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USE OF HYDRAULIC MODELS FOR HYDROELECTRIC PROJECTS IN CHILE

by Alberto Bennett L. and Horacio Mery M. with the collaboration of Roberto Muñoz

NOTE: This text is subject to editorial revision.

CONTENTS

/1. General observations

1. General observations

The purpose of this study is to show what use has been made in Chile of the hydraulic model technique for hydroelectric projects, and to devise a common method for its application to the different hydraulic works that are being planned in the country.

The need for hydraulic models is universally acknowledged, and since three to four decades ago the belief that small-scale models are a useful and necessary tool in hydraulic design is becoming increasingly widespread, especially for projects that require heavy investment. It is not too much to say that no important hydraulic scheme is ever planned in Europe or the United States at the present time without the safety and economy of each of its basic parts being first studied in a model. In Latin America, on the other hand, hydraulic construction has been proceeding at a very slow pace, and there have consequently been few occasions on which the use of a model has been clearly justifiable. Furthermore, the requisite laboratories and trained personnel have not always been available and foreign institutes have had to be approached for assistance. These circumstances, together with the lack of scientific background information, have often confused the issue and led to the identification of pilot studies with the basic research although they are in actual fact completely different.

In these circumstances, it is important to evolve a clear-cut policy on the application of hydraulic models, based on an overall plan which would include organizational and financial aspects. These aspects may have certain features in common in countries at a less advanced stage of economic development as those in Latin America.

When only a few small-scale projects are undertaken in a country very detailed designs are unnecessary since the work can proceed on the basis of general recommendations from abroad. But when a more advanced stage is reached and more ambitious projects are contemplated, general criteria are no longer adequate and, in the interests of the economy, individual solutions have to be projected to suit the particular characteristics of each project. Developments in Chile during the last

/few years

few years, are a case in point as the following examples will suffice to show: the electrification plan of ENDESA, based primarily on the harnessing of hydroelectric capacity, the vital irrigation plan, and the problems arising from the erosion of crop land and silting up of ports.

The use of hydraulic models for research purposes has been fully explored in Chile for a number of years past by Mr. Francisco J. Dominguez, Professor of Hydraulic Theory, but their use for purposes of design was not given serious consideration earlier than the last 20 years. Models of this kind have mainly been utilized for port projects and for hydraulic works in hydroelectric and irrigation projects. In the former case, the work was usually assigned to foreign institutions, but latterly has also been undertaken locally at the Peñaflor Hydraulic Laboratory, which belongs to the Ministry of Public Works (Ministerio de Obras Públicas - MOP), Department of Port Services (Dirección de Obras Portuarias). These models, which are fairly complex because of their magnitude, the amount of laboratory equipment they need and the fact that they are virtually a representation of the whole project, fall outside the scope of this study.

Models for hydraulic works in hydroelectric and irrigation schemes are similar in concept and aim, and come within the bounds of this study. They have been made chiefly by the National Electricity Company (Empresa Nacional de Electricidad S.A., ENDESA) and by the Irrigation Department (Dirección de Riego) of the Ministry of Public Works. The magnitude of the hydraulic works projected by ENDESA during the last two decades has entailed the use of hydraulic models on several occasions. In fact this company has made more use of the model technique than any other enterprise in the country.

2. Brief account of the principal models used by ENDESA

In order to explain the way the model technique has been applied in Chile, a brief reference to the principal models made by ENDESA will be helpful. Most of the models relate to studies on the behaviour of hydraulic structures with a fixed base at the draft project stage, or to the expansion or improvement of existing works. A few have also been made to examine

/the effects

the effects of scour and sediment transport in relation to movable beds and to study silt deposits. For the purposes of the present account, the models are divided into three groups: (a) Models of projected hydraulic structures with a fixed bed; (b) Models of extensions or improvements in existing structures (fixed bed); and (c) Models of scour and transporting and depositing of sediment.

