VERY HIGH RISE NAVIGATION LOCKS

PART I

by

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ABSTRACT

The article deals with the problems of using navigation locks when the rise is very important (50 to 80 m or even more) and when the traffic is very heavy.

In this situation which can occur for energy or navigation purposes, mechanical devices such as shiplifts and inclined planes come to mind at once.

It is pointed out that the use of lateral basins, built inside of the walls, solves many troublesome questions such as water saving, cavitation, surges.

SOMMAIRE

L'article traite la question de la possibilité d'employer des écluses de très hautes chutes (50 à 80 m ou plus) lorsque le trafic est important.

Dans ce cas, il est bien connu que les constructeurs pensent en premier lieu aux ascenseurs et plans inclinés.

On montre que l'emploi des chambres latérales, construites dans les bajoyers, résout nombre de problèmes difficiles tels l'économie d'eau, la cavitation et les ondes de vidange.

Navigation high rises can appear for two different reasons. They can be linked with the implementation of hydropower works and it is well known that economy prescribes building as few installations as possible with a maximum head for each of them.

As a consequence, there is an important hindrance for navigation. Without any idea of energy quest, high rises can occur simply due to the trend of navigation and very often in the case of linking canals between two different hydrographic basins. In the last few years, we have taken a strong interest in the following projects for large fluvial vessels.

a. The derivation of the Zaire river between Kinshasa and the Atlantic ocean, short-cutting the passage of the river through the Western part of the Cristal Mountain (Africa).

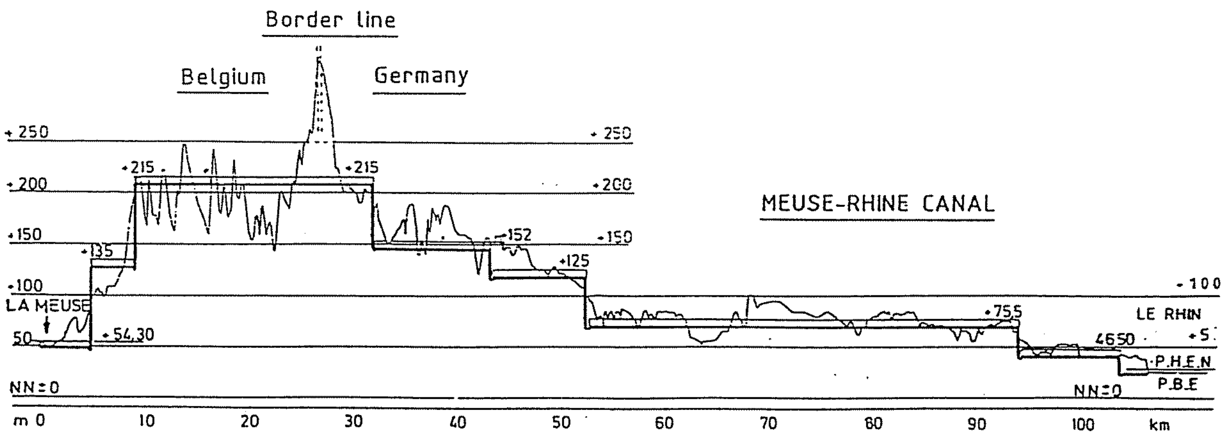


Figure 1

b. The linking canal between the Danube and the Aegean Sea (Europe).

c. The linking canal between the hydrographic basins of the River Rhine and the River Meuse in Germany and in Belgium (Europe).

In the three cases mentioned, the traffic would be very heavy, as important as 20 to 40 million tons per year so that pushed barges' convoys should be used, requiring a minimum width of 24 m and a minimum length of 200 m for the locking systems.

Another feature is the importance of the rises encountered : 50 m for the situation of the Zaire and 80 m for the case of the Meuse-Rhine connection. We are then faced with the question of very high rise locking systems.

* * *

Many possibilities exist which are rather well known. In this respect Belgium has a good experience with 4 hydraulic shiplifts of 15 m each, built some 90 years ago; with one inclined plane of 68 m rise completed in 1966 and with a cable shiplift which will be the highest one so far when completed : 73 m.

The dimensions of the containers of mechanical devices such as shiplifts and inclined planes are the major factors for the design of the whole structure, and nowadays they restrict their use to the dimension of 120 m x 12 m. These dimensions prevent the navigation of large push-tow convoys (for instance of 9000 tons) without dismantling them.

This is why our idea has evolved towards the project of very high rise locks.

Such a device looks like an important well, closed upstream by a retaining wall and downstream by a shield wall.

Many problems can arise due to the extrapolation of the data. Let us mention :

- the stability of the sidewalls, loaded with a very important earth pressure acting outside and water pressure acting inside the chamber,
- the water pressure acting on the downstream shield wall which is then expected to act as a dam,
- the strong loads transferred to the foundation and its variation during the use of the lock (full or empty),
- the large stresses of the chamber floor,
- the important stresses of the downstream gate,
- the behaviour of the vessels inside the lock chamber during the emptying or the filling operations,
- the cavitation inside culverts due to the very important head,

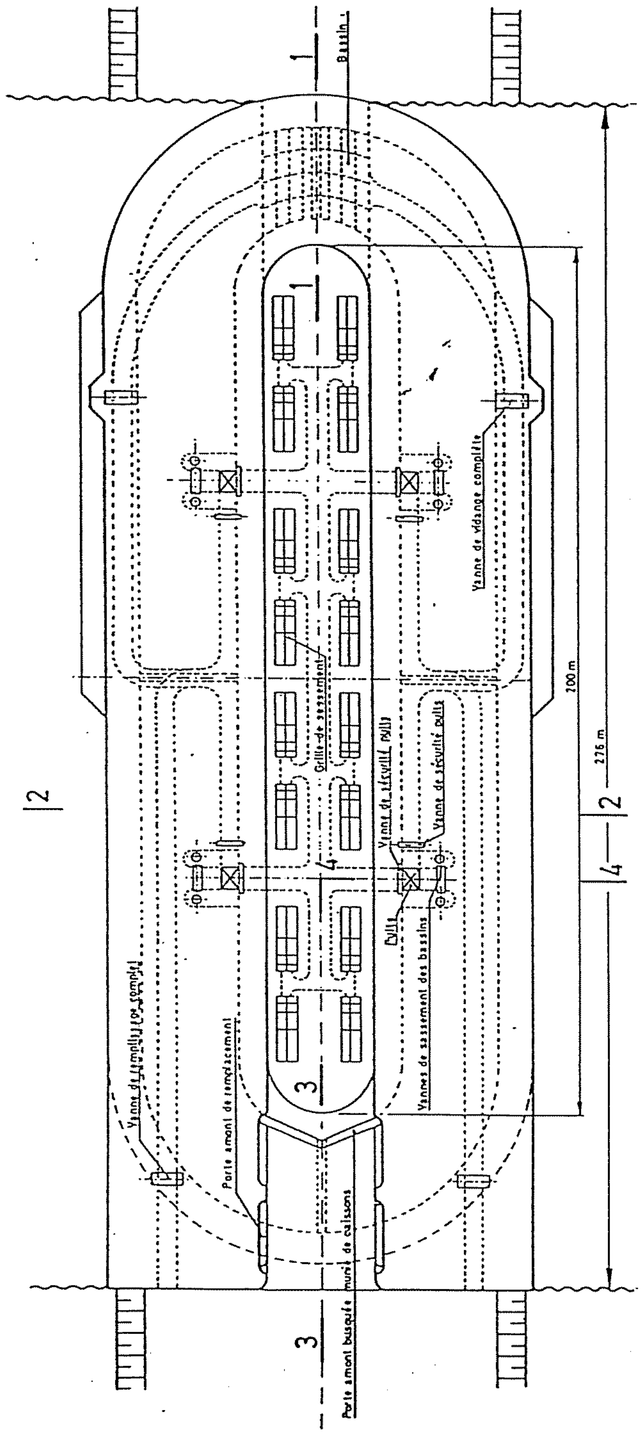


Fig. 3 - Horizontal plane

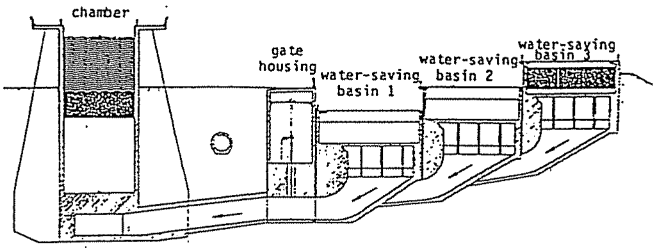
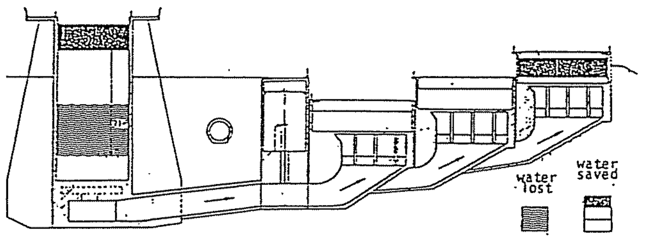


