RESTRICTED

THE HYDRAULIC LABORATORY
in
REYKJAVÍK

designed for model studies connected
with the hydroelectric development of
the HVÍTÁ and THJÓRSÁ river basins.

by
Stig Angelin
United Nations Special Fund

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Introduction

This section deals with the design of the hydraulic laboratory planned to be used for model tests connected with the hydroelectric development of the Hvítá and Thjórsá River basins. Other projects or fields of work which may provide tasks for the laboratory are also summarized.

Some general comments on the need and the value of model tests in the hydraulic design of hydroelectric plants are given. The intention is to give the design engineers a better understanding of the advantage of taking model tests into consideration at an early stage of the planning of a plant.

Most of the time during the assignment has been spent at the office in Reykjavík drawing up alternative plans for the hydraulic layout of the laboratory building, the water system and the main fixed equipment. A great number of informal and formal conferences has taken place in this connection, not only with the engineers at SEA, but also with the consulting engineer and the architect for the building. The projects and problems of immediate interest whithin the hydraulic field in Iceland have been also discussed with the aim to set up a first working program and a suitable first-hand equipment for the laboratory. The organizational status of the laboratory and the question of suitable staffing is also treated.

General information of the practical procedure to be followed in model construction and testing is also given. The reason for this is that very little earlier experience in the field of hydraulic model tests is available within the SEA-staff. Further detail information has been given during the assignment and will also be submitted during the counterpart´s study tour to Sweden and Norway.

To obtain a general idea of the problems connected with the water power development in Iceland, visits have been made to existing power stations and dams and to planned dam sites in northern, western and southwestern Iceland.

General Information

Modern engineering hydraulics is almost entirely based upon experiments. Even if the knowledge of the fundamentals is perpetually increasing there are a great many problems that can not at all be sufficiently treated theoretically. In many cases possible theoretical calculations are so complicated that a model test will lead to a practical result in a much shorter time and to a considerably lower cost. The approximations and more or less uncertain assumptions of coefficients that have to be used may often make it necessary to check the results in a model, even in some of the cases where calculations can be carried out.

Especially concerning hydroelectric plants and dams, model tests have therefore become a very valuable and very much used tool to find the best and most economical design. In many countries and for many power or consulting companies model tests are considered indispensable and are compulsory routine for any power plant or regulating dam.

No two rivers are identical or have the same properties and two stations in the same river will never be of quite the same design. Solutions in design as well as formulas and theories, which are developed for one plant in a certain river, can not therefore be simply adopted for an other case. If not the presuppositions and conditions,for which such a solution or formula is valid are enough known to allow for an adjustment to the actual case, it is necessary to be very careful in using it.

It is quite obvious, of course, that it is infinitely cheaper and less risky to experiment on a small-scale model than on a prototype. In other words: it is much cheaper to make the mistakes in the scale 1:100 or 1:40 than in 1:1. Within an hour or two one or several alternatives of design can be easily studied on a model at normal flow conditions as well as at extreme peak flood or low water conditions.

It is quite clear that a competent designer would not take any possible risks of serious damage to such expensive structures as are involved in power plant construction. Neither should he consciously suggest a design that could possibly give future operation troubles. Without model tests he is therefore often forced to take expensive precautionary measures against unknown risks. Nevertheless it may become evident, when the plant is taken in operation, that the expedients were unsuitable, unsufficient or unnecessary.

A good design in most cases can be reached at the same or even lower construction costs than the unsuitable. For example the construction cost of one single stilling basin or energy dissipator, designed by means of model tests, very often can be decreased so much, compared to a theoretically calculated, that it will not only cover the testing costs several times, but also the whole cost of the laboratory building including all the equipment. Nevertheless it can very well give a more efficient energy dissipation.

The future power production will have to repay the plant. By model tests a considerable improvement of the access flow and inflow conditions and a better detailed design of the power station intakes can be obtained. It is not quite unusual that the decreased head losses and the better turbine efficiency thereby arrived at can result in 1-2% higher output. For low-head stations (head$\sim$10 m) even 10% has been reported. It is obvious that in such cases the profit of the tests is very large, even if it mostly can not be estimated.

There is now practically no disagreement that an unfavourable intake flow, with whirls or vortices that may look rather unimportant or a spiral-flow in the penstock can cause serious cavitation damage to the turbines even at installations of rather high heads. Cavitation will mean not only repairing costs, but also a periodical shut off that mean a considerable amount of lost power.

It is also of a very great value for the construction period to have a model in which one can test various alternatives as regards height of cofferdams, diversion methods, scouring risks, ice problems etc. This is especially noticed when unforeseen occurrences or difficulties arise during the construction. These can cause for instance an alteration of the coffer dams or a change in the complete work sequence. Troubles will also be noted when it is realized that the assumptions made concerning the depth of reliable bedrock were not correct. In such cases a quick and correct decision can be made with the aid of the model.