(a) Models of hydraulic structures with a fixed bed at the draft project stage

(i) Model of an energy dissipation with high-speed jets - Lake Laja power station. This model was made in 1953 at the Hydraulics Labo of the Catholic University of Chile (Teaching and Research Laboratory). Although the solution to which the test project corresponds was subsequently discarded, this study is a typical example of a case in which a model may help to clarify a number of important points for the design. The draft solution consisted of two separate beds to dissipate the energy of two high-speed jets coming from valves by means of hydraulic pumps.

The model was made on the Froude scale of = 50 (the relation between lengths in the prototype and in the model being henceforward designated by), with an installed flow of 5.65 litres/second, and was constructed of waxed wood with rubber gaskets. One of the side walls of the bed was made of glass so that the runoff could be watched.

A view of the model is shown in Photograph I. Important conclusions were reached on the basis of this model regarding the design of the delivery structure to the bed, of the bed itself and of the delivery from the bed to the tailrace. (See photograph 1).

(ii) Model of the intake shafts in the Lake Laja power station. This model was made in 1958 at the Hydraulics Laboratory of the University of Chile. It was intended to project the two intakes of the supply tunnel for the future power stations at Lake Laja and the drainage tunnel for the Lake (for irrigation purposes and to feed the Abanico plant which operates downstream from the Laja power station).

/The construction

The construction of the model was justified by the difficulty of designing underwater intakes with several openings in deep lakes or reservoirs, owing to the inadequacy of the practical and experimental background and because it had been impossible to study the runoff in the tunnels and shafts by analytical methods.

The model, on the Froude scale with = 40 and a feed flow of 10 litres/second, was built in wood covered with liquid rubber. For the sake of symmetry, the model was cut along its plane of symmetry by a sheet of transparent plastic which allowed the runoff to be seen (see photograph 2).

Some conclusions were obtained from the model with respect to the advisability of making changes in the original design, mainly rounding to avoid leaks, and the elimination of vortices and unduly turbulent zones.

(iii) Design for the restricted orifice of the surge tank in the Isla hydroelectric plant. This model was made in 1958 at the Hydraulics Laboratory of the University of Chile for the purpose of designing the communicating orifice between the tank and the tunnel. The design envisaged a specific head loss for the ascending maximum flow and the greatest possible resistance for the descending flow. The problem, of designing a short-length resistance that was so precise in value could not be solved by analytical methods and a pilot study therefore had to be made.

The model, which was particularly difficult to construct internally (the forking of the tunnel into two pipes being done just below the tank), was built on the Froude scale with = 25 and a maximum feed flow of 34 litres/second. The bifurcation component was made of plastic mica with aluminium templates fixed to a framework of aluminium pipes. The tank shaft itself was made of metal plate and transparent plastic. The various outlets tested were made of a mixture of plaster and cement and were secured to the body of the bifurcation unit by a bolted flange.

The model served its purpose well and could even be used to observe the vortices that appeared while the level was descending, thereby making it possible to ascertain the minimum freeboard required for the maximum descent in the surge tank.

/(iv) Two models

(iv) Two models to determine the design of discharge syphons. In a power station that has a supply channel and surge tank, positive waves move up the channel during load rejection and, unless the channel has a horizontal berm and adequate freeboards, provision should be made for facilities to discharge the excess flow. In the model described below, the behaviour of a rapid priming syphon was studied as a method of discharge for the Pullinque power station (now under construction).

This model was made in 1957 at the Hydraulics Laboratory of the University of Chile. It is on the Froude scale with = 10 and a feed flow of 90 litres/second. The model was reduced to a draft design of the syphon, mainly on the lines of the standard design used by the Bureau of Reclamation. It was constructed in waxed wood, reinforced with metal hoops, and one side was made of transparent plastic. A general view of the model is shown in photograph 3. (See photograph 3.)

Although the materials used were not the most suitable for making a model of this kind, the model proved to be very useful for a design, such as the one in question, in which small changes in the project make a big difference in practice.

Discharge syphons for the waves that might move up the supply channel were designed in the case of the Sauzal power station. The design for these syphons, which are slower priming than those previously described, was determined by means of a pilot study undertaken in 1942 at the Hydraulics Laboratory of the Catholic University. (This was the first occasion on which ENDESA made a pilot study.) The syphons have given excellent results in operation.

