HIGH RISE NAVIGATION LOCKS
- Feasibility Study of 80 m and 113 m Rise Locks -

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Abstract

Standard locks are limited to ± 40m high due to mainly cavitation problem. Feasibility studies of high rise navigation locks of more than 80 m have been completed in the last decade at the University of Liege in Belgium. Such locks have been studied to provide a reliable alternative to flights of several lock, shiplifts and inclined planes when the water head between upstream and downstream reaches 50m, 80 m and even 120m.

High rise navigation locks are based on the use of basins which split the water head. On canals, they can be use in order to save 20%, 50 %, 90 % or even 100 % of the water required to fill standard locks. In this case, basins are required to avoid cavitation but are necessary to save water; we say "saving basins". On rivers, high rise navigation locks can also be a reliable solution and the basins function is mainly to get a cavitation free installation. In order to reduce the earth removing works, the idea is also to build the lock as a part of the dam.

At any time, due to the selected system of culverts and sluices, the relative pressure is kept positive. The water levels variations in the upstream and downstream sites 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 levels upstream or downstream.

Resumen

La cavitación limita los desniveles máximos de las esclusas a 40 m. En desniveles superiores la solución clásica consiste en una serie de esclusas (escalera de esclusas) o en ascensores hidraulicos. Hace mas de 10 años que en la Universidad de Lieja se han emprendido investigaciones sobre esclusas capaces de vencer grandes desniveles (50 m, 80 m y hasta 120 m). El principio de éstas esclusas consiste en la utilización de depósitos recuperadores que dividen el desnivel total en una serie de pequeños desniveles.

La utilización en canales de éste tipo de esclusas permite realizar economias de agua que pueden llegar hasta 100 % del agua necesaria para el funcionamiento de una esclusa clásica. Utilizada en ríos, las economias de agua no son necesarias pero en este caso los depósitos recuperadores se utilizan para evitar los fenómenos de cavitación.

Estas esclusas funcionan con grandes variaciones de nivel río arriba o río abajo, propiedad muy importante sobre todo para las aplicaciones en ríos tropicales. Los ascensores hidraulucos solo funcionan con pequeñas variaciones de nivel.

I. HIGH RISE NAVIGATION LOCKS IN CANALS

Belgium has a good experience in hydraulic structures dedicated to the navigation development. There are hundreds of standard ship locks from 5 x 50 m to 70 x 500 m (width x length). There are also 4 hydraulic shiplifts of 15 m each, built one century ago; one inclined plane of 68 m rise completed in 1966 and a new shiplift that will be the highest one in the world after the completion : 73 m high.

The dimensions of ship chambers of mechanical locking devices, such as shiplifts and inclined planes, are the major characteristics (constraints) for the design of the whole structure, and nowadays they restrict their use to the dimension of 120 x 12 m. In 1997, these dimensions are no more compatible with the modern navigation of large push convoys (for instance of 9000 tons) without dismantling them. That is why our idea has evolved towards the project of very high rise locks.

Our ideas have more specifically been focussed on the problem of 80 m high rises which would be compulsory for the navigation canal between the Rhine in Germany and the Meuse in Belgium ; see Figure 1.

Everyone knows the principle of the *saving basins*. These basins are usually built quite independently aside of the lock chamber (Figure 2). We suggest to take advantage of the saving basins to change the construction by placing the basins inside the walls, by giving them an annular shape around the chamber, so that the inside water pressure would be self-balanced. The lock then appears as follows (figures 3a -3.e) :

For canals, the rate of spared water is very important. This rate (%) is defined as 100 N/(N+2) with N the number of basins. In fiction, the water head of the ship chamber is divided in N+2 layers; N layers are saved using the basins and the two others are released (as for standard locks). For the present case, two locks of 80m with 18 basins each are proposed to save 90% of the water (by reference to standard locks). The computation of the hydraulic operations, proves that the filling or emptying time doesn't grow very quickly according to the number of basins and that it is reasonable to make a 90 % water saving by using 18 basins (figures 3a -3.e).

The cavitation problems disappear because the global hydraulic operation is split into a serie of low head operations (maximum 8 m in the actual case). There is no important surge downstream.

In fact, the only real problem is the pressure distribution on the foundation that requires a good quality of soil.

