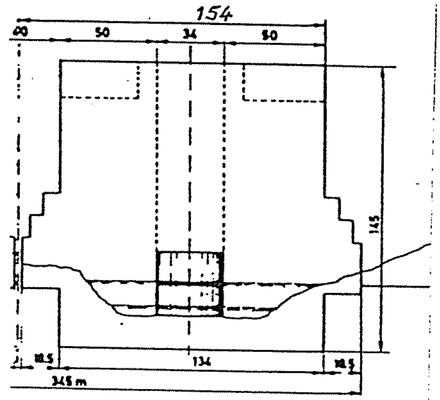
The hydraulic operations (head of 113 m)

In the case of Sandouping, the lateral basins are not used as saving basins. Their function is to get a cavitation free installation by reducing the operating heads.

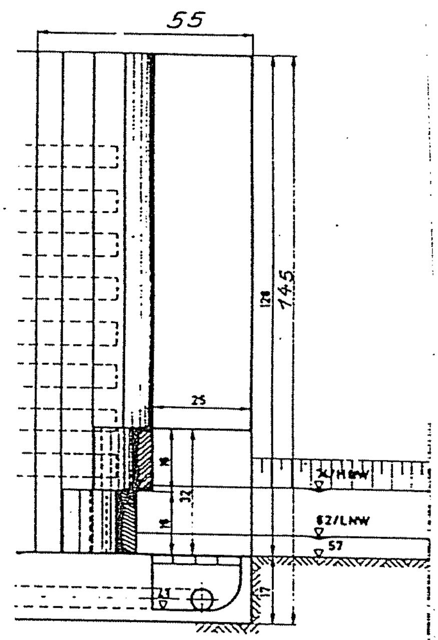
From previous studies, it appeared that 8 basins would be the optimum solution (Fig.7). Each of the basins is connected with the chamber through a special shaft in which a butterfly sluice is present. Four of such shafts exist. The water distribution is organized, in the chamber, in such a way to have a discharge evenly distributed over the surface chamber and from bottom outlets (or to the bottom inlets) (Fig.4). Each sluice has a opening of 16.2 m^2. The variation of the surface area of each sluice with respect to time is the one of the Fig.8 .

The maximum of the rising velocity of the water in the case of filling is 7cm/s and the value of the pressure at the sluice varies like at the Fig.8 kept in the positive zone due to its position in the shaft. The 8 basins being emptied, the additional time by using 2 culverts of 16.2 m^2 to fill the two last water layers, would be 1110 s. So that theoretical total filling time would be $T_t = 8 \times 305 + 1110 \approx 60$ minutes





Downstream side view



Cross-section 2-2

Fig.5 :
Downstream side view of
the 113 m rise lock

← ← Fig.4 : Plan view
of the 113 m rise lock.