Many new ideas of design or methods can not be used directly on a plant without too great risks of a failure. Some of these ideas may, of course, prove to be unrealizable, but often, after being studied and adjusted in a model, it may be found that they constitute a definite step forward in the technical field. A great part of the technical progress in the water power field must therefore in fact be credited to the possibilities of testing and developing new ideas in the hydraulic laboratories throughout the world.

The question of application of model tests for a plant is of course also an economical one and the costs will become the more important the smaller the plant to carry them is. It must be emphasized, however, that the main thing to consider is whether the tests will be justified
a) by the gain in construction costs that can result in bringing the hydraulic safety factor down close to 1,0.
b) by the possibilities of increased future output of the station due to higher capacity and more reliable operation,
c) by the greater security that future expensive measures can be avoided in connection with unforeseen damage to the structure itself or to the property or interests of outside people.

Model tests thus can help to deal with a great number of complicated problems, as well as problems of more routine character, connected with the design and the construction of modern power stations and is a very valuable instrument for finding the best solution in each case from the technical and economic point of view. However, it can not be too much underlined that they must be carefully applied with skill and judgement. If the model is constructed after erroneous maps or drawings, or if adequate knowledge of the flow conditions or the physical properties of river bed or structure are not available, or if the tests and measurements are not made with the required degree of accuracy or not analysed and interpreted correctly, completely wrong conclusions can be drawn and very serious design mistakes can be the result. If the model can not be made as a true copy of the prototype or the tests can not be made in a reliable way or if there is any doubt about the applicability of the similarity laws to the model scale that has to be used, then it is often better to refrain from the use of models.

It is of great importance that there is a close collaboration between the laboratory and the design and construction engineers not only at the planning of the model and during the tests but also afterwards so that it is granted that the results of the tests really are transferred to the performance of the prototype. The laboratory engineer(s) shall frequently visit and study the construction site and works and get acquainted with it in order to avoid mistakes or misunderstanding. He shall then also give advice and inform the construction engineers of the reasons of different measures decided upon during the tests.

The hydraulic laboratories have an important and quite dominating role in extending the basic knowledge of applied hydraulics. Field studies can of course provide enough information for an understanding of some problems, but an investigation based exclusively on field studies will in most cases be extremely time-consuming and expensive, because the nature itself governs and controls most of the variables. A certain amount of field data is indispensable as the basis also for laboratory tests and to verify the results. With some basic data available, laboratory experiments can, however be systematically carried out in a reasonably short time and the influence of the different variables sufficiently settled. A combination of field and laboratory studies will therefore give the wanted result much quicker and cheaper

History

Of the hydro-electric plants constructed till now in Iceland only the three stations on the river Sog are larger than 10 MW. They have all been designed by Icelandic or foreign consultants without any model tests.

At some of the plants rather severe operational or other troubles exist, in some cases in connection with ice problems. These very likely could, at least to some extent, have been avoided if the design had been thorougly studied on a model. Some tests have been carried out to find adjustments to the design in at least one case.

For Burfell hydro-electric plant in the river Thjórsá, the first larger project in Iceland, model tests are now being carried out in the laboratory at Trondheim, Norway. These tests concern primarily the problems of separation and diversion of ice and secondarily the sedimentation and general flow conditions.

For some years it has been discussed to build a hydraulic laboratory in Iceland to make model studies connected with the hydroelectric development possible.

In 1963 plans were made up for a laboratory building of 10.9 x 30,5 m to be placed at Keldnaholt some 10 km east of SEA´s office in Reykjavík. The reason for a location at Keldnaholt is partly that SEA already has some buildings there but mainly that this is the site of a planned centre of applied research in Iceland, comprising several institutes. One of these, an agricultural research institute, is now under construction and another, a building research institute, is contemplated in a near future. It is thougt to give certain advantages to have the laboratory located in this research environment. For orientation see fig. 1, location map.

The laboratory building of about 330 m^2 was planned as a first stage and it should possibly be extended by a larger hall of some 30x60 m in the future. In this second stage it should also be possible to carry out more extensive tests on harbours and the like.

Work started at the site in 1963 when the United Nations Special Fund Project concerning the Hvítá and Thjórsá basins was approved, by excavation and the prestressed concrete beams for the roofing were casted. Then the work, however, was withheld until it was taken up again in 1965 when the UN-expert arrived in Iceland.

A review of the plans of the building and the water system were made during May-June 1965 by the UN-expert in close cooperation with SEA as well as with the consulting engineer and architect.