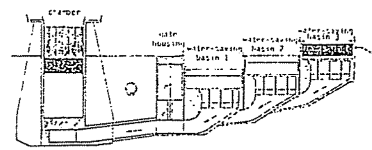

Fig.2: Saving basins on the Elbe Canal - Germany

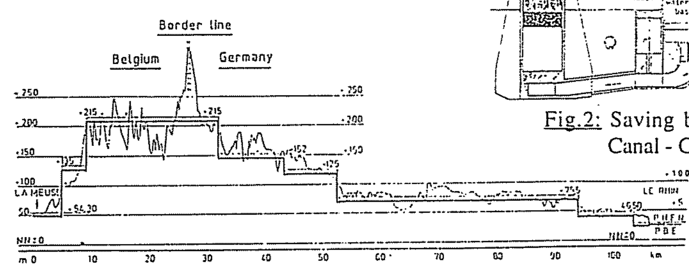

Fig.1: The Project of the canal between the Meuse and the Rhine rivers

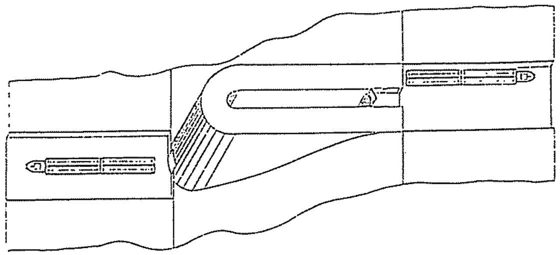

Fig.3.a: A 80 m high rise navigation lock.

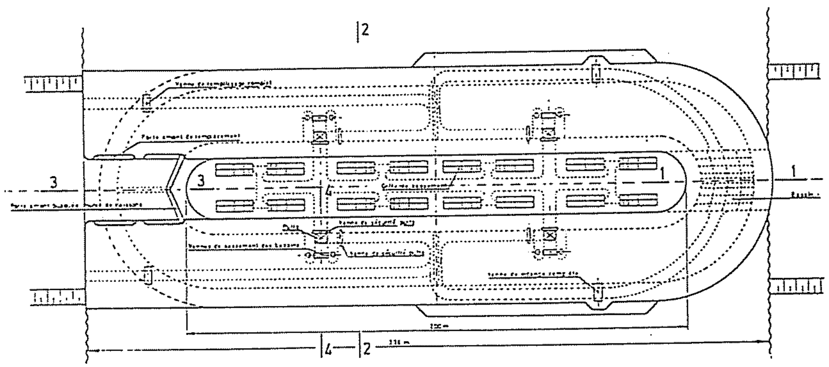

Fig.3.b: Plan view of the 80 m high rise navigation lock for canal

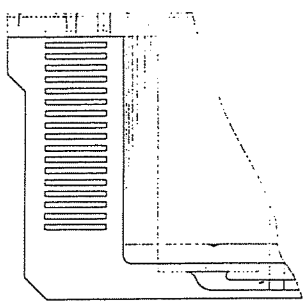

Fig.3.c: Upstream side (cross-section 3-3)

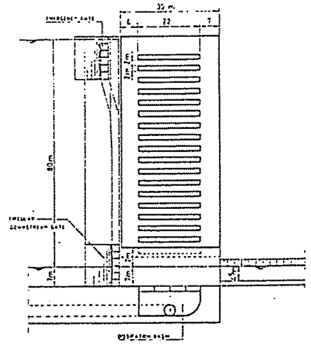

Fig.3.d: Dowstream side (cross-section 1-1)

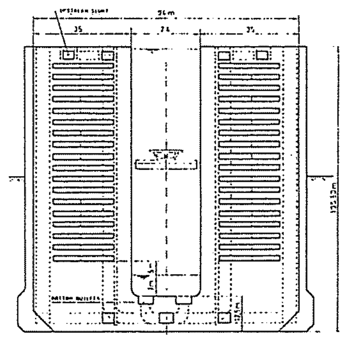

Fig.3.e: Chamber cross section (cross-section 2-2)

II. HIGH RISE NAVIGATION LOCKS IN RIVERS

II.1 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 (called *Three Gorges Project*) was selected as an other 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, that is to say 400 Mw more than the Itaipu installation. The maximum planned could be 18720 Mw (highest value of hydropower of the world to this day). But as it 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 it appears the problem of the navigation through the Sandouping dam. From a meeting due to the courtesy of the Yangtze River Scientific Institute in Wuhan in 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.