(v) Two models to determine the lay-out of automatic gates as discharge devices. For the same purpose as the previous pilot study of discharge devices, a study was made of the lay-out of an automatic gate operated by the water level for the Pullinque power station. (This is the discharge method finally adopted.) A similar solution has been adopted for the Isla power station (now under construction). Models were made of both installations at the Hydraulics Laboratory of the University of Chile; the first for the Pullinque plant in 1958 and the second, which is currently being tested, for the Isla plant.

/The first

The first model, on the Froude scale of = 46.1 (determined by the use of the materials) with a feed flow of 8.40 litres/second, was intended to ascertain the form for the tunnel between the channel and the gate installations so as to obtain an even runoff.

The model reproduced a stretch of 100 metres of channel and 50 metres of tunnel. A metal plate was bent to form the channel, and the gate area and tunnel were made of plaster mixed with cement.

By means of visual observations and measurements of hydraulic axes in different parts, the runoff conditions were progressively improved, for both normal periods and the most critical period during load rejection.

Photograph 4 shows how the final discharge design works in practice. In addition, discharge coefficients were obtained from the model for the different gate positions and flow combinations, which enabled the theoretical problem of load rejection to be tackled with a better supply of data to work from. The model was on a small scale, due to the fact that it had been planned on the basis of qualitative experiments only. (See photograph 4.)

The lay-out model of the Isla power station resembles the previous example; the scale is = 25 and the feed flow 34 litres/second.

(vi) Model of the general lay-out of the works at the Rapel power station. The choice of type and general lay-out for the Rapel power station works (reservoir type) was largely determined by the big rise of the river (estimated at 10,000 cubic metres/second). Two spillways to discharge the rise have been placed on both sides of the concrete wall arc. They are of the "ski jump" type, i.e., they discharge the water from a certain height above the river, thereby dissipating a large part of the energy in the air.

The hydraulic model of the works was made as a basis for studying the general lay-out in the Rapel power station, since it was the only way in which this could be done.

The model was built in 1957 at the Hydraulics Laboratory of the University of Chile, which, at that time, had little space at its disposal. A scale of = 100 was therefore adopted, with a flow of 100 litres/second. In order to show the level curves, aluminium strips bent to shape were used and kept in place by metal supports. The empty space was filled by bricks and mortar.

/Photographs 5

Photographs 5 and 6 show lay-outs for the spillways and jet dissipators. (See photographs 5 and 6.)

The model is essential for the satisfactory operation of the works.

(b) Models of extensions or improvements in existing structures (fixed bed)

These models have a great advantage over those discussed in sub-section (a), since the accuracy with which the model reproduces the phenomena to be studied can be checked.

(i) Model of the energy dissipator for the discharge chute in the Abanico power station. This model was made in 1954 at the Hydraulics Laboratory of the University of Chile with a view to improving the operating conditions of the bed energy dissipator at the foot of the discharge chute in the Abanico power station. It was constructed on the Froude scale of = 50, and consisted only of the bed and the end of the chute. For experimental purposes, the estimated speed and flow of the prototype were reproduced at the point of entry to the bed. The model was made of wood with the left-hand side of glass to facilitate observation. It showed the teeth lay-out, the modification of the arrival chute and the banking of the side walls. Photograph 7 shows how the bed operates on the basis of one of the solutions tested. (See photograph 7.)

(ii) Two models for studying forebays. In 1948, a model of the forebay for the Pilmaiquén power station was made on a site adjacent to the Hydraulics Laboratory of the University of Chile. It was built for a dual purpose: firstly, to study ways and means of improving the operation of the forebay, since disturbances and vortices had been observed at the entrance to the pipes, as well as areas of still water, and, secondly, to study the expansion of the forebay so as to include two larger units.

The model was made on the Froude scale of = 18, with a maximum flow of 95 litres/second. During the tests which were made with the existing lay-out of the forebay, the runoffs in the prototype and in the model were found to be surprisingly similar as regards speed distribution, and position and magnitude of vortices.

