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HIGH PRESSURE PENSTOCK – CONCRETE LINING

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Marcus Felipe de Aragão Fernandes [1]　　　　Francisco Rodrigues Andriolo [2]

ABSTRACT

San Gaban Hydroelectric Power Station II has, as a special feature, a 734m-long penstock, with a 60º slope , with no intermediary access. Among other challenges, concrete pouring in the penstock presented a series of problems whose solutions were innovative and "daring".

Hence, as a final solution, it was decided to pour concrete through pipes for up to 540 m, in an actual free chute, which was very successful in terms of lining quality and time reduction.

Key Words:
Concrete – penstock – concrete/pipe – concrete pouring

SUMMARIZED DESCRIPTION

The present paper reports the problems faced in the concrete works of San Gaban Hydroelectric Power Station II penstock (734m-long with a 60º slope) in Peru, due, principally, to the special characteristics of the job.

PRESENTATION

Introduction

The construction of San Gaban Hydroelectric Power Station (Figure 01) located in the Department of Puno, Province of Carabaya, in Perú, was divided into five lots and Construtora Odebrecht was responsible for Lot 3, called Machinery Hall and Appurtenant Works.

Among the appurtenant works, the penstock stands out, and whose construction was a major challenge considering both its excavation and concrete lining. It is considered a challenge and a great engineering work due to special characteristics, such as:

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[1] Construction Manager- Odebrecht SA- B.P.C. -Trajouce- Oeiras – Portugal; e- mail: marcus.felipe@bpc.pt; site: www.odebrecht.com.br

[2] Consulting Engineer- Andriolo Ito Engenharia SC Ltda- Rua Cristalândia 181- 05465-000- São Paulo- Brazil; Fone: ++55-11- 3022 5613 Fax: ++55-11- 3022 7069; e-mail: fandrio@attglobal.net site: www.andriolo.com.br

Length	Slope	Excavation Diameter	Diameter Lining
734.50 m	60º	3.40 m	2.70 m

Its most outstanding characteristic however, is the absence of an intermediary access, and according to non-official sources, it is the third in the world this long, not featuring this access. The present paper describes with details the concrete lining process, showing the problems faced and the solutions adopted to overcome them.

A remarkable engineering work, an on-going search for solutions, a "daring attitude" of breaking up with traditional procedures, and the support of some of Odebrecht consultants and collaborators, are to be mentioned. Among the latter, Messrs. Bayardo Materón and Francisco Rodrigues Andriolo as consultants, and Celso Silingardi, Francisco Tavares, Jean Contesse, Luis Roberto Chagas and Winston Lewis, as collaborators, deserve our appreciation.

Main Works

The work as a whole was divided into five lots (Figure 01), as follows:

Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
Upstream Work	Collecting Tunnel and combined works	Power House and Appurtenant Structures	Electro-mechanic erection	Transmission Line

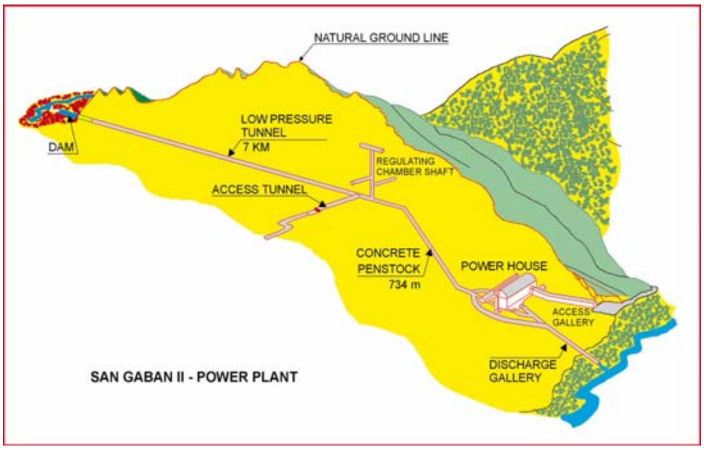

Figure 01 – San Gaban Project

Work	Unit	Quantity
Underground Excavation	m^3	73,000
Open Excavation	m^3	39,00
Shotcrete (Silica Fume+ Fiber)	m^3	1,550
Reinforced Concrete	m^3	15,000
Reinforcement Steel	t	1,200

Table 01- Lot3- Main works

The target of this Project is to generate 110 MW to interconnect with the country's integrated system, especially in the South and Southeast regions. The main figures of Lot 3 are indicated in Table 01.