After an estimation of the construction costs in August 1965 and a review of the projects to be studied in the nearest future, SEA decided to reduce the first stage of the laboratory to be built now, as will be accounted for below.

Subjects to Be Studied at the Laboraoty

Iceland is comparatively a small country with limited resources in economy and qualified engineers. It would therefore be imprudent to split the activity of hydraulic laboratory into different institutions.

Even if a laboratory is primarily built to solve problems connected with the development of the hydro-electric resources it should be prepared to undertake such investigations of hydraulic and flow problems that may arise in other fields within the country.

It is presumed that a laboratory in Iceland in the first stage of development will not have sufficient experienced technical staff or laboratory facilities to carry out model tests for the largest or most difficult plants or projects that can arise. Nevertheless any of the types of the tests described below can be actual.

Water power development.

For large plants it is very often desirable to make a survey model in a small scale, in which the general layout can be studied. Different alternatives for disposition, location and direction of power station intakes, spillway section, canals etc. can be studied and compared. The general layout of energy dissipators, excavations, protecting walls and similar structures can also be studied.

This type of models will also be very suitable to establish the main flow picture at a plant with the purpose to find out i.a. the best location of spillways to discharge ice.

In a case when different alternatives of layout are to be studied a small scale is wanted in order to keep down the costs. If the basic conditions of similarity in the state of flow are calculated to be fulfilled a scale to 1:80-1:100 is usually sufficient for a model of a plant in a larger river.

For the more detailed design of a plant a model in scale 1:40 or 1:50 is usually wanted. This scale will normally be sufficient to study the power station intake design, surge tank problems, the design of piers and spillways, stilling basins or other type of energy dissipators, guide walls, diversion canals, determine discharge capacity and discharge curves, study erosion and bed-load transport, scour risks etc., etc. In this scale also the many problems concerning the different construction stages can be studied, for instance best layout and necessary heights of cofferdams, needed coarseness of material in rock-fill cofferdams to avoid erosion etc., etc.

A model in scale in the region of 1:40-1:50 is to be considered the most common for the design of water power plants and practically all the main design problems, which are connected with the flow problems can in ordinary cases be solved in such a model.

In some cases, however, special components or parts of a plant must be studied very carefully in larger scales. It may be gates of different types, stoplogs for use in flowing water, spillways of new or special design or other structures, where pressure distribution, hydraulic load, risk of vibration etc. is of decisive importance. Such detail models are used for any kind of hydraulic problem, which need a closer study than the main model can give as well as in cases when only a special part of a plant has to be studied and no main model is built at all.

For such detail models scales of 1:15 to 1:30 are often used and in many cases the model is built in a glass-walled flume or constructed separately in perspex.

The field of general hydraulic problems still not fully understood is very large and there are many subjects for research or applied research. For a laboratory in Iceland it would be natural to attack the problem of how to handle the ice in the rivers and at the plants, frazil ice as well as ice-floe formation. At least in the first stage simulated ice of plastic materials should be used.

A testing program for study of ice problems should be settled only after a summary of all the experiences gained at the existing plants has been set up by the operation staff in charge of these stations. The report of the UN-experts on ice hydrology must of course also be studied carefully in this connection and their advice should be asked in any matter where it can be of assistance.

The bed-load transport problem is another subject that will need investigations of a general type. This problem will certainly have great importance in connection with many plants in the development of Hvítá and Thjórsá, but even more in some other of the greater rivers in Iceland. The light volcanic material can probably give some extra difficulties in this connection.

Laboratory tests on bed-load and sedimentation preferably should not be started until more field data are available to make possible a calibration of the properties of the bed material to be used in the model. Besides, movable-bed models and tests are more complicated to carry out than ordinary tests with fixed bottom. Therefore this type of tests should not be included in the very first program of the laboratory.

Unfortunately it is not possible to state at this stage, which plant on the Hvítá or Thjórsá system, under consideration in the Special Fund Project, will come first. Likewise it is impossible to foresee when the design work for that plant will reach the stage where model tests can start. A better estimate of this will be possible when the Master Plan is ready.

The first larger plant to come is Burfell in Thjórsá for which the construction will start in a near future. This plant is outside the Special Fund Project, but can nevertheless become of some importance to the laboratory.

The main tests for Burfell are as mentioned above being carried out abroad. It is, however, our feeling that further tests concerning the detail design of the intakes and other parts of the plant will be valuable, and also wanted as the design work proceeds, if a laboratory is available then.

In the near future a third hydro-electric plant will be built on the small river Laxá in Northern Iceland. This project would be a very suitable training subject for a new laboratory. The tests would very likely give results in cheaper and safer design that would pay the costs.