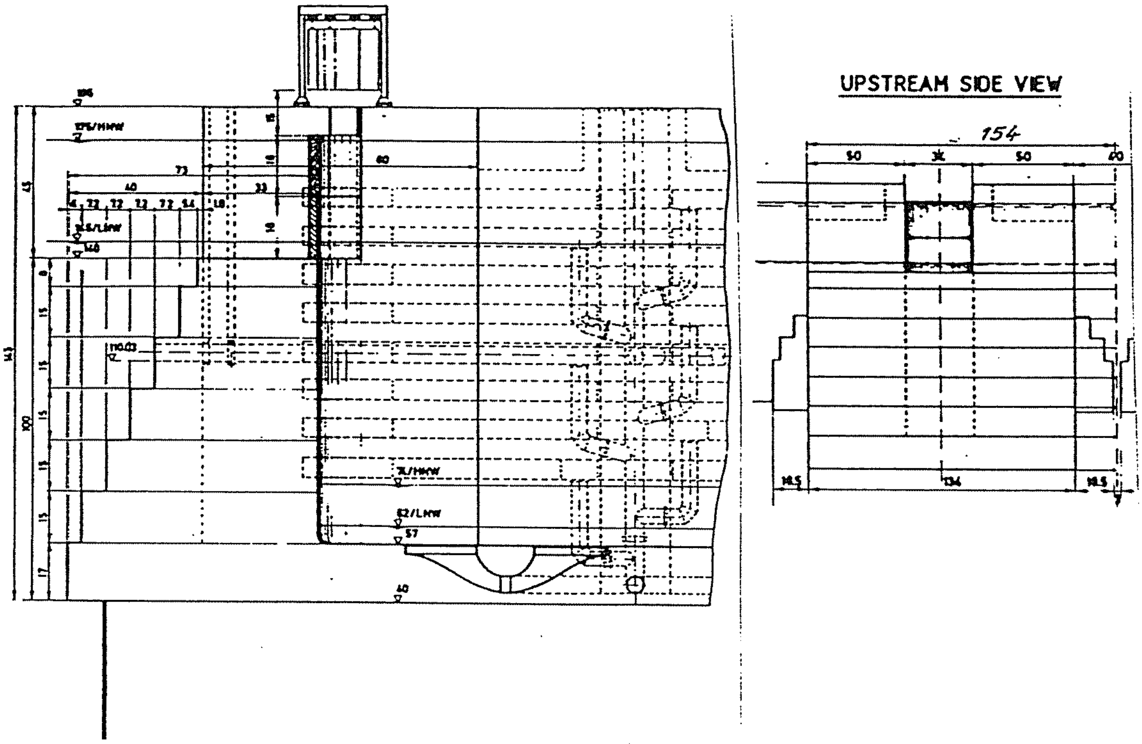


Fig.6 : Upstream side view of the 113 m rise lock.

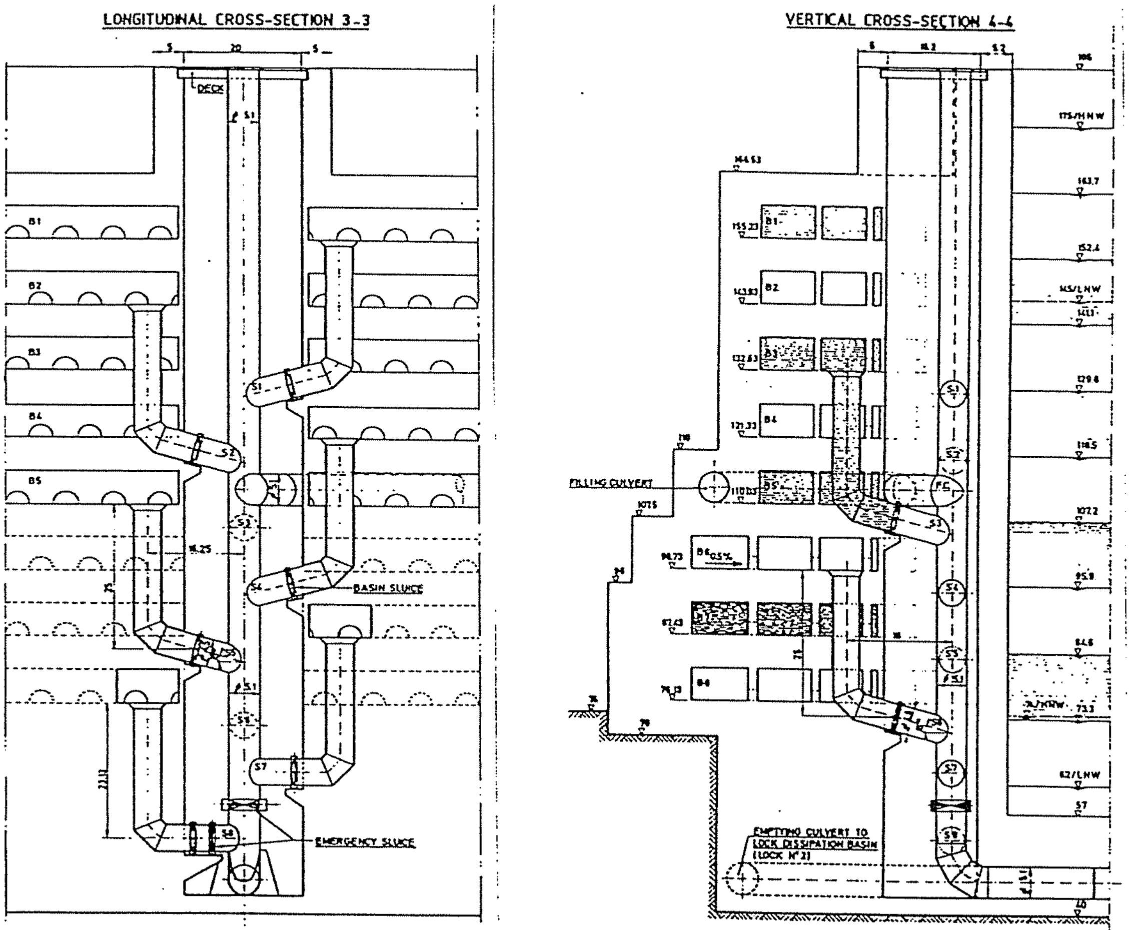


Fig.7 : Cross-section of the hydraulic system of filling and emptying (basins).