The Penstock

The penstock is composed of an pressure shaft (inclined part), with a 60º slope, being 734.50m long and of an almost horizontal part (2.0% slope) at the lower part, 115m long. It starts at the very end of the intake tunnel (low pressure tunnel) at El:2.055m and is connected to the Power House at EL:1.416m, giving a gross head of 678m, as the regulating dam has a maximum level at El:2.094m. As pointed out, the free diameter after lining is 2,70m and the excavation diameter is 3,20m in line "A" (theoretical line); and 3,40m in line 'B' (tolerance line) – Figure 02.

Excavation

The excavation of the penstock was carried out in an ascending process using an Alimak equipment. Excavation work lasted for 14 months and a total of 7.523 m^3 were excavated.

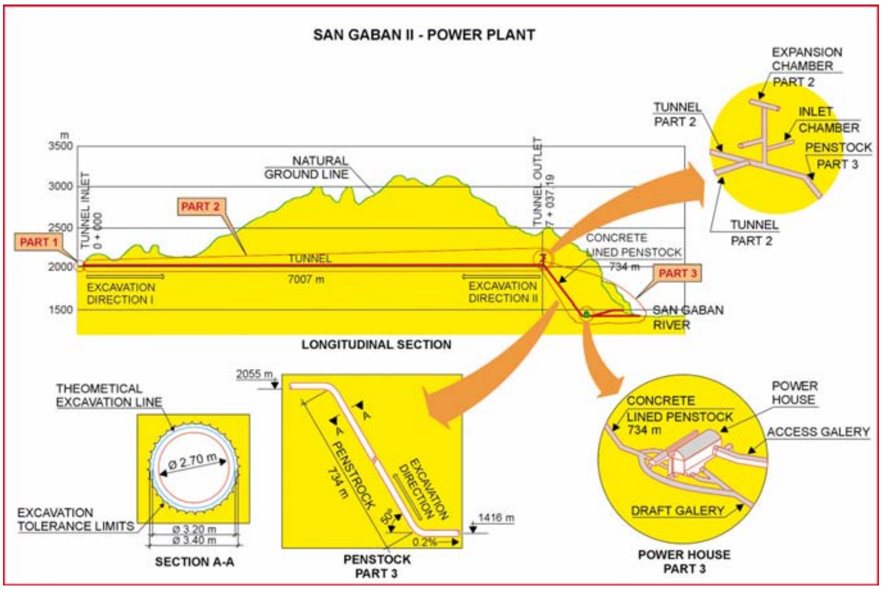

Figure 02- General Scheme, Lots and Excavation Lines

Concrete Pouring

Concrete pouring being the background subject of this paper, it will be explained in detail what was initially planned to be done, what made its execution impossible (previous situation) and what was actually done (incorporated actions) to achieve the expected result.

SITUATION PRIOR TO INNOVATIONS

Proposal Methodology

The technical proposal presented the penstock lining construction through conventional procedure, using a railway from the upper part to the lower part, concrete feeding through the upper part and transportation to concrete pouring front by means of a special wagon driven by an electric hook also placed in the upper part. It was planned to use a 12m-long telescopic mould temporarily fixed, that would move upwards after concrete setting and beginning of hardening.

The Impossibility of Adopting the Methodology

As it can be seen in Figures 01 and 02, there is a stretch of construction common to Lots 2 and 3 which is the access to the upper part of the penstock and serves as access to the collecting tunnel at its final part. ("Casahuiri" Access Tunnel).