Model tests will certainly also be of great value to find out the best way to improve some of the existing plants and to eliminate some of the operational troubles due to unsuitable design.

Other Problems

Erosion and sedimentation problems as well as ice problems will arise also when highway and bridge construction is considered. Also for these projects model tests will be a very useful tool to ensure adequate and safe structures in the most economical way.

Many Icelandic rivers keep salmon and trout and are of great value for sport-fishing. It will very likely be of interest to make laboratory studies in this connection, i.a. concerning fish-ladders, counting devices, regulation of the flow picture to improve the passing way of the fish etc. It is discussed to set up hatcheries and also in that connection minor tests can be needed.

Iceland has a great number of harbours and the design of new harbours as well as the redesign to improve conditions in existing ones very often need model tests. These tests are now made abroad and it is considered to have some advantages to do so also in the future, at least for larger projects. It is quite true that a cooperation with a large foreign harbour laboratory will make the experiences from other parts of the world available to the harbour design engineers in Iceland and that the contacts will provide information of great value to them, which otherwise could be difficult to obtain. Nevertheless it must be valuable to have possibilities to study smaller projects and for instance make wave tests of breakwaters in a local laboratory. Thereby the Icelandic harbour designers will also get a better understanding of the testing methods etc. to judge upon suggestions coming from a foreign laboratory. With some experience of their own a mutual exchange of experience with many other laboratories can be easier attained.

Fishery is the backbone of the economy of Iceland, today warranting more than 90% of the export value. The laboratory could certainly in some cases assist in testing new equipment for seafishing, thereby contributing a little to reaching the highest possible efficiency of this industry. Some testing of this kind is now being carried out abroad, but it would undoubtedly be of great advantage to be able to make this within the country. It would then certainly also be profitable to engage the hydraulic engineer also in some of the half- or full-scale field tests.

Hydraulic problems can very well come up in connection with the exploitation of the hot-water resources. Such problems of the hydraulic nature can in most cases certainly be studied in the laboratory using ordinary water. Adjustments of the results due to the difference in viscosity can probably be made theoretically afterwards in the cases where it may be of importance.

Possible density current problems connected with hotwater reservoirs or with muddy water outflow can also be studied at the laboratory using a separate hot-water system or a liquid of different density to obtain the density current or layer.

Description of Proposed Laboratory.

Although it has not been possible to set up a fixed or concrete program for the nearest future of the work of a hydraulic laboratory in Iceland, it is quite clear of what is said above that there should be enough hydraulic problems existing to keep a laboratory busy. It must, however, start in a small scale and develop in time to meet the growing demand of its service. A hall with an area usable for models of about 265 m^2, as originally planned, can not in any way be considered too large as a first step. The high and steadily rising construction costs in Iceland made it, however, necessary for SEA to decide upon a division of this project into two stages, starting with completing only about half of the building. This can be made without serious consequences as the further development of the hydro-electric resources of Hvítá and Thjórsá, for which it is primarily intended, will not start within some years. During the first years projects of only limited size will probably be actual and the working load will not be heavier than a reduced water system can handle.

These two stages of the development of the laboratory are shown in principle on figures 3-6. The final laboratory hall will be 30.5x10.9 m, outer measures. The rough outer concrete body of the building will be constructed to the full length from the beginning.

In the first stage the south-east end will be left in that state and only a 16.85 m long part of the building will be insulated and finished. A provisional wall will be erected in the building as a temporary SE gable. An 8.2 m long glass-flume is placed along this wall. It is suggested to be 0.8 m wide and 1.0 m deep and will likely be the most used place for model studies from the beginning. In order to save some money the inner wall of the flume could originally be equipped with only two middle glass-plates.

The remaining space usable for floor models will be 12,9x9,0 á 9.5 m in the first stage. To be able to use the floor area as freely as possible for several models, floor wells are arranged along one of the outer walls and across the south-east end. When not in use these are covered by steel lids and can be overbuilt.

In the second stage the remaining part of the building will be finished and the return water canal system completed with another set of floor wells along the outer wall and across the south-east end. The glass-flume will then be moved to a place near the new gable end along the outer NE wall. The usable floor area will then be 22.5x9.0 á 9.5 m, which in ordinary cases should be enough for at least two, sometimes perhaps three, models, for instance one design model and one "survey" or "detail" model. The whole area will of course sometimes be needed for one model, and the limited width of the building will not even make it possible to use always the scale that may be wanted.

To facilitate the construction of the models a truck gate is placed on the outer N.E. wall to make it possible to unload sand, concrete, heavier model parts etc. inside the building. The limited height of the ceiling will probably allow only smaller trucks to enter and tip its load. It will probably be advisable to move this gate closer to the S.E. corner in the second stage.