A fleet of ships carrying 12000 tons (one pushboat and 9 barges) should be able to pass without dismantling. The draught should be 5 m at the sill and the air clearance 15 m. At Gezhouba two large locks are currently used and 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.

II.2 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 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.

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. 4). We develop hereafter the feasibility study of a single 113 m rise lock. In fact, a double lock is necessary according to the traffic requirements (see figures 5 and 6).

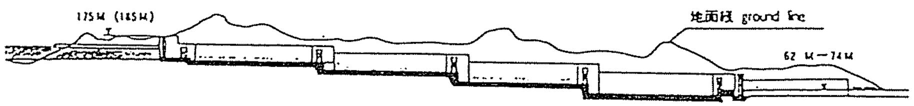

Figure 4 : The double flight locks.

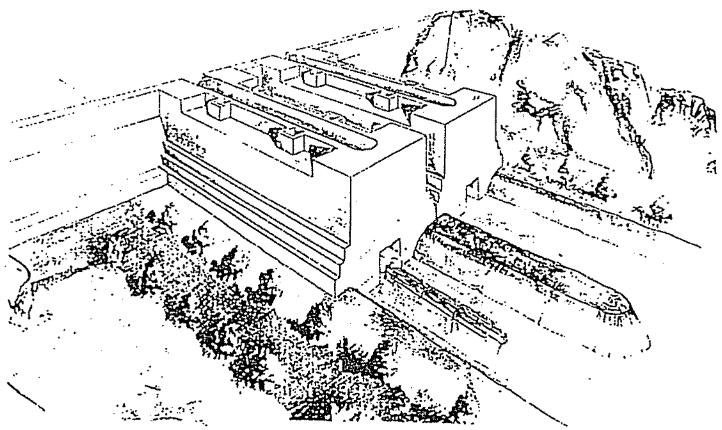

Figure 5 : Artist view of the double 113m rise lock (downstream side).

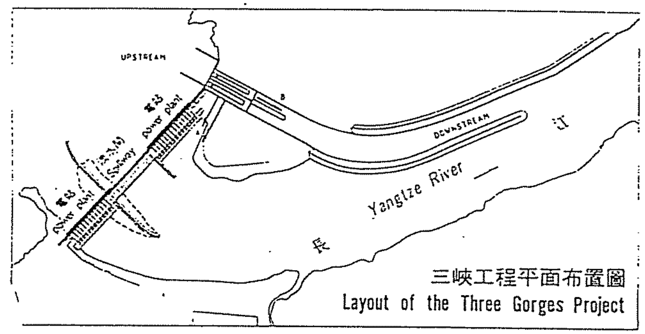

Figure 6 : The Three Gorges Project with a double 113 m rise lock.

II.3 General result of the feasibility study

The study dealt with the questions of stress distribution on the foundation, the stress level in the walls and the floor, the system of the filling and emptying, the way to completely avoid cavitation, 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. 8), downstream head (Fig. 7), upstream head (Fig. 9) and cross-section with the hydraulic system (Fig. 10).

II.3.1 Study of the concrete structure

In order to reduce the earth removing works, the idea has been retained to build the aforementioned locks in the vicinity of the hydropower plant and to make use of a protection shield wall for the navigation. The locks replace about 250m of dam. Moreover, this solution requires less excavation than 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.7 to Fig.10, 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 design of Figs.7 and 9. The longitudinal walls should be established with inner basins as indicated and with partition walls inside of the basins. A finite elements analysis (FEM) performed on the structure (side wall and foundation) gives the following results :

Basins full of water and lock chamber empty

- Maximum displacement at the top of the walls : 36 mm (2 x 18 mm) that decreases of the chamber width.
- 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 that enlarge the chamber width.
- Maximum stress transmitted to the foundation : 17 dN/ cm^2.
- Maximum vertical stress : currently smaller than 60 dN/ cm^2 and reaches 90 dN/ cm^2 in very small zones.
- Maximum horizontal stress : 25 dN/ cm^2.

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

II.3.2 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 provide an installation free of cavitation by reducing the operating heads.