Upon completion of the penstock excavation, the company responsible for Lot 2 had not finished excavation works for the collecting tunnel, (front 2) or started concrete placing of the floor on this work front, so it was practically impossible to conciliate operations in this stretch of the construction. Furthermore, the same company was carrying out excavations of the surge chamber chimney, what made Odebrecht presence in this area still less viable.

As a rule, start-up of the penstock lining would await completion of services of Lot 2. Due to the Client's request, though, and to avoid a halt on this front, a solution to start concrete placing work was sought.

PROPOSAL ACTIONS AND METHODOLOGY DESCRIPTION

Initial solution

The impossibility previously described, led to seeking a solution that should necessarily use the access exclusively through the lower part, at least until it was possible to enter and use the upper part. Accordingly, it was decided to use a chariot especially conceived to transport personnel and concrete, from the lower part up to the concrete placing front (Photo 01). This chariot transported all the other material required, including personnel food.

Foto 1 - Carro para transporte de concreto, pessoal e alimentação.

Photo 01- Bucket-truck to conctrete handling

Foto 2 – Fôrma Deslizante

Photo 02- Sliding Form

The chariot moved through an electric hook placed in the lower part that through a set of pulleys and steel cables tractioned the chariot. To fix the basic pulleys, it was necessary to place a beam in the middle part of the penstock, with three pulleys. A set of roller bits was added to it at strategic points which blocked the contact of the cable with the rock and with the concreted surfaces. In fact, a slope was implanted, with a chariot on tires (Figure 03).

For security reasons a plug was placed immediately above the beam that supported the pulleys, positioned to block a possible stone chute from the upper part. This plug permitted periodical inspections in the pulley, as the excavation platform was still in the upper part. The mould formerly proposed to be telescopic and temporarily fixed, was substituted by a sliding formwork type (Photo 02).

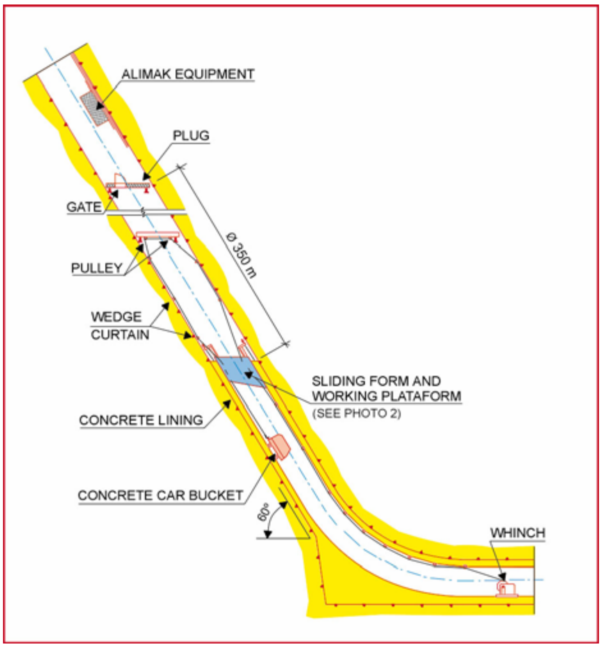

Foto 3 – Caminhão Salsicha

Figure 03- Equipments

Photo 03- Concrete truck agitator

<u>Concrete</u>

The concrete was produced at the plant and transported to the point to load the chariot by concrete truck agitator (cigar or sausage truck) (Photo 03).

Table 02 shows the three concrete mixes used. It was necessary to increase the “slump” of the concrete coming from the plant, since the concrete placing front was getting more distant from the point to load the chariot, in order that the concrete kept adequate characteristics at the moment of pouring. As it can be observed, a plasticizer as well as accelerator admixture was used. The first one, to give adequate consistency to the mix and the second to accelerate the setting of the concrete, to control the form sliding.