The main water system is separated from the laboratory hall and placed in a higher building at the N.W. gable end. In the first stage only half this building and half the water system is constructed. To make it possible to extend the lowlevel tank at the second stage, without disturbing the work in the laboratory hall, sheet-piling along the remaining length of the NW end of the laboratory building is suggested. The water system building will be about 7 m high and 6 m wide. In the first stage it will be 5.5 m long only, but later it will have the same length as the width of the hall building.

Dimensioning of the water system

The water system of the laboratory must be designed in relation to the highest discharge figures valid for the different plants to be studied, taken into account the normal model scales given above. The diagram on fig. 2 shows the relation between the water discharge in prototype and in model for various model scales. There is also shown the highest water flow as estimated by SEA for a number of rivers or plants that can be actual for laboratory tests. Looking upon these discharge figures it must be kept in mind that many of them are very extreme peak values, several times higher than the highest observed flood. These high floods will hardly be decisive for the design of the plant otherwise than for an emergency discharge capacity. The absolutely main part of the tests for the design of a plant will be carried out at a much lower rate of flow. Thus in most cases it would be better to choose the model scale in accordance to a "normal highest flood", which can be set as 20-50% above the highest observed. Extrapolation of for instance discharge curves can then in most cases be made rather safely for higher discharges as the discharge coefficients can be calculated from the measured parts of the curves. While for instance a model of Burfell needs a pump capacity of about 800 l/s for the design flow to be built in the scale 1:40 it will need only 200 l/s for the highest observed flow and 250-300 l/s if a "highest normal flow" is used. Corresponding values for the scale 1:50 are 450, 120 and 150-175 l/s respectively.

In the first stage not more than one model is normally supposed to be operated at a time. Then one pump unit of about 250 l/s is considered to be sufficient. In the second stage somewhat larger models can be actual, but in addition several models will be operated simultaneously. Then a pump capacity of about 500 l/s will be suitable, which means that another pump of the same size will be added to the system. The pump capacity of 250 l/s for the first stage as well as 500 l/s for the second stage have been marked on fig 2. The diagram thus shows what is possible to handle during these stages of development.

The low-level water reservoir from which the water is supplied must have a suffcient volume not only for the models, but also for filling measuring weir(s), high-head tank, feeding pipes, etc. The volume needed is smaller in the first stage especially as the water content of the return canals gives a comparatively larger contribution to the usable net volume. Only half the length of the low-level tank is therefore constructed for the first stage. Including the water volume of the return canals and excluding the water demand for operating the system (high-head tank, measuring weir, pipes, return canals etc.) a net volume of about 80 m^3 is available for floor models and glassflume. When the low-level tank and the return canal system has been extended for the second stage it will contain a total water volume of 270 m^3, including the pumppits, of which a net volume of 125-175 m^3 can be used in the models.. A float-guided indicator will be installed to show the actual water-level in the low-level tank. The indicator itself shall be placed on the model hall side of the wall, so that it is visible from any place.

Vertical pumps with submerged pump-wheel are suggested as the most suitable and reliable and not needing any filling arrangements at start. They are probably also the most economical both in purchase and in operation. Offers have been received from four manufacturers and recommendations have been given SEA about these. The discharge capacity of the pump to some degree depends upon the water level in the low-level tank. Thus a little higher discharge can be obtained if the tank is well filled. When needed it can be filled, while the system is in operation.

The water is pumped to a high-head tank, giving a constant water level 5,9 m above the floor level in the laboratory. See fig 6. To obtain this constant level the high-head tank is fitted with a system of 9 overflow flumes by which the water, which is not at the moment needed in the models, is discharged directly back to the low-level basin. During operation the level in the high-head tank will normally vary less than about 10 mm. Thereby the practically constant pressure to the connection pipes for the measuring weirs of the models is provided, which is indispensable to guarantee a stable and quick operation of the models and to allow more than one model to be operated at the same time.

The surplus water discharge pipe from the high-head tank and the outlet of the return canal in the low-level tank have both been placed in the end of the low-level tank opposite to the pump(s). Hereby it is hoped that the air, fed into the water at these points, will be released before the water reaches the pump(s). Thus a stable and undisturbed operation should be facilitated. The unsymmetrical outflow of the return canal may make it necessary to install some sort of energy dissipator or flow guider at this point to avoid other disturbances of the pump operation. As it most likely will not be needed and any measures can as easily be taken afterwards, nothing is suggested in the original design.

The high-head tank in the first stage has four separate connections for model feeding pipes and one larger connection for the glass-flume. In the later stage it is suggested that a 50 cm diameter pipe is installed from this larger connection to feed the glass-flume. This pipe should then be fitted with three extra connections in the hall to enable models to be erected in any place and direction in the hall building.

