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MORE THAN EVER : INTELLIGENCE IS CAPITAL.

- A tentative application in the field of the hydraulic structures -

New Requirements for Structures
and their Reliability

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ABSTRACT: An example of innovative design based on high human capital is presented. Nine old mobile weirs located in a protected environmental area (Belgium) have to be renewed. For economic and environmental purposes, use of prefabricated weirs is recommended. Weirs are composed of two radial gates. To transport the materiel, the complete structure is divided in four prefabricated designed as floating pontoons. To reduce the weight, an aluminum alloy is used. Elements are set afloat and towed to the weir location. There, the four elements are linked together, ballasted, immersed and then, cast with steel fiber reinforced concrete.

1. INTRODUCTION

In December 1993, the European Community published a "White Book" to establish the bases of a new development to support the European economies facing the international competition. The opinion is that there is a future for the European economies. Owing to his human capital (education, qualifications, ability to innovation, industrial tradition), its financial reserves, its efficient bank institutions and its strong model of society, Europe has many advantages and we must make it yield a profit.

The European Community's contribution is to promote a movement which combines our historic background and our wishes to keep the leadership in the tomorrow's word. To reach this aim, huge infrastructure projects are planned for an amount of 600. 10^9 ECU. All of them concern projects related to the civil engineering: highways, railways, waterways, water treatment system of cities and telecommunications. These projects, are multinational ones and, even being very large ones. They have to be realized in a short time as funds will come from the private sector. The international competition will be extremely important. There will have no more similitudes between these projects and some old projects such as the Pyramids, the Great Wall in China, or the Ming's tomb forwhich, decades or centuries were necessary before completion of the project.

If we try to evaluate the requirements of the tomorrow's projects, they will be : an extreme competition, a research of the top quality, a look for reliable functioning systems, a reduction of the construction and exploitation costs, the development of the "just in time" concept in each manufacturing process, a higher respect of the environment during the works and after their completion, the importance of the general easthetic and all these constraints in the shortest delays.

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The global answer to bring these partial requirements has to be considered in a very wide context which drive us to the basic functioning of any private company. The bases of the activity of such company are the three following ones: its financial capital, its material capital and its immaterial capital. This last one includes : (i) the know- how, (ii) the marketing expenses and (iii) the expenses for the maintenance and development.

The expenses (ii) and (iii) can easily be evaluated but it is much more difficult for the know-how or the intellectual capital carried by the staff members, i.e. mainly by the engineers. The main differences between companies are not related to their financial or material owning but chiefly to their intellectual capital, i.e. the capacity to reply and solve a problem with innovative designs based on their previous experience. According to this statement, we think that the only projects verifying all the aforementioned constraints will be those having the highest intellectual content coming from a high level intellectual capital. Moreover, the general design is the most important. If this design is fine, the detailed design will allow no more than 2 or 3 % of reduction of the construction cost. The only solution is than to invest in the intellectual capital of the company.

On the other hand, the extraordinary wide range of investigations which are necessary today to study a large project (even a small one), from soil mechanics to computer science, from the strength analysis of material to pisciculture, from hydraulics to the diplomacy (as you have experience in your country!) ... , shows that the "only one engineer" managing a project alone is over. Tomorrow, the time of the "only one engineer" will be replaced by a team of designers and not all of them will be civil engineers and sometimes not engineer at all. Economists, transport analysts, biologists, etc., must be included in a staff composed of civil engineers but also mechanical, electrical and electronic engineers, as well as some other ones (geologist, naval architect, ...). Moreover, engineers having, different backgrounds and experiences, and coming from different institutions or universities will be an important requirement to develop high quality and feasible innovative projects.

Then, for the tomorrow's projects, the solution is to combine the qualities of each "player" to form a team under the responsibility of a leader who sublimates their individual qualities, such as a conductor in a symphony. Therefore, for the tomorrow's projects, intelligence and symphony are the first requests.

In full agreement with the aforesaid philosophy, we would like to present you a study which we enjoyed largely. We considered it as a challenge and tried to put in its design as many idea as we were able to, working together hands in hands, engineers and technicians. This study was performed during the years 1991-92 and when, at the end of 1993, we received the *call for papers* of this Prague conference, we found ourselves in perfect similarity of views with the conference objective: "*Recent developments in structural design influenced by ...technical know-how combined with higher requirements ...* ". So, is the project of the Sambre river in Belgium, for which we received a study contract from the New Technologies Ministry of the Walloon Region.

2. THE PRESENT SITUATION

The Sambre river is a medium class waterway (class IV - 1350t) between Charleroi and Namur. It becomes class I (300t) on its upper reaches (upstream of Charleroi towards France). This waterway is used to link the Northern part of France to the Southern part of Belgium and its industrial cities but also to the Dutch and German waterways network.