Materials	Unit	Mix 01	Mix 02	Mix 03
Cement	(kg/m^3)	310	320	350
Fine aggregate (MF: 3.00)	(kg/m^3)	1,117	1,233	1,191
Coarse Aggregate (MSA: 25mm)	(kg/m^3)	786	670	638
Water	(kg/m^3)	164	170	185
Plasticizer	(kg/m^3)	1.855	1.915	2.393
Accelerator	(kg/m^3)	6.352	6.557	7.172
Slump	Cm	16 $\pm$ 2	19 $\pm$ 2	24 $\pm$ 2

Table 02- Mixes proportions

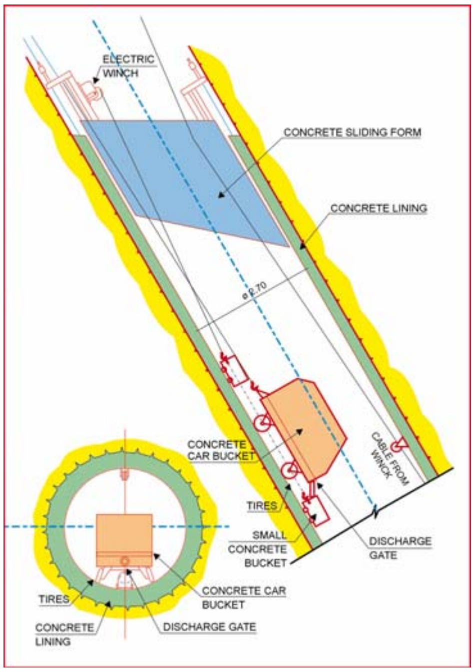

Figure 04- Concrete car bucket

<u>Concrete pouring</u>

The afore mentioned chariots- concrete car buckets- were loaded by the "sausage trucks” at the lower entrance of the penstock and then, through the described system, went upwards where the mould was. The discharge was made through a valve located at its lower part, using 30-lt. buckets and, from that point up to the mould they would move up with the help of a small electric hook located at the work stage. When the download was over, the chariot would go down for a new load and so on, successively (Figure 04). At each operation, about 1,5 m^3 was cast.

Communication, a fundamental element in the development of the services and in security, was effected through telephones located in the mould and next to the hook. On the other hand, there was telephone communication between the hook and other parts of the construction, especially the concrete plant.

Through this process, 190m of penstock were advanced, though the daily progress was too modest. Daily average of sliding (2 shifts) was around 2.50m and the maximum achieved was 4.92m. However, this maximum number was obtained when the concrete pouring front was around 80m.

As the distance from the point to load the chariot increased, the daily slide operation decreased considerably (average= 1.90 m/daily), since the upward and downward travel of the chariot that started with a cycle of approximately 15 minutes, would get slower and slower, until reaching 60 minutes in the last trips. It should be noted that all this length of time was used to pour only 1.2 m^3. The amount handled each time also decreased with the increase in distance, for security measures.

Intermediate solution

While the impossibility of getting through by the upper part lasted, the concrete pouring process was carried out as indicated above. During this period several alternatives were studied and tested so that when the problem hindering the access was solved, another front could be opened and completion of services sped up. Among the several alternatives considered, studied and tested, it was decided to effect the lining keeping the lower process (initial solution), for though it was slow it was already a reality, and add a new front with an access through the upper part.

At this time it had already become difficult to introduce the methodology of the technical proposal in the way the mentioned alternatives indicated for the possibility of pouring concrete through pipes, in a free chute. The tests performed in a kind of model developed in a slope, culminated with the check-up of the viability of the pouring, with a rubber ball ahead of the concrete, to prevent the segregation of the mix on the way down (based on “tremie concrete” concept). The pipe diameter was 5”.

Intermediate stages were also introduced, based on the dissipator concept which enabled the momentary decrease in speed by interruption of chute and also inspections and facility to unclog, in case of need. These stages were fixed on rock and had spaces for the presence of a worker and a big funnel where the concrete would fall and from that point restart its travel pipe down (Figure 05). To improve the dissipation, a flexible PVC hose part was installed in the last tube before each of the stages, which contributed to the decrease in speed and segregation. At the arrival at the mould there was also a hose to facilitate concrete distribution all over the perimeter.