To avoid flooding of the laboratory if too much water should be fed into the system the final low-level tank for the second stage is equipped with an overflow weir. Excess water entering the tank is discharged by this to an outdoor well and out in open terrain. In the first stage there is no overflow weir and in order to avoid overfilling the water system then should preferably not be filled during operation.

To facilitate emptying of the system for cleaning etc. a special connection from the high-head tank to the discharge pipe of the overflow weir is suggested, by which the main part of the water volume can be pumped out with an ordinary pump. A temporary pipe can be fitted to the high-head tank to be used at the same occasions for the first stage. The last part of the water must in any case be removed by means of a drainage pump.

The location of the water system in the NE end of the building will make it possible to connect it also for the possible future larger laboratory hall. As this to a great part probably will be used for harbour models, it will ordinarily not need a large amount of flowing water. Thus this hall could be equipped with a supplementary water system in the NW end while the system of the first building could be used for the SE of this hall.

Measuring equipment.

The measuring equipment shall be kept at minimum from the beginning and extended in time to the need and the development of the different types of work.

The discharge measurement in the models is suggested to be made by 90° V-notch measuring weirs, i.e. Thomson weirs. These give an accurate measurement in the whole region of water discharge and are quite reliable and simple to handle. If they fulfill certain conditions of dimensions and performance the discharge coefficient is exactly defined in the literature. If these conditions are not met in all respects a calibration must be made. At the first stage two measuring weirs will be installed, one for the main floor model, with a capacity of about 250 l/s and placed under the high-head tank and one for the glass-flume, capacity

175 l/s. Because of limited space, but also to keep down the costs, the larger weir is made a little narrow to comply with the conditions for the largest discharge. The deviation from the standard curve of measurement is probably without practical signification, but it is nevertheless recommended to make a calibration at an early occasion, when the floor area can be used for making a volumetric measuring basin. That will also give a good training in accurate measurements. The measuring weir for the glass-flume is of a type calibrated at SOGREAH, Grenoble, France and it is suggested that the steel-plate with the V-notch is purchased from them. It is then presupposed that the calibrating curve shall follow the delivery. To buy the whole measuring tank from France will be unduly expensive. For the regulating of the discharge ordinary shut-off valves can be used for feeding the measuring weirs. By these a little higher discharge than needed should be fed into the basin and the final exact adjustment of the flow is provided by releasing water through the 3" valves from the bottom part of the weir. This system gives a much easier regulation than if the considerably more expensive needle type valve should be used for the feeding pipes. For measurement of the overflow head accurate point gauges shall be used. At the second stage, when another pump is installed, one more measuring weir of 250 l/s is placed under the high-head tank for the main model(s). For possible other floor models smaller movable measuring weirs are planned. They can be fed from the connections along the glass-flume pipe or directly from the high-head tank.

For water velocity measurements in the models a laboratory current meter should be procured. It is also suggested that a small-size field current meter is obtained. This can be used in some model tests, but also for simple measurements at visits to the site. For higher velocities at least two pitot tubes including glass-tube scales, should be obtained.

For water level observations in the models at least two point gauges are needed in the first stage. As only one model is supposed to be operated at a time a total of three point gauges would originally be enough, one for the measuring weir and two for the model.

Two or three stop-watches of good quality are needed for current meter or float measurements. To study the flow picture dye-liquid (preferably potassium permanganate) and suitable pipettes are needed.

A good camera with flash-light and photolamp equipment is necessary for the recording of interesting tests. For movie pictures and more advanced photographic work outside facilities should be used.

It is not suggested that any electronic equipment for measurements or recording are obtained at a first stage of the laboratory. Should such equipment be needed at some special test it is better to hire or borrow a suitable equipment and buy or manufacture only the measuring pickup device.

For marking and measurements at model construction as well as during the tests ordinary surveying instruments are needed, like levelling instrument, teodolith (not frequently) measuring-tapes etc.

Model construction equipment.

Most of the heavier work must at the first stage be made by outside facilities. For smaller works and for changes in the model during the tests a basic set of tools must however be available. A wheelbarrow, showels, buckets, trowels etc as well as a surface vibrator for sand packing and a small concrete mixer, must be available at the laboratory. Likewise a set of carpenters tools, a carpenters bench and some suitable hand machines for sawing, drilling and polishing is needed for wood, wood-fibre and perspex works. Corresponding tools and handmachines for thin steelplate work will also be necessary. Probably it will also be suitable to have a simple equipment for oxygen cutting and welding. Air compressor and tools for that should be borrowed or hired, when needed for model removal.