On the upper reaches, locks have 5.2 m width and 40.5 m long. Aside each lock there is a mobile weir designed in the XIX century with stop logs. Built more than 100 years ago, they are nowadays unsafe and inefficient for the flow regulation. The actual locks will remain. There is no plan to increase the lock sizes as a bigger traffic is not forecast (±600 000t/year in 1992).

Our study concerns the 9 stoplog weirs located in the upper reaches of the Sambre river which have to be replaced. They are located in a environmentally protected area. Almost no place, or very few, is available for the renewal projects around the present weirs. The water height of the nine weirs is between 1.23 m and 2.73 m. For the 34 km long upper reach, the total fall is 22 m high and the medium slope is 70cm/km.

Traditionally, with the help of pumping devices working 24 hours a day, weirs are built in the river inside of a sheetpiling screen. This is the most efficient way for wide rivers with large accessible banks. For the present project, traditional methods are not reliable. Therefore, we propose a new construction technique based on (Figs.1 and 2):

- a prefabrication system with four self supporting floating elements including the radial gates and the manoeuvre's mechanical devices,
- elements designed as a floating pontoon,
- elements towed from the shipyard to the weir location,
- elements ballasted and then immersed to rest on keelblocks,
- radial gates designed in one piece, allowing overshot and undershot runs,
- use of aluminum to reduce the weight of the floating elements,
- aluminum stiffened plates to build the radial gates and the steel formworks of the piers, abutments and floors,
- steel fiber reinforced concrete used to fill all the prefabricated elements (piers, floor, .) and, to cast the structure with the foundation and the banks (for traditional weirs).

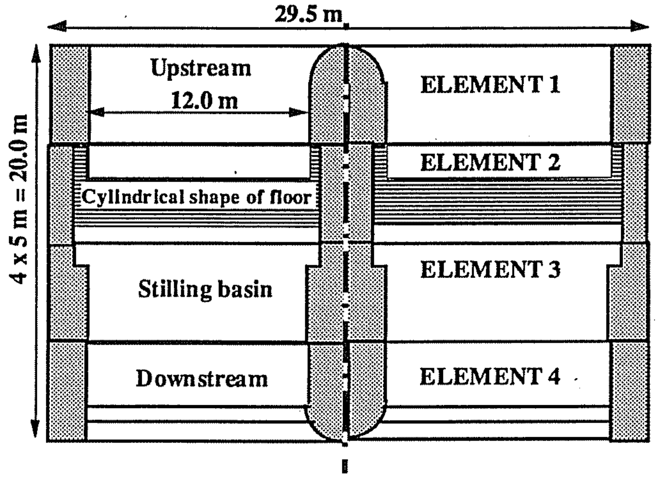

Fig. 1 : Bird eye view of the 4 prefabricated floating elements

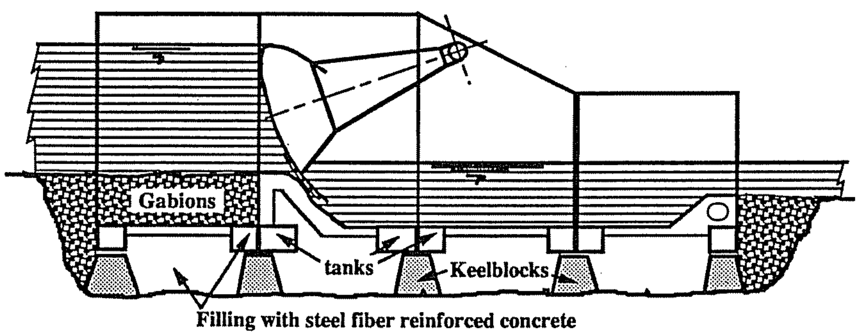

Fig. 2 : Longitudinal cross section in the 4 prefabricated floating elements

To set up an efficient and reliable technique of prefabrication, the following researches were realized:

- Hydrologic (discharge) and hydraulic (flow) regimes of the river.
- Prefabrication process.
- Steel fiber reinforced concrete.
- Design of the structure [1, 2]:
  - design of the structure (strength and stress analysis of the gate) with a dedicated software (L.B.R.-4 [3]),
  - hydraulic study of the weirs: relationship between gate position and the discharge for different downstream water level (the upstream water level remains unchanged

to allow the navigation), and study of the energy dissipation basin,
  - study of the synchronization motions between the two gates to avoid wave propagation on the reaches which could be very dangerous for the navigation.
- Scale model studies:
  - a hydraulic Froude model to study the stilling basin and the relationship between the gate position and the discharge
  - a structural model with the accurate mass similarity to check the stability of the floating elements during their towage and at each stage of the ballasting process.