Figure 2 UELZEN LOCK - ELBE LATERAL CANAL - GERMANY



CROSS-SECTION 2-2

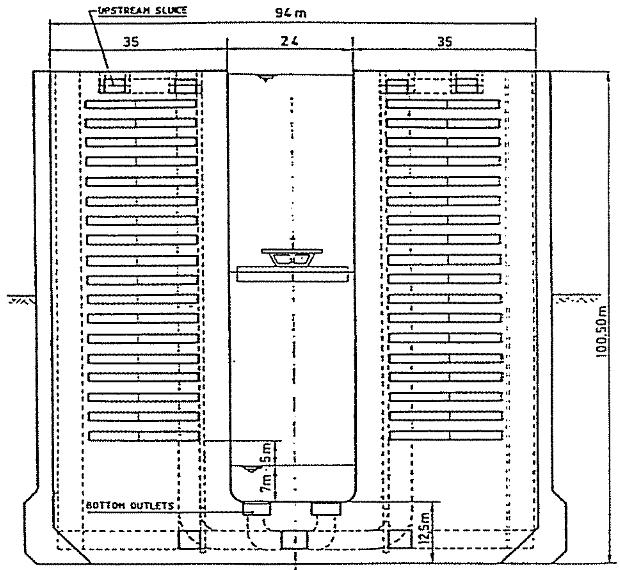


Figure 5

CROSS-SECTION 1-1

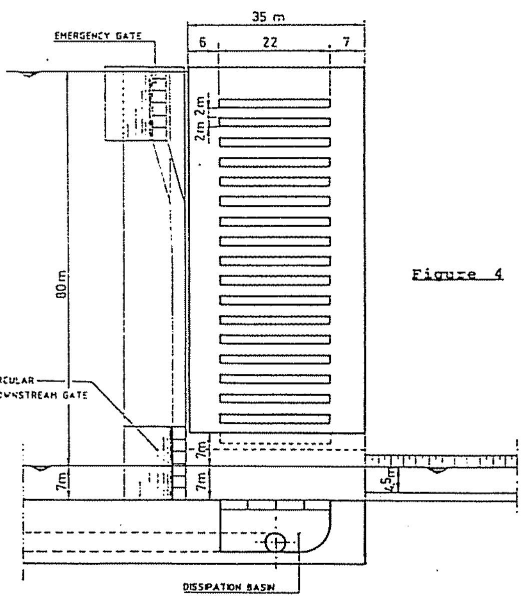


Figure 4

CROSS-SECTION 3-3

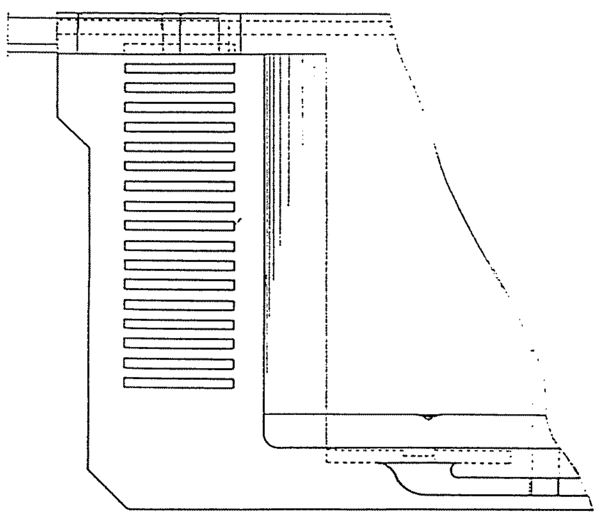


Figure 6

- the filling and the emptying time,
- the consumption of water from the upstream reach and the surges in the downstream reach.

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 (F.R. Germany) and the Meuse (Belgium)(Figure 1).

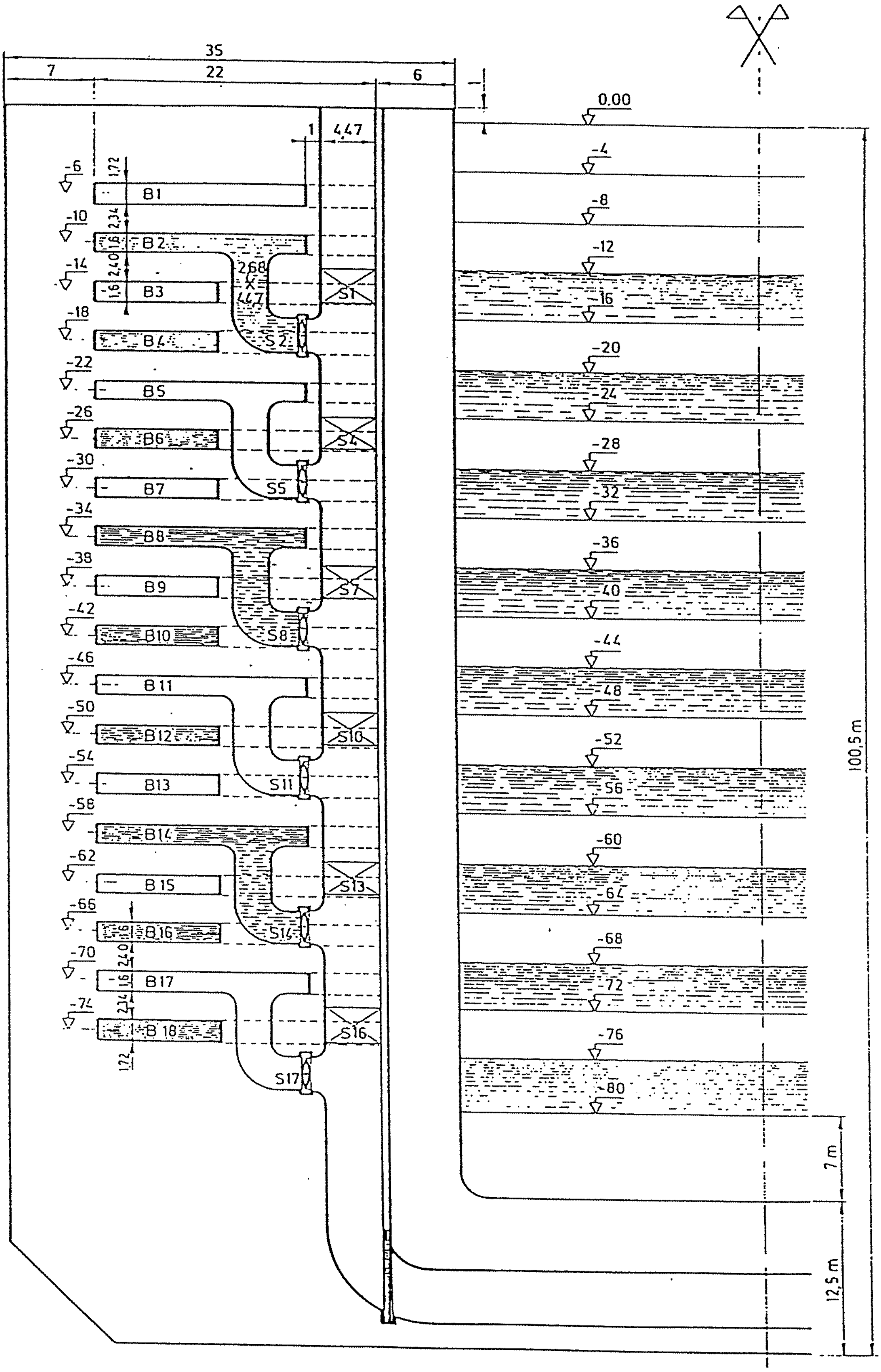


Fig. 7 - Vertical cross section 4-4

* * *

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' use 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 be self-balanced and to set the whole construction on a thick floor. The lock then appears as follows (figures 3,4,5,6,7) :

1. It has many saving basins (18 in the case of an 80 m rise). 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 (figure 5).

2. These basins are marked by a ratio

$$\frac{S_{basin}}{S_{lock\ chamber}}$$

as high as 2.5 (Figure 5). The surface area of the basins ensures the stability of the walls by increasing their width.

3. The annular shape of the basins comes to a zero resultant force in the downstream direction and the curved parts shall reduce the stresses' concentrations (Figure 3). The whole structure has to be studied in relation to the foundation's shear resistance.

4. The maximum stress transmitted to the foundation is more or less constant due to the existence of the saving basin : its order of magnitude is 15 bars (Figure 5).

5. The lock is partly banked up, the downstream zones are visible. There is no canal bridge : it is an economy in construction, maintenance and operation (Figure 8).

6. The upstream gates could be mitre gates equipped with air chambers to balance their own weight. They should be doubled for security reasons (Figure 3).

7. The downstream gates should be lift gates with a circular sheathing strengthened with ribs. They are also doubled, upstream of the shieldwall (Figure 4).