It was settled that the upper part, 380m long, would have four intermediate stages, distant approximately 80m one from the other, and one more sliding mould equal to the lower part. Transportation of personnel and all required material to the work stage was made by Alimak, which was still in the upper part of the penstock. Certainly, for this methodology to come true a series of adjustments were necessary plus introduction of support described ahead.

Concrete

The concrete mix was adequate to the relatively hard pouring conditions, in a way to have a mix with little or almost no segregation during the pouring process. At first, this adequation focused basically the improvements in the consistency, in order to have a mix with characteristics of self-compacting concrete. Table 3 illustrates the characteristics of the new mix.

Concrete production and handling

Concrete production also had its particularities as the transversal section of the access tunnel did not allow for the entrance of a concrete mixer truck. Thus, it was necessary to use Big Bags, (Photo 04), in which the aggregate previously mixed was transported, from the plant up to a stationary concrete mixer, placed at the upper part of the penstock.

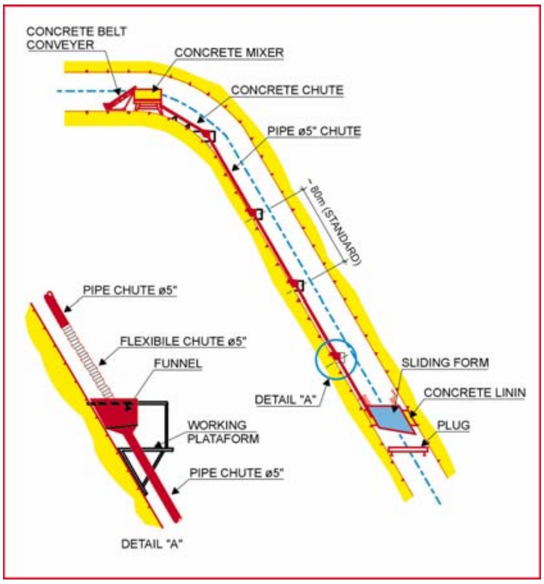

Figure 05- Free drop chute

Foto 4 – Caminhão carregando os big bag´s

Photo 04- Truck mixer being charged

Materials	Unit	Mix 04
Cement	(kg/m^3)	382
Fine aggregate (MF: 3.00)	(kg/m^3)	1,105
Coarse Aggregate (MSA: 25mm)	(kg/m^3)	603
Water	(kg/m^3)	203
Plasticizer	(kg/m^3)	1.962
Accelerator	(kg/m^3)	7.838
Slump	cm	25 $\pm$ 2

Table 03- Adjusted concrete mix

Foto 5 – Carga das plataformas

Photo 05- Charging the pallets

Transportation between the plant and the entrance to the penstock was made by the usual trucks and concrete mixers (Photo 04). At this point the aggregates were passed into the bags, and from there to the inside of the tunnel they would follow on platforms over rails. The load on these platforms-pallets was made with the help of a truck-crane (Photo 05).

To discharge the platforms and place loads in a strategic internal stock and to load the concrete mixer, two electric whinches were used besides a conveyor belt. The latter was used only to load the concrete mixers (Photos 06 and 07) placed at the upper part of the penstock. Cement was added in bags directly to the belt and from there would go to the concrete mixer. Immediately afterwards water and admixtures measured in recipients adequately graded were poured in.

Foto 6 – Carga da correia transportadora

Foto 7 – Içamento de big bag para colocação na correia transportadora ou estoque

Photo 06- Loading the belt conveyor

Photo 07- Big bags handling

<u>Concrete pouring</u>

At the end of mixture, Slump was evaluated and if it was within specifics, concrete was ready to be poured. Between the concrete mixer and the 5"- pipes column there was a metallic chute with a metallic mash, (Photo 08), which permits the removal of occasional big stones that appeared accidentally once in a while and could cause clogging.