There is no special workshop at the laboratory in the first or second stage. It is presupposed that the room under the high-head tank should be used as a working place at the second stage. It will then probably be necessary to place some walls between the pumps and this room to insulate against the noise. Eventually a simple ceiling will also be needed below the high-head tank. At the first stage the erected part of the same room can also be used, although it then will be rather narrow and probably noisy. From the beginning it may be possible to have enough free area in the laboratory hall. Alternatively a working place can be obtained in the provisional part of the hall building.

Fittings that could be locked for keeping instruments, tools and handmachines should be made at a suitable place, perhaps along one of the walls of the water system building.

Office

An office place with telephone, desk and possibilities to make calculations, diagrams and simple drawings must be obtained. In the first stage it is supposed that a prefabricated office room is placed either in the hall or in the provisional extension part of the building. The permanent office with toilet and two smaller rooms is placed in the SE end of the extended hall. This office can be finished at any time before the main hall is finally completed. A quiet room is wanted not only for the staff of the laboratory, but also for small group discussions at visits of engineers from SEA, Landsvirkjun or other ordering firms.

Costs

The cost for the first stage of the building including the rough concrete body of the whole length but exclusive any office is estimated to 3,3 M.Isl. kronurs. The equipment for the same stage will cost about 1,15 M.Isl. kr. giving a total cost of 4,45 M.Isl. kr.

Organization and Staff

A suitable building with an equipment well balanced to meet the ordinary need in model construction and testing may be the first condition for a successful laboratory. Of quite the same importance is, however, that it has a good organization and staff.

How good the available laboratory facilities ever may be, a laboratory will not be able to assume and will not get assignments for more interesting and important studies, if the technical staff has not the necessary qualifications and experiences. On the other hand, if a laboratory can not offer interesting tasks it will not be able to obtain and to keep the qualified engineers it needs. The status and the organizational location of the laboratory is of great importance for an efficient operation of the laboratory. It also greatly affects the possibilities for the laboratory to get in touch with all the problems that naturally can be handled by it, considering both work for its own parent organization and for other organizations.

In this connection the special system now used in Iceland at water power development must be kept in mind. The governmental organization SEA carries out pre-investigations and preplanning, but when a project has advanced to the stage of final design and construction it is taken over by companies that actually build and operate hydro-power plants, such as the half governmental and half municipal power companies Landsvirkjun and Laxárvirkjun; various municipal power works and the State Electric Power Works, a section of SEA that supplies most of the electric power used in the more sparsely populated parts of the country. Of these the Landsvirkjun is by far the largest undertaking.

For the hydraulic laboratory this means that of the work in the hydro-electric field in the future normally 15-25% should be for SEA concerning general investigations and tests on the preplanning stage and 75-85% for the supply undertakings, above all Landsvirkjun, concerning tests on the design stage and for plants already in operation.

The laboratory is erected by SEA and shall stay within the management of this Authority at least for the first years. Its location in SEA´s organization chart should then preferably be direct under the chief engineer of the water power development. He is in a position to create a collaboration between the laboratory and other sections of the organization when needed. He should be capable of establishing priorities in cases when the working load of the laboratory is too heavy and to decide which problems of general or future interest need laboratory studies and are to be carried out in times of low-level employment. He can also keep a continuous contact with "Landsvirkjun" and other companies and authorities for which the laboratory can get work assignments.

It has been proposed that the Laboratory shall later on be incorporated into the organizational framework of the Building Research Institute (BRI), which according to its statutes also will have hydraulic research on the working programme. However, it is understood that this Institute does not presently carry out any hydraulic research or testing and that other subjects will be given priority over such research, at least in the immediate future. Therefore, it is definitely recommended that the laboratory should not be transferred to the BRI too soon. It is very important that the latter should have become really active in the hydraulic field before the transfer takes place. Otherwise, the laboratory may, so to say, be left "hanging in the air", without the necessary support of a parent organization it certainly will need to develop in a favourable way. For similar reasons it is not recommended that the laboratory is given an entirely independent status right from the start.

If, as a matter of policy, it is decided that the laboratory shall eventually become a part of the BRI, it is recommended that the decision as to when this takes place is postponed, until the growth and direction of evaluation of both the laboratory and the BRI can be better appraised than is possible at the present time. Until then, it should remain with the SEA.

A third alternative that may be discussed in the future is that the laboratory is taken over by the largest power supply undertaking, i.e. Landsvirkjun. This will probably look natural if water power projects would be quite dominating on the future program of the laboratory. Besides operation of completed plants Landsvirkjun is primarily concerned with design and construction of projects to be completed in the nearest future. If this scheme is adopted care must therefore be taken to ensure that the more general and long-range aspects of power development, which are of great importance to SEA in its preplanning function, are given a suitable part of the laboratory´s time and are not unduly extruded by work of immediate concern. As a rule general investigations fit in naturally between peak loads of design projects as far as the capacity of the technical staff of the laboratory is sufficiently dimensioned for the total amount of work over the year.