/The experiments

The experiments led to some important conclusions on how to improve the operation of the forebay by the elimination of vortices (caused by local disturbances, mainly of the buttresses at the entrance to the pipes). The model also indicated the best way to expand the forebay. Photograph 8 shows the general lay-out of the model. (See photograph 8).

At the present time, experiments are being carried out at the Hydraulics Laboratory of the University of Chile on the improvement of the forebay in the Abanico plant, with a model on the scale of = 30. Photograph 9 gives a general view of the model. (See photograph 9.)

(c) Models of scour and transporting and depositing of sediment

Although models of structures with a movable bed are as yet a comparatively unknown quantity in Chile, ENDESA has experimented with two which will be briefly described below.

(i) Model for studying the operation of the intake at the Sauzal power station. The object of this study was to see the way in which sediment was removed, and the form taken by the deposits at the intake area in the Sauzal plant, as well as to devise possible improvements in the original design in order to obtain optimum operating conditions.

The model was constructed in 1944 on a site adjoining the Hydraulics Laboratory of the University of Chile. It was on distorted Froude scale of = 25 (vertically) and $_H$= 40 (horizontally). The feed flow was 240 litres/second (the maximum rise in the river being estimated at 1,200 cubic metres/second). The bed of the river was reproduced for a stretch of 500 metres upstream and of 150 metres downstream from the barrier. It was made of earth covered with a layer of mortar, half an inch to an inch thick, and based on the form assumed by the intake area during the dry season. (This was made possible by the fact that the new bed would be higher, since the bottom of the intake area is rock.) The gate structures were made of wood with movable parts in order to allow for possible alterations.

The materials used for sediment were fine sand (carried along at speeds of from 50 to 60 cm/second, which, in the prototype is equivalent to from 2.50 to 3 m/sec.) to represent the coarse sediment carried along

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when the river rises, and screened industrial fine coal (carried at a speed of 30 cm/second which is equivalent to a speed of 1.50 m/second in the prototype).

Coal and sand were fed in under supervision at periodic intervals, but arbitrarily, since no information could be obtained to make a prior comparison between the model and the prototype in order to determine the time scale for sediment. (As the solid material was inserted in abundance, this probably speeded the experimental rates in comparison with actual conditions.) The experiments carried out in this respect were of course qualitative in nature. The deposits accumulated after a test can be seen from photograph 10. (See photograph 10.)

At the same time, the hydraulic operation of the works could be observed (water beds at the exit of the collector channel, torrents downstream from the barrier, etc.).

In general, the model indicated a number of ways in which the draft design of the intake could be improved.

(ii) <u>Model of the energy dissipator for discharges purposes in the Isla power station.</u> The energy dissipator at the end of the discharge chute in the Isla plant simply consists of a jet of water into the river. As it is based on alluvial matter, substantial scours are expected at the foot of the structure. The purpose of the model was to make these works both safe and economic.

Experiments with the model of this structure, and of the stretch of the river on which it is situated, are currently being completed at the Hydraulics Laboratory (University of Chile). The model was built on the Froude scale with = 33.3 and a maximum flow of 17 litres/second. Photograph 11 shows a general view of the model. (See photograph 11.).

Scours at the foot of the structure were studied by the method recommended by Professor Scimemi. It consists in testing various kinds of materials of uniform diameter in the bed of the river, and obtaining through extrapolation the values that will ensure completely safety.

In this case, a model is undoubtedly the only way in which to decide how to project a structure of the type in question.

/3. Analysis of

3. Analysis of the development of the model technique in Chile

It is useful to analyse the development of the model technique from its inception to the present day, since the process has clearly been a natural one in response to the requirements of more complex hydraulic designs.

Most of the models have been conceived and tested by the same project-makers, who have often had to grapple with all kinds of difficulties. When the first few models were made, there was no proper laboratory in which to house them and the measuring instruments had to be improvised. In some cases, experimenters were recruited from among the civil engineering students, who worked under the supervision of the project-makers.