Foto 8 – Vista da canaleta com malha .Ao fundo se ve a betoneira

Photo 08- Metallic shute

Materials	Unit	Mix 05
Cement	(kg/m^3)	382
Fine aggregate (MF: 3.00)	(kg/m^3)	1,105
Coarse Aggregate (MSA: 25mm)	(kg/m^3)	603
Water	(kg/m^3)	203
Super- plasticizer	(kg/m^3)	4.904
Accelerator	(kg/m^3)	7.838
Slump	cm	25 $\pm$ 2

Table 04- Mix 04 addjusted

It is convenient to make clear that it was not thought of, and in fact there was no operation with the line of pipes (380 m.) being completely full. Obviously, by the pressure the concrete exerted on the pipes, for security, and because in case of possible clogging, it would be easier to clean smaller quantities of concrete. Therefore, each pouring was at the maximum of 1 to 1.5 m^3, although many times 2 m^3, were mixed in, but the pouring was partial. It was observed at the beginning, when the distance was 380m, that downwards speed of concrete reached 100m/min, so that at the end of approximately 3 minutes, counted from the opening of the gate of the concrete mixer, the concrete would get to the work staging.

New adjustments

Services were started but some adjustments were necessary in the methodology and in the concrete, as indicated below.

Methodology

Although at the beginning it was possible to work with concrete pouring in free chute and with a ball, it was observed that the latter caused a problem, because since the pipes were placed directly on the surface of the rock, there were small curves in their union and for several times the ball was stuck in one of them causing a clogging of the line. Therefore, with a certain "daring" attitude, it was decided, tentatively, to do a pouring without ball, thus making it a true free chute of approximately 370m, as approximately 10m had already been concreted. Concrete arrived with the same characteristics it had arrived until then when using a ball, so its use was eliminated. This elimination permitted a better development of the services, as there was a sensible decrease in clogging, but the speed of concrete pouring increased considerably, being necessary to apply a new adjustment in the concrete mix.

Concrete

Studies to effect the new change in the concrete were carried out aiming at reducing time of setting. A solution was found through laboratory test with the substitution of the plasticizer for a super-plasticizer. The introduction of a super-plasticizer, associated with the presence of reflectors, made a better performance of the services possible, as it enabled better daily advancements, providing a sheer acceleration of the phases of setting and hardening, which led to faster displacements of the mould. Table 04 indicates characteristics of the last concrete used.

During the use of this so-called intermediary solution, it was possible to notice a substantial difference in the daily advancement of each front, for while the lower average was 1.90m/day the upper reached 3.40m/day on the first days, which led to the introduction of the last change described below.

Final Solution

In view of the improvement in daily advancement, a decision was made to interrupt the lower process (initial solution), keeping the chariot only for personnel transportation, materials and food.

It was necessary to introduce a "by-pass" in the upper mould and double the attention regarding communication, for the coordination between the concreting fronts and between each one of them and the concrete mixer became fundamental, so telephones played an important role in the process. In this way, at the end of each mixture it was necessary to establish a communication to decide which front should the newly prepared concrete go to (Figures 06 and 07). When it was destined to the lower part, personnel of the upper part would open the "by-pass" and let the concrete pass to the tube columns that conducted the lower mould. There was a significant decrease in "dead time" considering that the use of the upper concrete mixer, until then being under-used, became almost full-time.

With this solution, pouring from the upper part to the lower part by a maximum length of 540m was achieved, as 190m of the lower part had already been lined when it was decided that such procedure would be adopted. Thus, the 540m mark stood for the "record" of free chute pouring during the penstock lining. To set out this process it was necessary to stops services at the lower part for some days, while installation of the pipes was being carried out, starting from the upper mould down to the lower mould, passing by the median plug. This interruption was fully compensated by the subsequent advancements that significantly exceeded what was being obtained on this front up to then.