3. DESCRIPTION OF THE PRECAST SYSTEM.

The proposed precast weirs are composed of two radial gates of 12m span (Figs.1 and 2). The floor dimensions, including the stilling basin, are 20 m long and 29.5m width Including the floor thickness and the pier high, the total height is 7.6m. To ease the transport from the shipyard to the weir location, the structure is divided into 4 elements of 5m wide, 29.5m long and 7.6 m high. These elements are designed such as floating pontoons. The gates with their arms are transported on the floating elements themselves which are towed or pushed as a standard barge (Fig.3).

Because the floating elements have to go through the lock chambers, the size of these floating elements is restricted to the lock dimensions (5.2m x 50m). Moreover, as bridges air clearance is only 4.00 m., upper part of piers and abutments must be realized in two pieces. These upper parts, as the radial gates, are transported on the floating elements and then be assembled on the weir location itself (Fig. 3). In fact, these elements are the cofferdams for the floor, piles and abutments which are prefabricated.

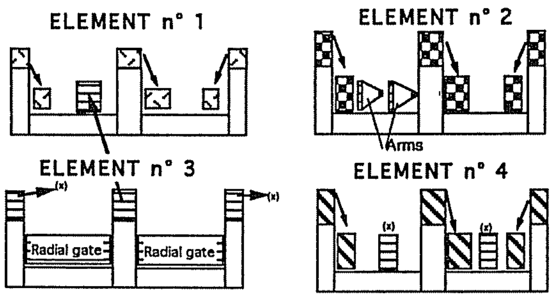

Fig. 3 : The 4 floating elements loaded with their 2 radial gates, 4 arms and, pier and abutment upper parts.

The assembling and casting operations are the followings ones:
- prefabrication in a shipyard of the four self supporting floating elements used for the transportation of the 2 gates, the 4 gate arms and the upper parts (Fig. 3);
- towage of the four floating elements from the shipyard to the weir location;
- adjustment of the water ballast of each floating element to have the same freeboard in order to ease the linking and assembling of these elements (the elements are still floating when they are firmly attached each other);
- gates, arms and upper parts are assembled at their predetermined position;
- the main tanks located in the 4 floor elements are ballasted. When the floor elements are immersed, position of the structure is easily controlled using the tanks located in the pier and the abutments. These tanks are required to keep the stability of the structures;
- at the end of the immersion, the elements rest on concrete keelblocks;
- at the final stage, the element's elevation is checked (vertical position), and, before to be cast with steel fiber reinforced concrete, the structure is fixed laterally to four sheetpiles which have been previously drilled in the foundation;
- to avoid deformation of the structures during the casting, supports are adjusted under the floor of the four ballasted elements;
- casting process is the following:
  - steel fiber reinforced concrete is poured (injection) under the structure,
  - concrete can be injected in all the tanks to replace the water ballast,

- pier and abutments are filled in with concrete, and finally,
- connections between the banks and the weir abutments are realized.

To assess the feasibility of this new precast system, it is necessary to raise the following uncertainties:

- flow regime and discharge duration curve of the river to determine the weir sizes,
- shape and dimensions of fibers to obtain the required strength and the reliability of the steel fiber reinforced concrete poured under water in aluminum formworks,
- choice of gates to have an efficient flow regulation of the river,
- behaviour of the floating element during transportation and ballasting.

All these questions will be raised in the next chapters.

4. FLOW AND DISCHARGE IN THE RIVER

For the design of the new weirs, it is necessary to know the "duration curve". It gives the mean daily discharge with the annual probabilities of occurrence of this discharge. Such duration curves were plotted for the last 27 years. Using the mean curve, the discharge is selected for several probabilities of occurrence (10 days, 1, 3, 6 and 9 months). Unfortunately, data discharges were only available in Salzinnes (60 km at the downstream side of the considered reaches). In order to extrapolate the accurate discharges for each reach, the square root of the ratio between the surface area of the hydrographic basins is used. Examples of the extrapolated discharged are shown on Table 1.

Annual Probability of occurence	Discharges (m3/sec.)
10 days per year	105.0
1 month per year	60.0
3 months per year	25.0
6 months per year	10.0
9 months per year	5.6
355 days per year	1.0

Table 1: Discharges related to annual probability of occurrence (duration curve).