From previous studies, it appeared that 8 basins would be the optimum solution (Fig. 10). Each basin is connected with the chamber through a special shaft in which a butterfly sluice is present. Four of such shafts are required. The water distribution is organized, in the chamber, in such a way to have a discharge uniformly distributed all over the surface of the chamber . The water arrives in the chamber through bottom outlets (or the bottom inlets for emptying) (Fig.7). Each sluice has a opening of 16.2 m^2. The variation of the opened section of each sluice with respect to elapsed time is shown at the Fig. 11.

The maximum of the rising velocity of the water for the filling is 7cm/s and the pressure at the sluice is kept in the positive zone due to its position in the shaft (see Fig. 11). The chamber filling operation starts with the emptying of the lowest basin and continues with the others. For each basin, it takes about 305 s. After emptying these 8 basins, additional water (volume of two basins or *layers*) is introduced in the chamber as done in standard locks (by using additional culverts) and it takes about 1100 s. So that the theoretical total filling time would be = 8 x 305 + 1110 = 60 minutes.

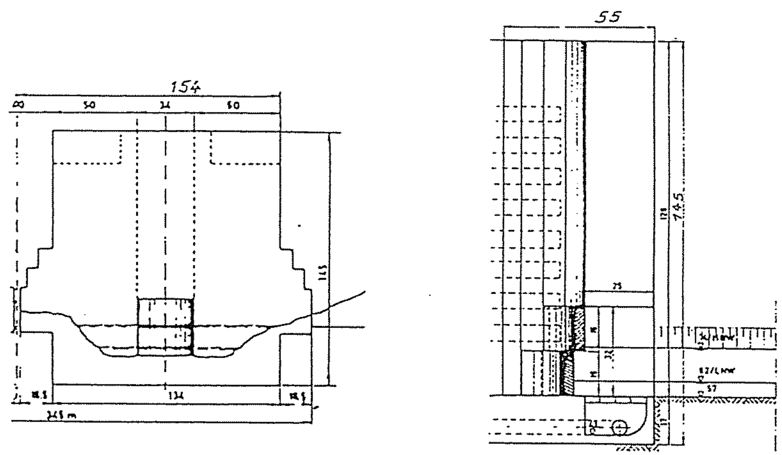

Fig.7 : Downstream side view of the 113 m rise lock

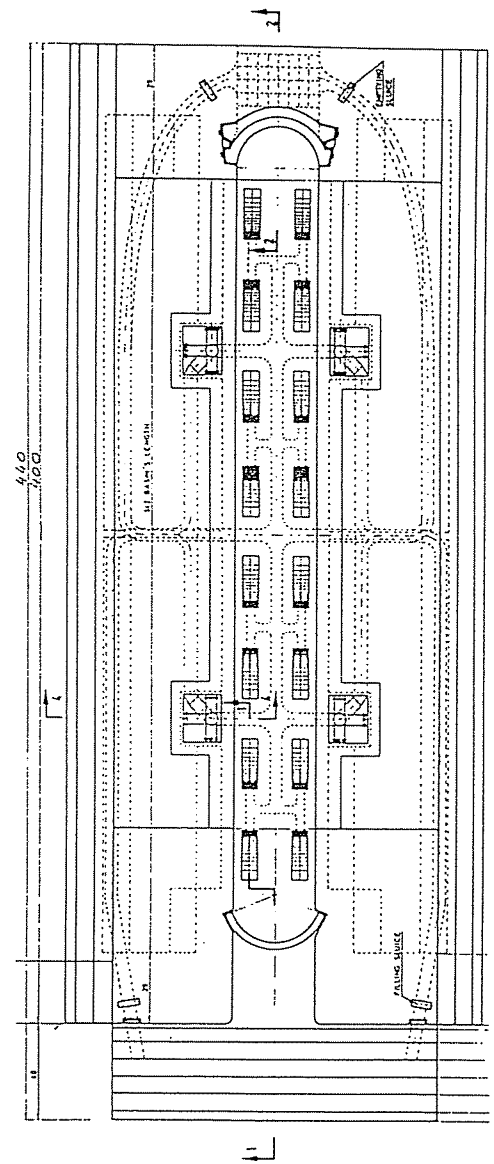

Figure 8 : Plan view of the 113 m rise lock.