The construction of the Hydraulics Laboratory as a subordinate body of the School of Engineering, University of Chile, and the fact that a certain amount of space was set aside for pilot studies, largely overcame the problems arising from the lack of adequate premises and of feeder equipment for the models. In the beginning, the models were built and tested by the project-makers themselves, with the aid of the Laboratory equipment. This situation changed in the last two years when the Laboratory acquired a permanent staff, consisting of both engineers and trained technicians and specialized workers. Thus, the building and testing of the latest ENDESA models were undertaken by the Laboratory, in close collaboration with the project-makers.

To put a models laboratory into operation, construct and equip the buildings and, above all, train the scientific and auxiliary personnel, requires heavy investment over a number of years and the results are not entirely satisfactory. In Chile, such investment has taken the form of a direct State subsidy through the University of Chile.

At the present time, there is a system of joint financing based on direct subsidies and fees. The State subsidy for this purpose comes from the funds which the State puts at the disposal of the University in order to encourage applied research. The fees fixed for each study

/are fairly

are fairly high, even when they are based on real operating costs. It should be explained that, in actual fact, both forms of investment are the same, since the Chilean enterprises that may need pilot studies are largely governmental, and the question is thus one of national accountancy.

The Hydraulics Laboratory is fundamentally a teaching unit, and is perhaps the only institution where basic research in hydraulics has some chance of prospering in Chile. It has a new building covering an area of 1,900 square metres in all, of which 1,340 (70 per cent) constitutes the space allotted for experiments, the remainder being distributed among offices, classrooms, workshops, etc.

On the whole, the models can be said to have fulfilled their purposes as may be realized from the details supplied on the principal models made by ENDESA. Pilot studies have frequently been the source of important improvements in designs, and have invariably enabled a much fuller study to be made of the different phenomena that may arise during the operation of the works. Far more mistakes have been committed through the lack of models, which may be remedied through the subsequent study of works that have already been constructed.

A certain amount of experience has already been acquired on models with a fixed bed, and sufficient information is available on the theory, the experimental techniques and the materials that should be used. Conversely not enough is known as yet about models with a movable bed, which have seldom been used in Chile.

Lack of experience in model technique has raised the cost of the studies which, in no case, can be considered unduly high. Normally, the cost of a pilot study is a very small percentage of the total investment demanded by the works in question (1 or 2 per cent). This is borne out by some of the models made whose cost could be approximately estimated.

Model	Cost of model		Direct cost of works		Percentage
	Escudos	Dollars	Escudos	Dollars	
Intake, Lake Laja power station	4,700	4,480	300,000	286,000	1.6
Overflow works, Pullinque power station	2,300	2,190	150,000	143,000	1.5
Discharge syphon, Pullinque power station	2,400	2,280	150,000	143,000	1.6
Restricted orifice, surge tank, Isla power station	3,300	3,140	280,000	267,000	1.2
Overflow works, Isla power station a/	3,500	3,340	250,000	238,000	3.2
Energy dissipator, Isla power station	4,500	4,290			

a/ The percentage has been calculated on the basis of the whole overflow works for the Isla power station, i.e., on the two models.

Note: The costs indicated are expressed in terms of October 1960 values. Local currency was converted to dollars at the rate of 1 dollar to 1.05 escudos.

The present situation undoubtedly has a number of advantages over the past, mainly because of the training of specialized personnel, the creation of experimental techniques, acquisition of satisfactory measuring instruments, etc. In fact, up to two years ago, a certain amount of time was unavoidably lost through inexperience, and the experience accumulated at the end of a pilot study was wasted as the project-maker and experimenter did not usually make more than one model.

Granted that the existence of a models laboratory is beneficial to the country, for a number of reasons to be explained later, and that the different enterprises do not prepare projects at a sufficiently rapid rate to justify the investment involved in setting up a laboratory and giving specialized training to a group of technicians, a models laboratory attached to a research and teaching laboratory offers certain advantages in a country such as ours; it guarantees that its work will be sound, since it is performed under the auspices of a scientific institute and

/reduces the

reduces the capital investment required to some extent. Thus, the formula of two co-ordinated laboratories is evolved, each of which is autonomous so far as its work is concerned.