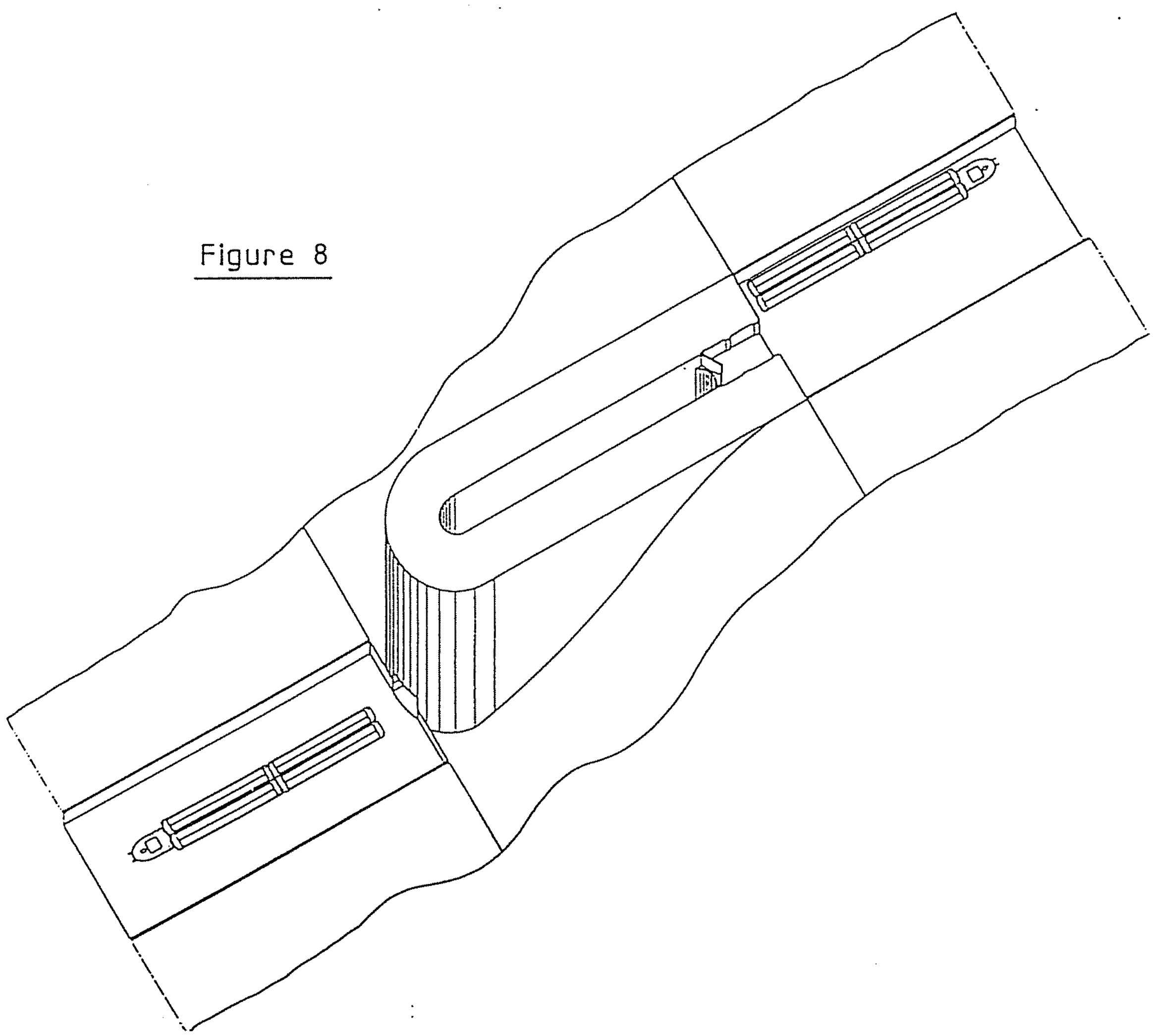
8. In the case of an 80 m rise lock, 18 saving basins will allow to stock 4 m deep slices. Two slices of 4 m (8 m) have then to come from the upstream reach and two slices of 4 m (8 m) have to be sent into the downstream reach (Figure 5).

9. In order to speed up the hydraulic operations, a uniform distribution of the water will be yielded from the bottom of the chamber, the operating sluices will yield a total section of 50 m^2; the operations will be implemented through 4 wells and butterfly sluices (4 x 12.5 m^2) (Figure 3).

10. Due to these data, it appears that the filling operation takes $\pm$ 35 minutes, corresponding to a mean velocity rise of 2.3 m/minute and a peak velocity of 5 m/minute. In a first approximation, the filling time in a lock equipped with saving basins is given by :

$$T_t = \mu T_e + T_s = \frac{S\sqrt{\gamma}}{\omega\sqrt{2g}} \left[\frac{\mu\sqrt{h}\,(2 - \frac{\varepsilon}{h}\sqrt{\frac{\varepsilon}{h}})}{1 - \frac{\varepsilon}{h}} + 2\sqrt{2h} \right]$$

Figure 8



with :

μ number of saving basins

T_e emptying time of one saving basin

T_s duration of the filling operation due to the upstream reach contribution

S surface area of the lock chamber

γ hydraulic losses coefficient

ω cross section of the sluices

h and ε as defined in figure 9.

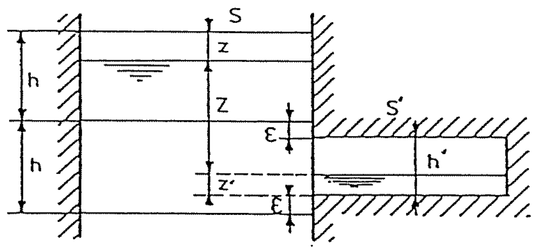


Figure 9

It can be understood that if ω and ε are large, it is possible to obtain a reduced filling (or emptying) time even if μ is important.

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

12. If the tonnage of the pushed convoys is 9000 tons (4 barges), the total traffic can be as high as 40 million tons per year.

13. The introduction of the saving basins inside the wall ensures an important bending stiffness to sustain the earth and water pressures.

14. The same applies to the floor, due to the presence of the culverts in the bottom of the lock.

15. The experience we have acquired in the field of orthotropic steel structures, guarantees that the design of the downstream gate is perfectly feasible.

In fact, the only real problem is the pressure distribution on the foundations which require a good quality soil.

So it appears that creating an 80 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.

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VERY HIGH RISE NAVIGATION LOCKS

PART II

Feasibility study of a 11.3 m rise lock for the Three Gorges site on the Yangtze river (P.R. China)

by

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I. 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 from the city of Shangaï (figure 1). Some 40 km upstream from Gezhouba, the Yangtze river cuts through three majestic canyons named : Qutang Gorge, Wu Gorge and Xiling Gorge (the Three Gorges).

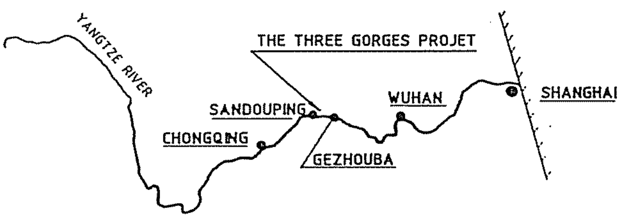

Figure 1

As early 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 in the world today). 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 from Sandouping is also a purpose of the project.

So the problem of the sailing through the Sandouping dam arose. From a meeting due to the courtesy of the Yangtze River Scientific Institute in Wuhan, in November 1988, we got the informations that the discharge could vary between 3000 and 110,000 m^3/s. At the dam, the upstream water level variations would be between el.175 m and el.145 m and downstream, between el.62 m to 74 m. The draught should be 5 m at the sill, the air clearance 15 m.

A fleet of ships carrying 12,000 tonnes (one pushtow and 9 barges) should be able to pass without dismantling.

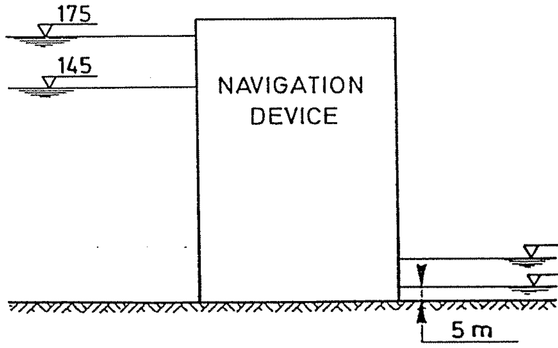

Figure 2

(*) This article has been prepared under the guidance of Prof. N.M. Dehousse by a team composed of R. Arnould (PhD), Chef de Travaux; M. Sahloul (PhD), Premier ingénieur de recherches; Ph. Rigo (PhD), Assistant; I. El Dakdouki (Civil Engineer), Assistant; J. Lambrecht (Chief Technician).

At Gezhouba where two large locks are currently used, the lock chambers have 280 m in length and 34 m in width.

The sketch (figure 2) shows that the maximum rise of the navigation device could theoretically be 113 m and the minimum 71 m but apparently it should more likely vary between 101 m (175-74) and 83 m (145-62).