5. DESIGN OF THE PREFABRICATED RADIAL GATE IN ONE PIECE

For river weirs with small water head (2 to 5 m), Dehousse N.M and Rigo Ph. [1, 2] have recently shown the interest of radial gate designed in one piece (Fig. 4). For river with high water head, radial gate and lifting gate, are usually designed in two pieces (1/3 for an upper hinged shutter and 2/3 for the main piece). Classically, the upper hinged shutter is set at the top of the main one. This shutter is used for small discharge (overshot run - flow over the weir) that allows the transit of floating bodies (woods or floe ices). The main piece is only raised for high discharge (undershot run - flow under the gate). Fig.4 shows how a one piece radial gate is able to provide alternately the two types of river flow (overshot and undershot runs) and get all the full gate height for the rigidity of the structure (box girder). According to this idea, it is possible to reach 25, 30 or 35 m span for small water depth (2 to 5 m). On the other hand, with the traditional system, only 2/3 of the gate height is got available for the main box girder. Economically, the structure can not be rigid enough to reach more than 20 m span.

The design of the aluminum structures (gates and formworks) was achieved using the LBR-4 software (stiffened plates and shells - release 4) developed by the LHCN laboratories [3]. The mechanic characteristics of AL 5083 & AL 5086 are :

$E = 71.00\ 10^3$ N/mm^2	(Young Modulus)		R_e = 125 to 190 N/mm^2	(Yield stress)
$\nu = 0.33$	(Poisson coefficient)		R_p = 275 to 350 N/mm^2	(Ultimate stress)
$\Delta = 26.6$ kN/m^3	(Specific weight)		R_a = 85 N/mm^2	(Admissible stress)

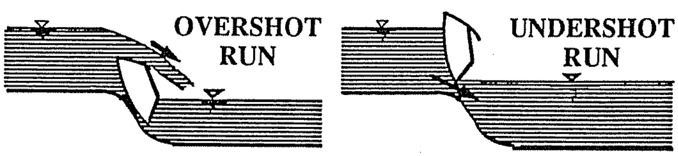

Fig.4 : A radial gate designed in one piece.

6. STEEL FIBER REINFORCED CONCRETE.

Since 1969, steel fiber reinforced concrete is studied in our laboratories. Their main advantage is to avoid the usual heavy, time consuming and sometimes costly, conventional steelbars. For applications of concrete poured under water, the steel fiber reinforced concrete is a technique which is particularly suitable. When cracks must be avoided, steel fibers are particularly recommended, for instance in marine and river engineering works where corrosion of standard reinforced concrete is forecast.

The following composition is proposed (for 1 m^3): cement (309 kg), gravels of ±10mm (800kg), sands (935kg), water (the ratio water/cement = 0.54) and steel fibers (25kg). Strength characteristics will be 9 N/mm^2 in bending and 50 N/mm^2 in compression. This composition is suitable for steel fiber reinforced concrete injected and poured under water.

Nowadays, for buildings, block of flats and office blocks, aluminum becomes more and more used. It is not yet the case in civil engineering where tradition and conservatism still impose steel as the standard metallic support. Long term corrosion of aluminum remains a great uncertainty for the designer. In this study, we have investigated the reactions between aluminum and different materials (concrete, steel fiber and steel fiber reinforced concrete) and, the influence of water on these reactions.

The Al.Mg.4Mn (or Al 5086) and Al.Mg.4.5Mn (or Al 5083) are selected for high corrosion properties, good behavior at low temperature and ease for forming or welding. The selected steel fiber type is the Wirex Arbed 1/60 Eurosteel (1mm of diameter and 60mm long). This steel fiber type was strongly investigated 10 years ago into our laboratories. Cements are Portland cement mixed with pouzzolane cement (PPZ30) or with blast furnace cements (HK40 and HL30). These cements have a high resistance against sulphates.

More than 300 samples were tested for the following conditions: aluminum and cement in dry condition, aluminum and cement under water, aluminum and steel fiber reinforced concrete in dry condition and aluminum and steel fiber reinforced concrete under water.

7. SCALE MODELS

For new weir types or dimensions, numerical methods are not reliable to determine accurately the discharge. Only a scale model can consider all the local weir particularities (pier, floor and gate shapes, contraction coefficient, head losses, position of the hydraulic jump, energy dissipation, influence of the river bend, etc.). Moreover, towage on the waterways, assembling operations, ballasting and immersion are operations which have to be checked on a scale model.

Two models were built on the scale 1/15. For the first one, the Froude similitude was respected to study the river flow over or under the gates (overshot and undershot runs), i.e., to calibrate the weir. For several upstream water levels, the diagram of the discharge versus the downstream level was obtained. Only external shapes and dimensions were respected; it was a fixed model. The second model concerns the modeling of the floating elements. Weight pattern and weight similitude were respected in order to assess the stability of the floating element at each stage of the transportation, assembling, ballasting and immersion.

8. FINAL REMARKS

The details of the design will be published soon by the Acta Polytechnica Publications from the Czech Technical University in Prague.

At the end of year 1993, a very important flood occurred in the concerned area, adding to the idea of replacing urgently the 9 mentioned weirs.

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