As far as the emptying is concerned, each basin takes very approximately the same time than for the filling operation (305 s). Two solutions have been studied for the additionnal emptying operation : through two lateral culverts sending the discharge in the stilling basin of the hydropower plant (solution A), or through two longitudinal culverts sending the discharge in a special stilling basin for the lock (solution B) (Fig.3).

The elapsed time in both cases are respectively 20 and 19.5 minutes. So that the emptying and filling operations take for each of them one hour. The mean elevation speed is 1.91 m/min with peaks of 4.05 m/min in the range of the operation The 60 minutes time for 113 m head comes 42 min for the 71 m head.

At any time, due to the chosen installation of the culverts and the sluice (Fig.7), the relative pressure is kept positive. The water levels variations in the upstream and downstream bays can be encountered without any problem: an easy policy of filling or emptying can be set up to keep the elapsed time at a minimum value for any position of the upstream or downstream level.

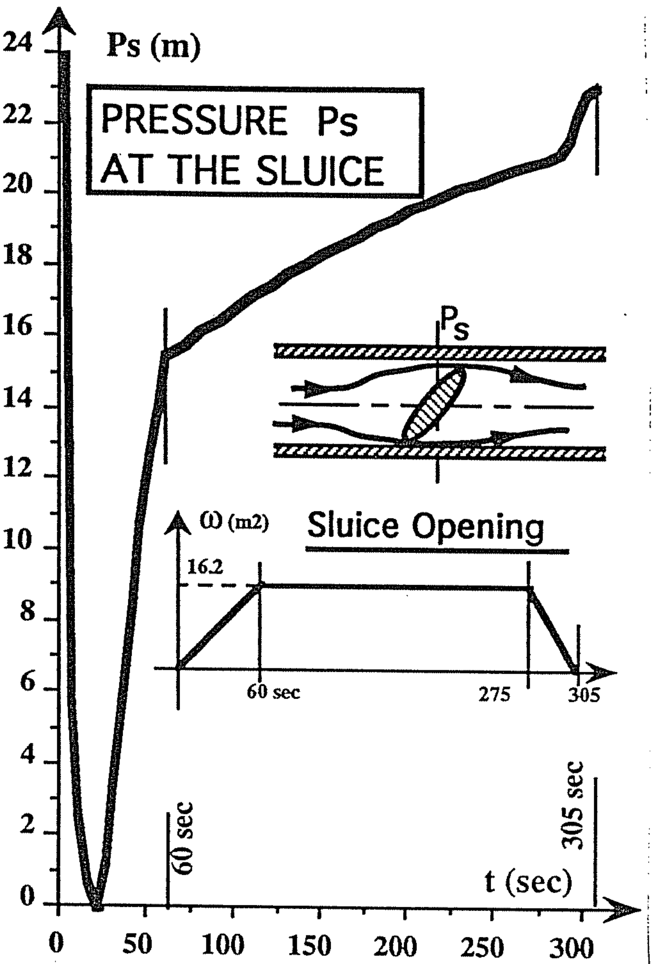


Fig.8 : Relative pressure at the sluice location in the contracted zone

With respect to flight locks, the filling and emptying time will not be increased.

The upstream and the downstream gates

In order to cope with the important variations of the levels upstream and downstream; the gates should be made in two parts. Their operations will be by vertical transfer (Figs 5 and 6). At the upstream head, the two parts will be superimposed and at the downstream head they will be offset for evident practical reasons. Their shape will be circular (pressed upstream and traction downstream).

The study of their steel fabrication as orthotropic shells [3] has given 2.5 m in thickness upstream and 4 m downstream.

Estimation of the total traffic of the lock

The theoretical time of going through the lock could be 86 minutes : going in of the convoy (10 min), operating the gate (3 min), emptying or filling (60 min), operating the gate (3 min) and going out of the convoy (10 min).

If we consider six lockings per day during 250 days per year, with a usual convoy of 12 000 tons, we come for one lock to the annual theoretical traffic of :

$6 \times 250 \times 12\,000 = 18.10^6$ tons/year and 36.10^6 if two such locks are built aside.

References

[1] Dehousse, N.M. and all (1989) "Very High Rise Navigation Locks", PIANC, bull. n°67, pp. 35-51.

[2] Dehousse, N.M., (1990), Les écluses de Navigation, L.H.C.H., University of Liege, Belgium.

[3] Dehousse, N.M., Rigo, Ph. (1989), "The Design of Cylindrical Orthotropic Plates and Shells", IASS, Congress of Madrid, Numerical Methods, Vol. 5, Madrid, 19p.