For the sake of safety, we will deal hereafter with the extreme rise of 113 m.

II. CHOICE OF A NAVIGATION SYSTEM

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

Inclined planes with counterweights of the Ronquières or Arzviller's 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 elevator system has been realised 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 immerges it into the other bay. It has been designed to accommodate a 150 tons barge.

It is technically unconceivable 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 with the double flight of 4 locks (figure 3).

We develop hereafter the idea referred to in Part I of this article, in a feasibility study on one single lock.

III. 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 behaviour of the barges in the chamber, and the question of the surges in the downstream reach.

The results are presented in the following figures :

- figure 4 General View - Downstream Side
- figure 5 General View - Upstream Side
- figure 6 Longitudinal Cross-section of the Lock
- figure 7 Bird's Eye View of the Lock
- figure 8 Cross-section and Hydraulic System.

IV. 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.

In fact, two locks should be foreseen (figure 9), according to the traffic requirements.

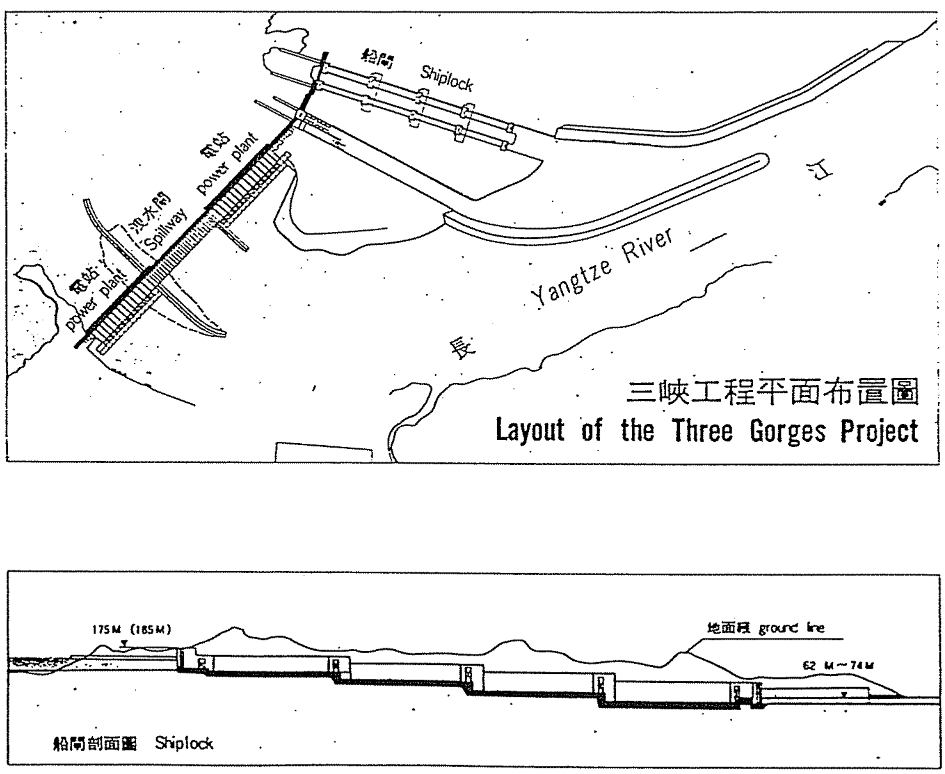

Figure 3

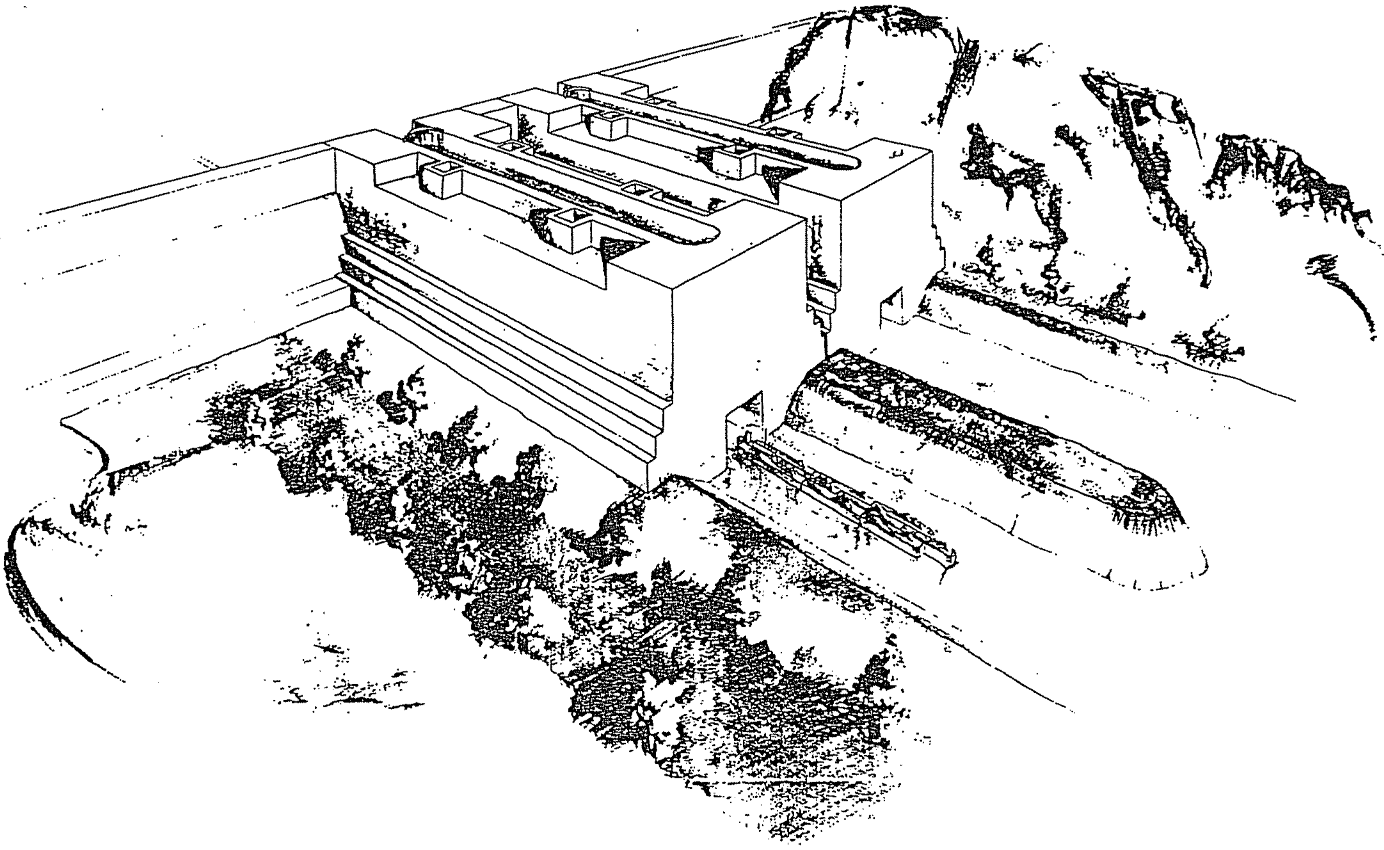

Figure 4

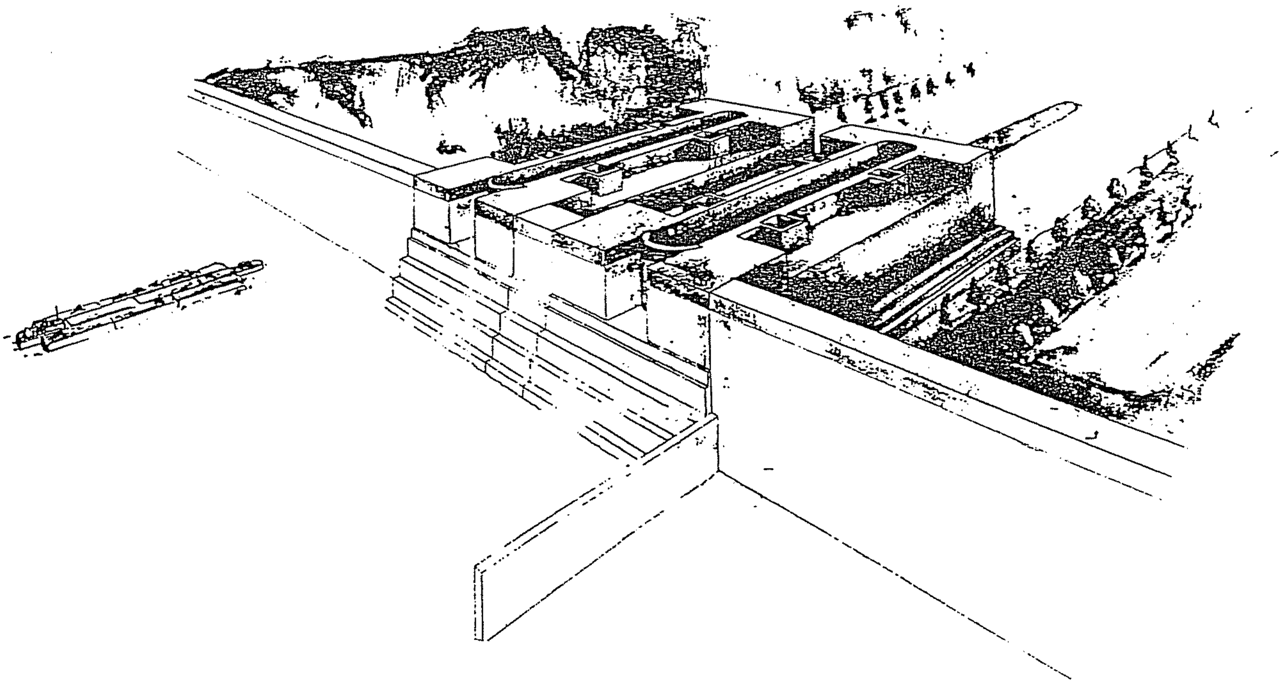

Figure 5

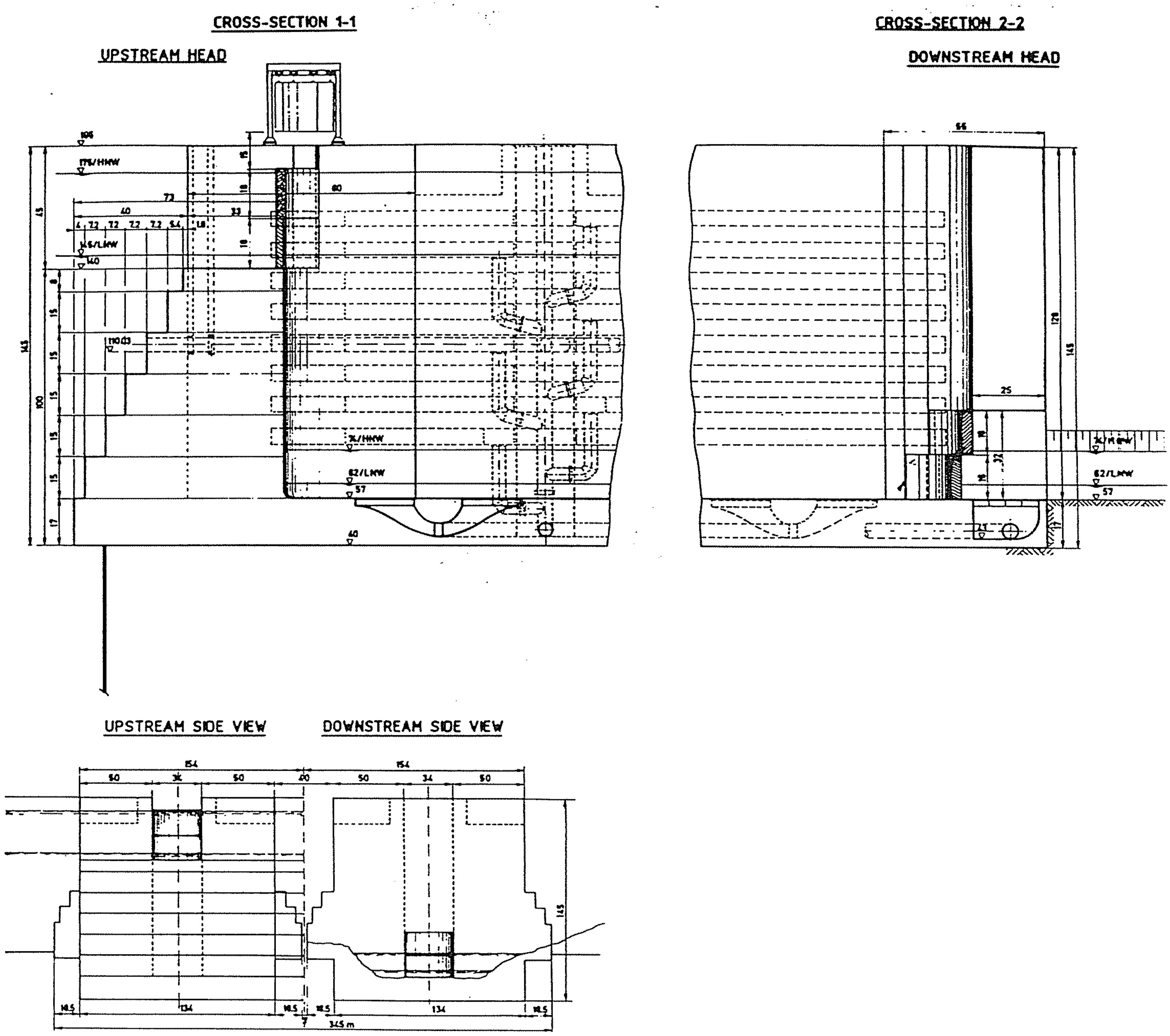

Figure 6

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 of figure 6 the stresses transmitted to the foundation are smaller than 50 bars.

The downstream head feasibility study (figure 6) leads to a maximum stress of 32 bars. The computation of the stresses and the displacements in the chamber itself, lead to the drawing of figure 8. The longitundinal wall should be established with inner basins as indicated and with partition walls inside the basins. A finite elements method study (323 elements) has given the main following results :

Basins full of water (figure 10)