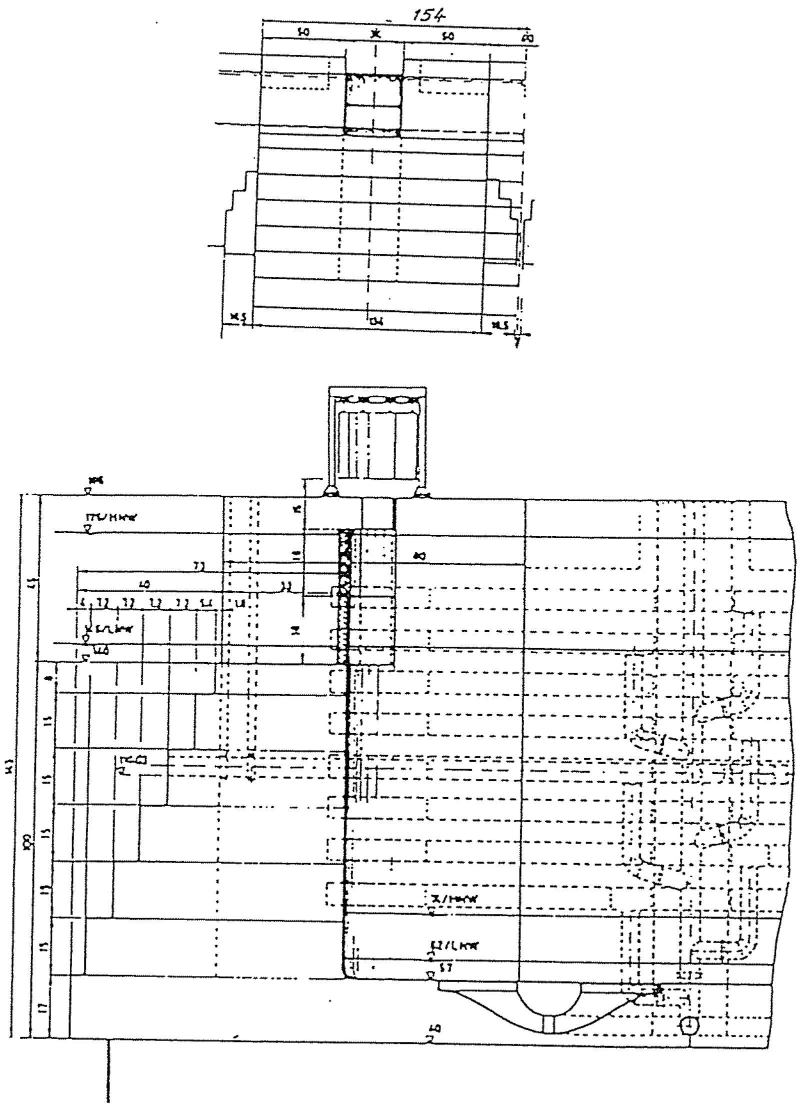

Figure 9 : Upstream side view of the 113 m rise lock.