4. Need for a models laboratory in Chile

In view of the big technical advances made by research and models laboratories in more industrialized countries it is a moot point whether the models should be made in the country or requested from abroad. It will be demonstrated that the country would benefit greatly from the presence of a models laboratory, which could make nearly all the necessary models, except those that are difficult or require special installations (e.g. some sediment transport models) that might be contracted abroad. Contacts with foreign laboratories, advice, study trips, selected literature, etc. will undoubtedly enable rapid progress to be made in this field. The main advantages of a local models laboratory may be summed up as follows.

(a) Importance from the point of view of the professional training of engineers

A models laboratory gives engineer-experimenters and project-makers an opportunity of improving their knowledge. The person who projects a hydraulic design must naturally acquaint himself with the behaviour of the works he is planning. This is often a difficult and long-term task. If he can observe their behaviour in a model, the same purpose is fulfilled in less time. For project-makers who work for some time in the laboratory, it will mean that they can become thoroughly familiar with the operation of hydraulic structures and fully alive to the limitations and uncertainties of design standards that are apparently accurate. Above all, it will give them breadth of vision to perceive or predict the effect of a given structure on runoff. Moreover, it is desirable for a laboratory engineer to practise on a project in order to improve his understanding of the purpose of his work and instil in him the ability to distinguish the important from the unimportant problems in practice.

/A models

A models laboratory would undoubtedly enable engineer-experimenters to perfect their training and would thus provide the necessary body of specialized personnel, who after a pilot study had been undertaken, could take measurements of the prototype in order to compare the results with the data obtained from the model and check the accuracy of the pilot studies. This would add to the experience of the personnel and enhance their skill with the model technique.

(b) The model as part of the design proper

A pilot study is not a pure research project, but one of the stages in the projection of a specific hydraulic structure. Hence, these studies should be undertaken on the basis of a general principle that is valid for any and every project.

The model should be used to test ways and means of building and operating on the natural scale, the best solution being sought from the two angles of safety and economy. A pilot study must find a solution since the project itself has to be put into effect. When it is borne in mind that, apart from the characteristics mentioned above, a model also refers to a specific case, the differences between a pilot study and research can be clearly grasped. For this reason, the studies should be carried out by a team combining the practical criteria and experience of a project-maker with the knowledge and technical expertise of a laboratory engineer.

It is obvious from the foregoing considerations that the laboratory and project office should be close to one another. Lack of proximity is one of the great disadvantages of seeking assistance from foreign laboratories, unless they are to make the whole project.

(c) The reasonable cost of pilot studies

The models made in Chile have not cost unduly large sums, and if expenses have sometimes been higher than they should have been, this may be ascribed to inexperience which prolonged the duration of the studies, or to unsatisfactory planning of the model.

/Moreover, it

Moreover, it should be taken into account that, during the first stage of the laboratory's operations, the increased cost of the models will be translated into materials and equipment and, above all, into experience for the personnel. Furthermore, since the factor that is primarily responsible for raising the cost of a model is the time consumed in the study, this can best be dealt with by reducing time-limits to the minimum and improving construction techniques, and by paying special attention to the standardization of equipment and instruments as well as to the flexibility of staff organization and of the lay-out for the permanent laboratory installations. The cost should naturally be kept as low as possible even though no profitability criterion is applicable, since there are times when a pilot study does not represent an economy but even raises the cost of the works for the sake of safety or better operating conditions. Hence, the organization of the models laboratory should be in keeping with the industrial role assigned to it, which differentiates it from a laboratory destined for teaching and research.

In view of the fact that other South American countries are facing similar problems while still at an early stage, full justification may be found for an international campaign to create regional laboratories, with equipment and personnel at the highest technical level, which could undoubtedly serve groups of countries that have the advantages of geographic proximity, a common language and customs, etc. One of the salient functions of these regional centres would be to direct and encourage the national laboratories of the countries in their sphere of action.