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

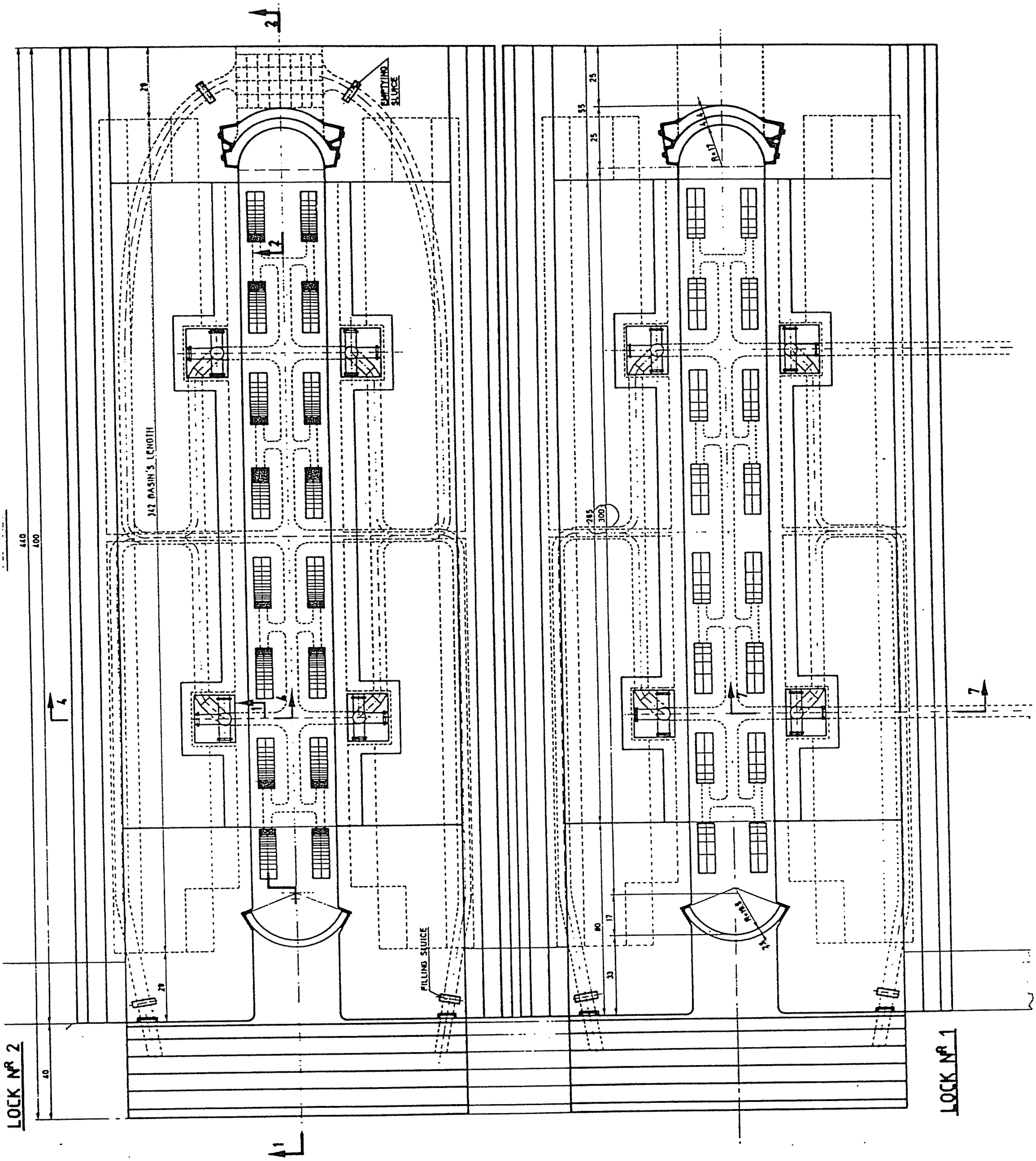

Figure 7

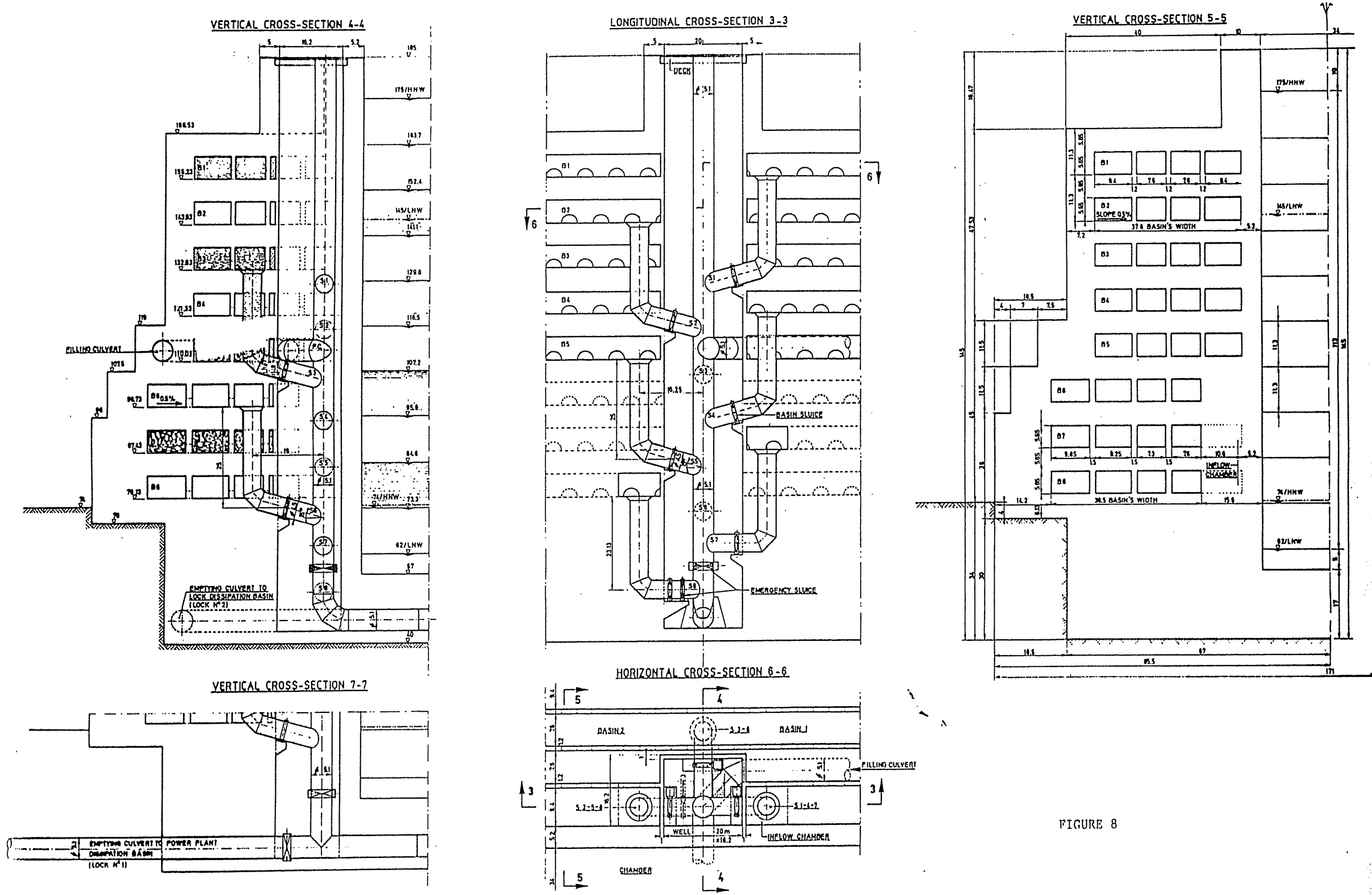
VERTICAL CROSS-SECTION 4-4
FILLING CULVERT
EMPTYING CULVERT TO LOCK DISSIPATION BASIN (LOCK N°2)
VERTICAL CROSS-SECTION 7-7
EMPTYING CULVERT TO POWER PLANT
DISSIPATION BASIN (LOCK N°1)
LONGITUDINAL CROSS-SECTION 3-3
DECK
BASIN SLUICE
EMERGENCY SLUICE
HORIZONTAL CROSS-SECTION 6-6
BASIN 2
BASIN 1
FILLING CULVERT
WELL
INFLOW CHAMBER
CHAMBER
VERTICAL CROSS-SECTION 5-5
175/HHW
145/LHW
74/HHW
62/LHW
SLOPE 0.5%
37.6 BASIN'S WIDTH
36.5 BASIN'S WIDTH
INFLOW CHAMBER

FIGURE 8

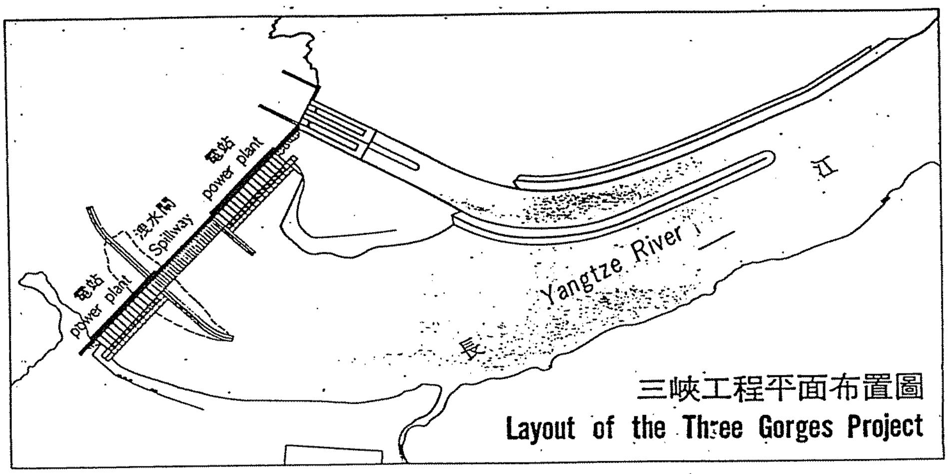

Figure 9

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 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) (figures 7 and 16).

The time elapsed in both cases is respectively 20 and 19.5 minutes. So that the emptying and filling operations take one hour for each of them. 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 the 113 m head becomes 42 min for the 71 m head.

At any time, due to the chosen installation of the culverts and the sluice (figure 8), 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 for filling or emptying can be devised to keep the elapsed time at a minimum value for any position of the levels upstream or downstream.

Lock chamber full of water (figure 11)

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

V. 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 (figure 8). Each of the basins is connected with the chamber through a special shaft in which a butterfly sluice is present. Four such shafts exist. The water distribution is organized, in the chamber, in such a way as to have a discharge evenly distributed over the surface chamber and from bottom outlets (or to the bottom inlets) (figures 6, 7 and 8). Each sluice has an opening of 16.2 m^2.

The variation of the surface area of each sluice with respect to time is the one shown in figure 12.

The diagram of the rising of the water in the case of filling is as in figure 13 and the value of the pressure at the sluice varies like in figure 14 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, would be 1110 s (figure 15). So that the theoretical total filling time would be

$$T_t = 8 \times 305 + 1110 \approx 60 \text{ minutes.}$$

VI. 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 (figures 6 and 7).

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 tracted downstream).