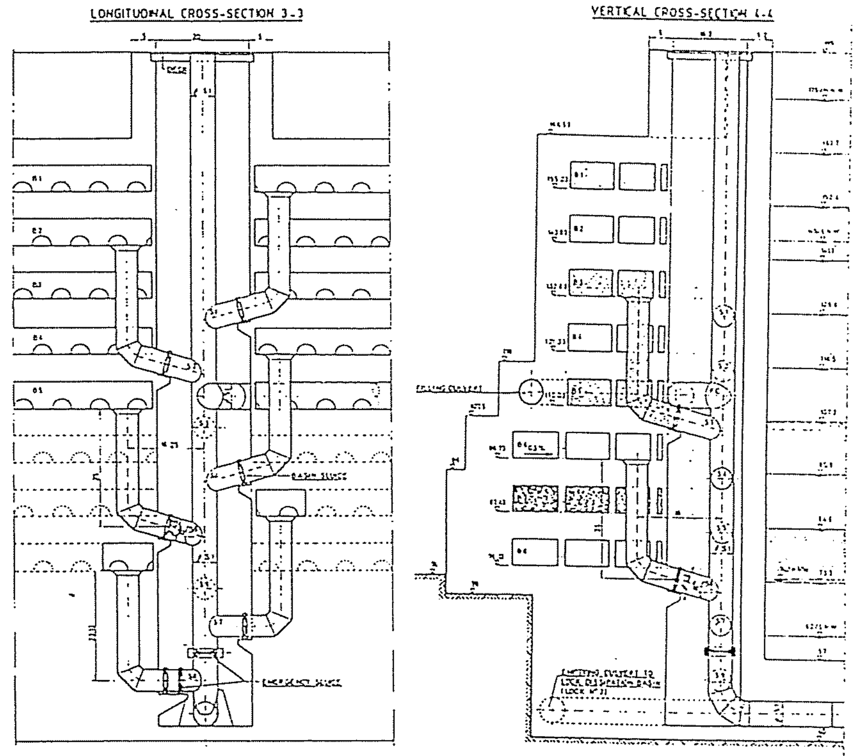

Figure 10 : Cross-section of the hydraulic system of filling and emptying (basins).

As far as the emptying is concerned, each basin takes very approximately the same time as for the filling operation (305 s). Two solutions have been studied for the additional 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. 8). The elapsed time for both alternatives are respectively 20 and 19.5 minutes. So that the emptying and filling operations take for each of them, about one hour. The mean elevation speed is 1.91 m/min with a peak of 4.05 m/min during the operation The 60 minutes for a 113 m head becomes 42 min for a 71 m head.

At any time, due to the selected system of culverts and sluices (Fig.10), the relative pressure is kept positive. Therefore, the cavitation can not occur. 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.

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

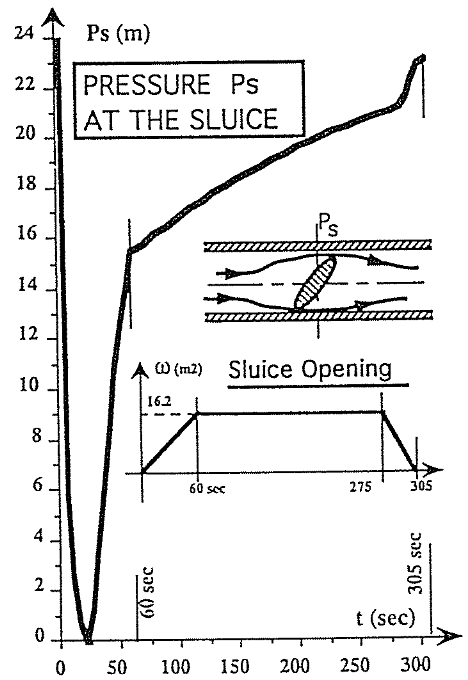

Fig.11 : Relative pressure at the sluice location in the contracted zone (cavitation risk analysis).

II.3.3 The upstream and the downstream gates

In order to cope with important variations of the upstream and downstream level; the gates should be made in two parts. Their operations will be achieved by vertical transfer (Figs 7 and 9). At the upstream head, the two parts will be superimposed and at the downstream head they will be offset for an obvious reason of space saving. Their shape will be circular (compressed upstream and in tensile downstream).

The preliminary design of these gates has been achieved using the LBR-4C software [3]. A 2.5 m and 4.0 m thick double faced (or skinned) gate is obtained for, respectively, the upstream and the downstream side.

II.3.4 Estimation of the total traffic of the lock

The theoretical time of going through the lock could be 86 minutes :

- entrance of the convoy (10 min),
- operating the gate (3 min),
- emptying or filling (60 min),
- operating the gate (3 min),
- departure of the convoy (10 min).

For six lockings per day during 250 days per year, with a usual convoy of 12 000 tons, the annual theoretical traffic for one lock is evaluated to be :

	18.10^6 tons/year	(6 x 250 x 12 000)
and	36.10^6 tons/year	if a double lock is built.

III. CONCLUSIONS.

It appears that designing an 80 m or even 120 m rise lock is not at all an utopic view and that this possibility has to be studied carefully when the choice of a locking device for very high rises has to be made.

Acknowledgements:

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References

[1] Dehousse, N.M. , Rigo P. & all (1989) "*Very High Rise Navigation Locks, Part I and II*", PIANC, bull. n°67, Brussels, pp. 35-51.

[2] Dehousse, N.M.,.(1990), "*Navigation Locks (in french)*", Text Book, University of Liege, Belgium.

[3] Rigo Ph., (1992) "*The Stiffened Sheathings of Orthotropic Cylindrical Shells*", Journal of Structural Engineering of the ASCE, USA, vol. 118 n°4, p926-943.

memorias

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