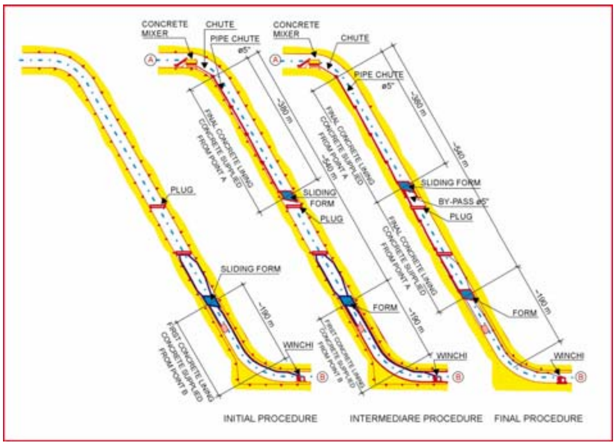

Figure 06- Concrete pouring processes

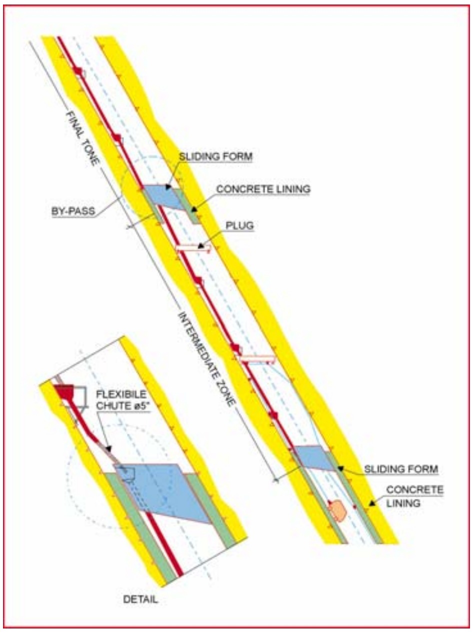

Figure 07- Detail

Continuity of the pipe line was maintained during execution of services by moving the pipes, which as a consequence of sliding of the upper mould had to be removed, to the lower part of it and they were soon after connected to the existing column. The work proceeded this way until the end.

CONCLUSIONS

The basic conclusion that can be reached from this work experience is that difficulties many times lead to a need to break up with what is traditional, to stop being conservative, and to "dare", exercising free thinking and trial, in the sense of obtaining results adequate to the circumstances.

It is convenient to observe that traditionally it could seem impossible to pour concrete for up to 540m down in free chute using piping, even with the 60^o slope, especially if we consider in an analogical way that such procedure is equivalent to pouring concrete from a height similar to almost 1.5 times the height of a building like the Empire State Building and at arrival obtain concrete with good characteristics and not the segregation. The Table 05 indicates improvements in terms of monthly advancement average for each of the fronts, considering principally the process of transportation by chariot and with pipes. The table only shows the average obtained in the months of full-time work, in order not to distort calculation.

Savings yielded by the work were reflected in the decrease of the scheduled completion due date, which was anticipated in almost 2.5 months, considering the daily advancements that were being obtained with the initial solution or even with the intermediary. This reduction in the term for completion represented a decrease in costs of US$ 500.000,00 at least.

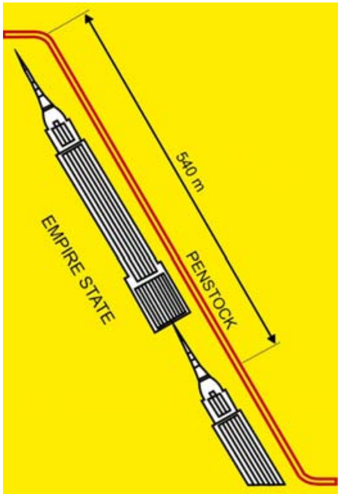

Figure 09- Ilustration

Month	Formwork	Sliding	(m/month)
	Lower	Part	Upper Part
	Car-Bucket	Pipe	Pipe
1	56.5		
2	49.9		
3	45		67.9
4		99.2	113.4
5		85.2	141.2
Average	50.5	92.2	107.5
Incresing car	Related to using (%)	82.7	113.0

Table 05- Averaged displacements

Even though the process described herein is very specific for the problem faced, it is possible to use this solution in similar works. Including, the same should be taken into consideration in the planning phase. It is also possible to use it in the same way, or similar, in the execution of special concreting with considerable height differences to be overcome and with difficult access. As an example, the interest to adopt this solution in diversion tunnels plugs.