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

VII. ESTIMATION OF THE TOTAL TRAFFIC OF THE LOCK

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

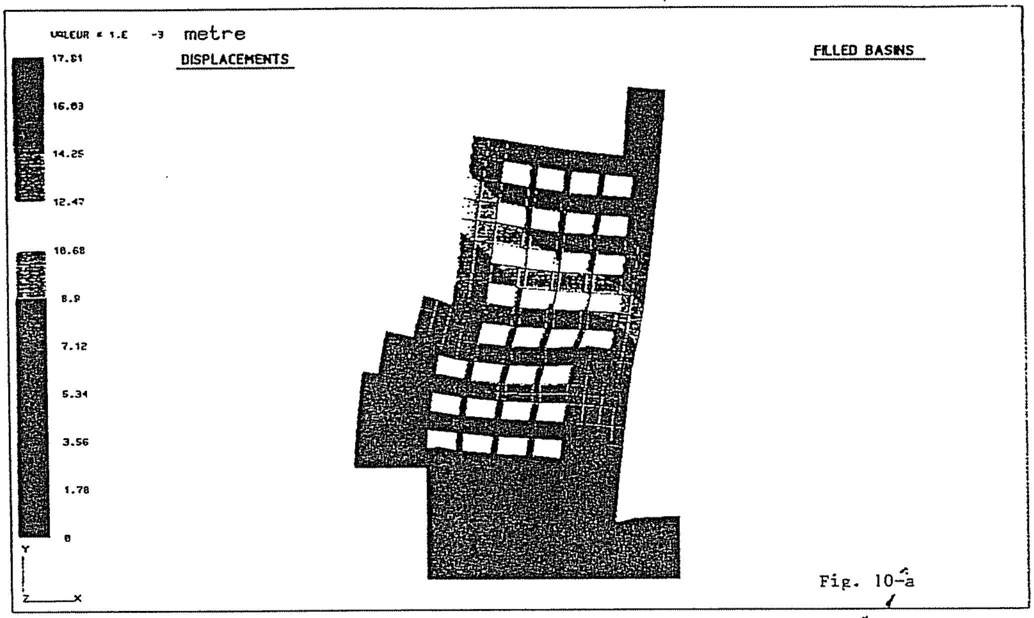

Fig. 10-a

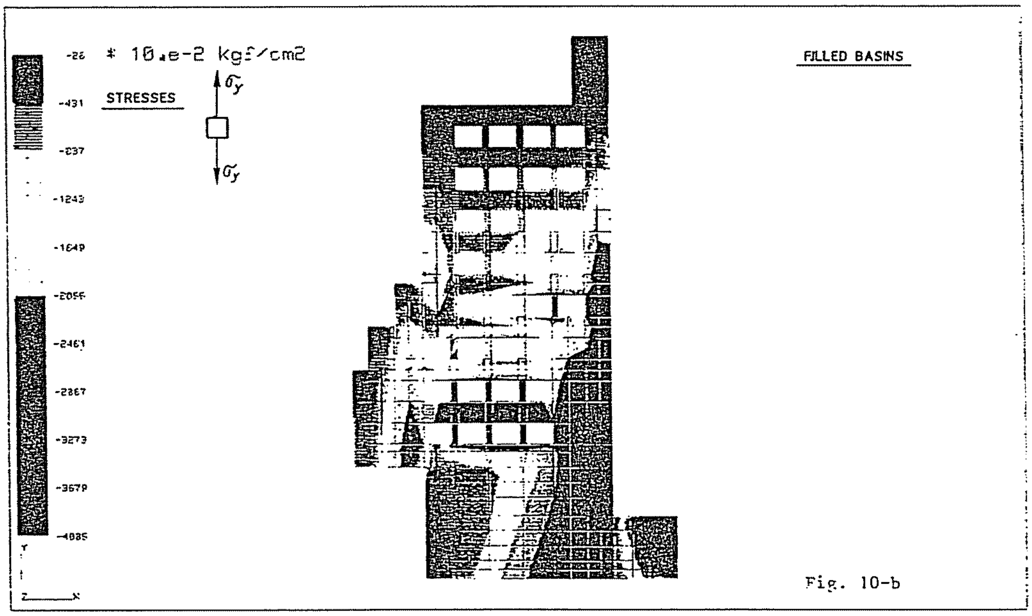

Fig. 10-b

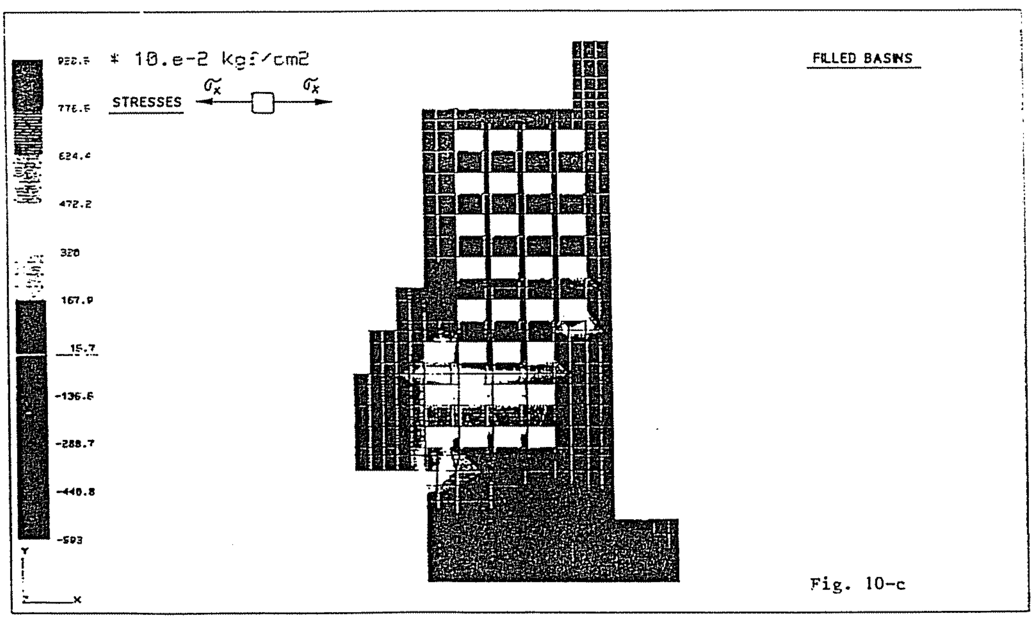

Fig. 10-c

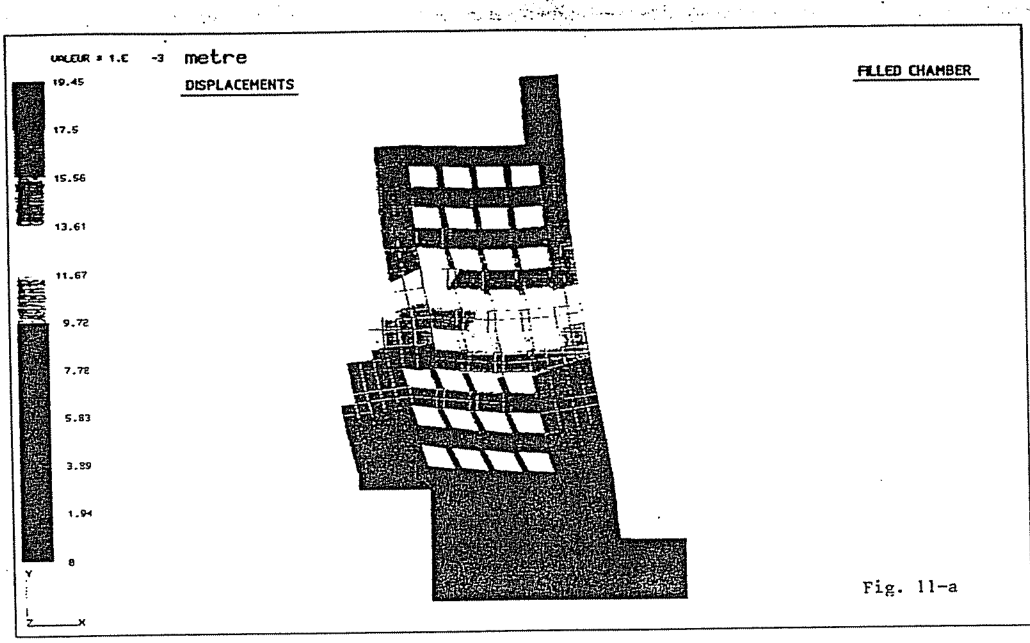

Fig. 11-a

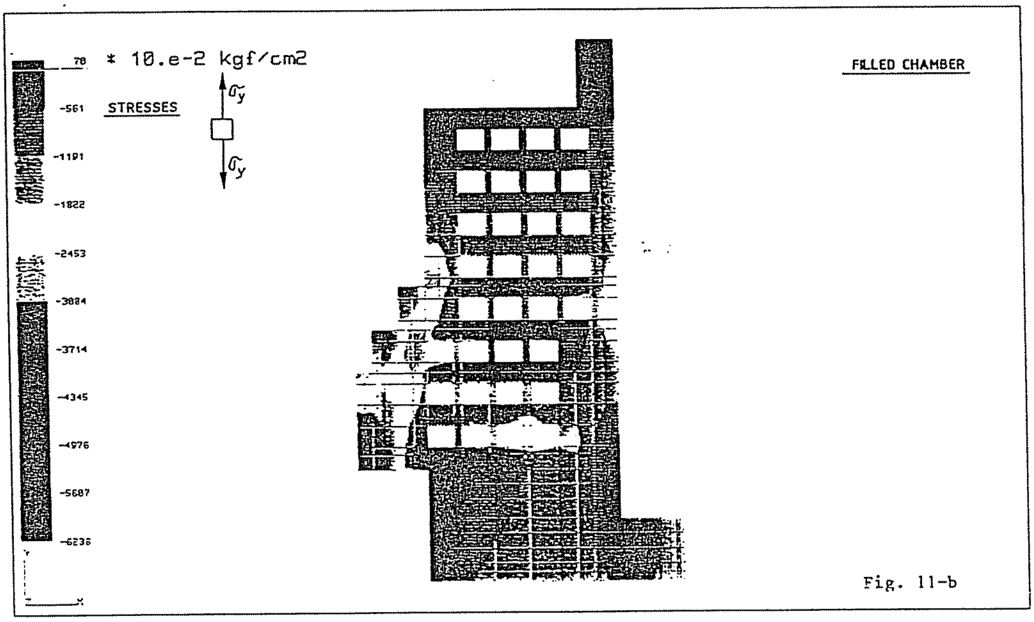

Fig. 11-b

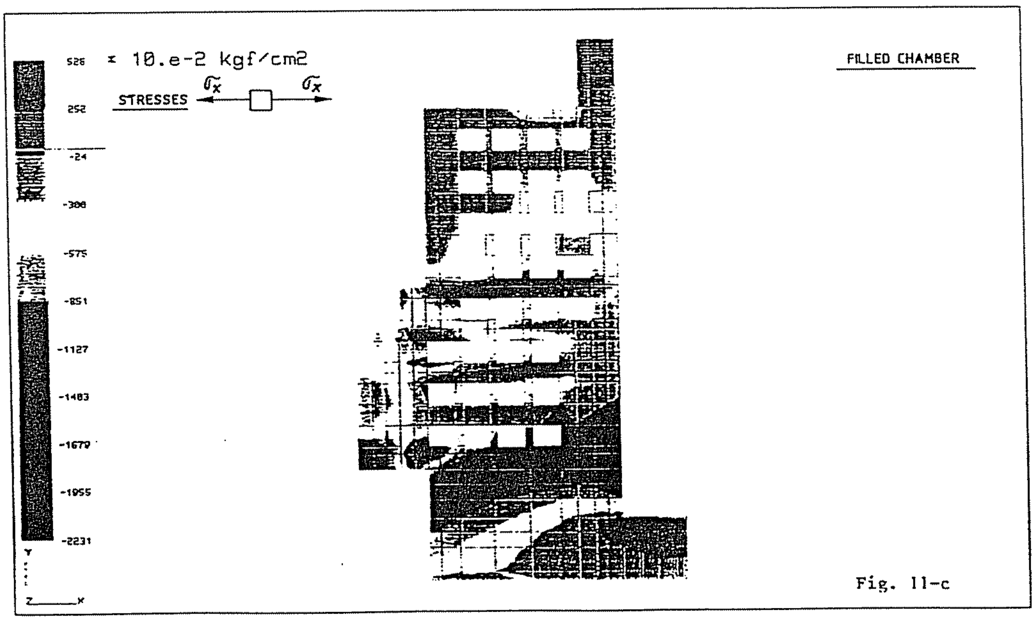

Fig. 11-c

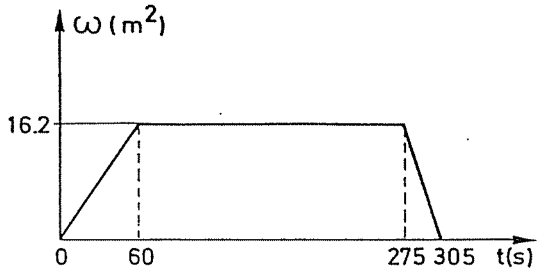

Figure 12

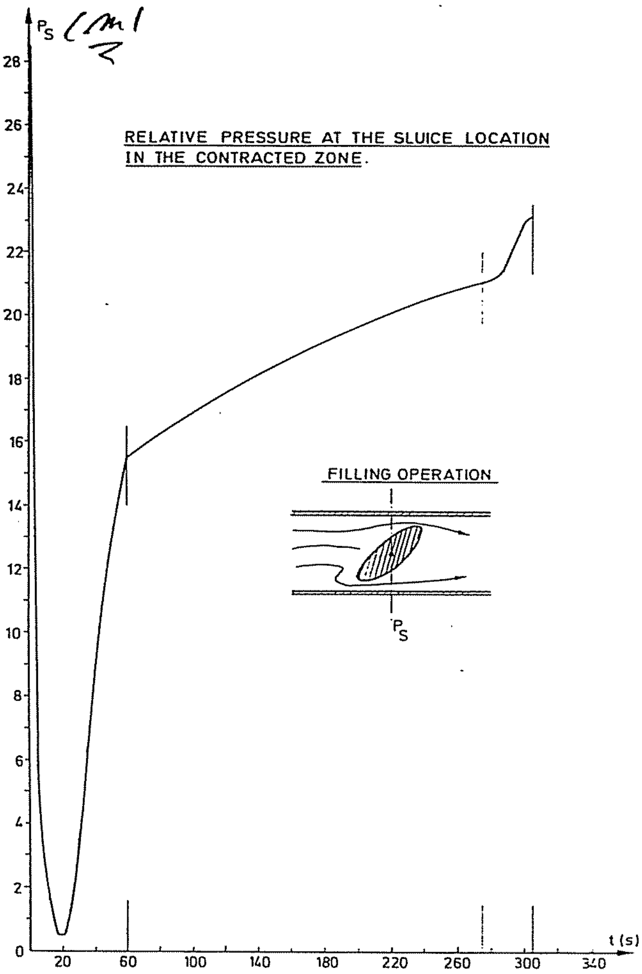

Figure 14

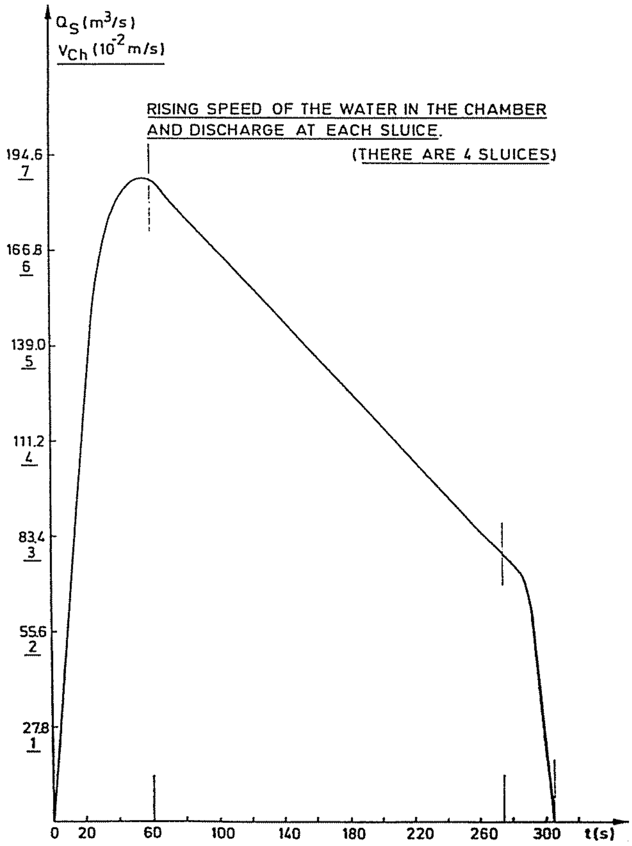

Figure 13

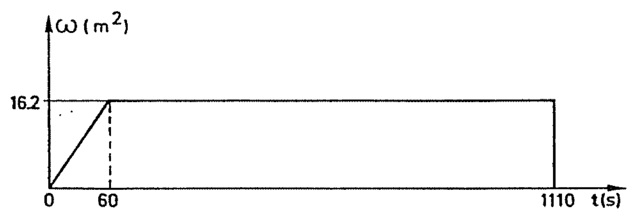

Figure 15

- going in of the convoy 10 min
- operating the gate 3 min
- emptying or filling 60 min
- operating the gate 3 min
- 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 tonnes, we come, for one lock, to the annual theoritical traffic of :

$6 \times 250 \times 12{,}000 \doteq 18.10^6$ tonnes/year and 36.10^6 if two such locks are built side by side.

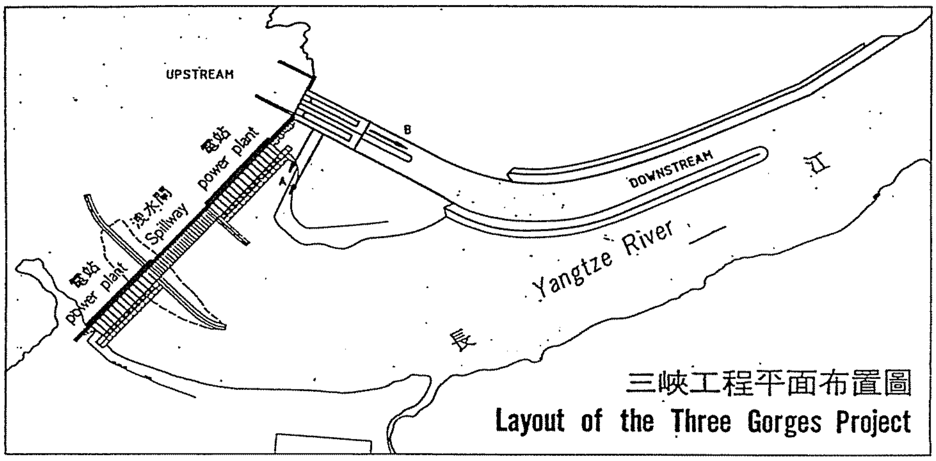

Figure 16