Since the laboratory may get a part of its job from fields outside water power developments, e.g. harbour models, testing of fishing gear, high way and bridge problems, etc., it is very important that the laboratory creates and maintains, right from the start, good liaison with firms and organizations in such potential fields. A practical and effective way to achieve this would be to establish a consultative committee attached to the laboratory, consisting of representatives from these fields as well as from the power companies. This committee should meet at least twice a year. Then a report of the work carried out since the last meeting can be given by the laboratory chief and corresponding comments on the results by the representative of the company or authority for which each investigation was carried out. In this way the results and the profits of different kinds of laboratory investigations will be immediately known and an interest of using the laboratory should be encouraged. Another standing point on the agenda of these committee meetings should be that the different representatives report which studies they want the laboratory to carry out in the near future. The timing of the different studies could then be discussed and, if possible, confirmed.

Another possible way would be to place the laboratory under a governing board of representatives from SEA and the various other firms or organizations concerned. This scheme, however, would make the laboratory unduly "top heavy" and the first method therefore appears preferable.

Whatever status of organization is chosen and which type of consulting committee may be created the key words must be co-operation and joint deliberation of all parties who are interested in a prosperous future of the laboratory.

In the first years of its operation it is also of greatest importance that the laboratory really is assigned all such tasks that are suitable for laboratory studies, in order to give the technical staff the training and the experience that is indispensable for its future achievements. This must in some cases involve a certain generosity from SEA and Landsvirkjun by giving work to the laboratory also in cases when the possible profit of the model tests in relation to the construction cost or to the possible gain in power may look somewhat uncertain. Tests of this type, which of course always must be of meaning and value for attaining a better design, can be actual for instance for Burfell and for the new Laxá station but also for the improvement of existing plants in Iceland.

The laboratory must be allowed a sufficient yearly budget for its work. Until a certain knowledge of the facilities and technical capacity of the laboratory has been spread in Iceland, no income from possible unknown contract works should be calculated into the budget.

A basis for the economical conditions on which the laboratory can undertake studies for outside bodies should be settled as early as possible. A system of a fixed price for model construction and a running account for the tests is often adopted. Then the common costs are included as a fixed overhead percentage of the salary of the staff.

Initially the full-time staff should be kept at a minimum and outside facilities used to highest possible extent. The first permanent staff is therefore suggested to be only two persons.

The chief of the laboratory shall be a civil engineer, who will be in charge of the technical planning and performance of the work as well as of the administration of the laboratory. Much of the model manufacturing and other services will have to be made by contractors or others outside the laboratory, which means that the administration and supervision part of his work will be comparatively large.

To operate the models, make minor changes and works in them during the tests, carry out measurements of routine character, etc. a skilled worksman is needed. It should be a very dexterous man with a good common sense. He must also have a distinct sensefor accuracy to make certain that works or measurements carried out by him are reliable with the smallest possible amount of supervision. It will probably not be easy to find the right man, but it is of essential importance for the laboratory chief that he gets a reliable and usable man as his only assistant at the start.

Heavier work for model construction can best be handled by contract. This includes erecting of external model walls, placing and compacting sand and gravel, concrete surface layer, etc. If possible the same contractor and the same persons should be used from time to time, especially for the placing of the final model surface. Worksmen with some experience in this very special type of work will namely provide a more accurate work in a considerably shorter time than the unexperienced and will also need less supervision and control.

Manufacture of the structural parts of the model will mainly be carried out at the workshops of State Electric Power Works - a section of SEA. The equipment of this workshop will sooner or later have to be supplemented with some tools for perspex works and a heating oven for moulding complicated model parts in the same material.

Especially for the workshop but also with regard to the contractor works it would be advantageous to have some agreement that limited work for the laboratory can be made without delay. Otherwise it may be impossible to maintain an efficient operation of the laboratory.

Outside facilities are also considered adequate for more extensive high-quality photographic work as well as for taking movie pictures of the tests. Daily photographic documentation of the tests of pure technical character should, however, be made by the ordinary laboratory staff when needed.

It is of course necessary that the laboratory is assisted by all means by its parent organization. It must be guaranteed that technicians can be temporarily placed at the laboratory to assist in the tests at periods of time-limited investigations as well as in evaluating the results of the tests etc. Service activities like typing, drafting, duplicating etc. and administrative functions as purchasing, book-keeping, etc. are also presupposed to be handled by the proper ordinary units of SEA.

The use at the laboratory of engineers and technicians from SEA's ordinary staff for shorter or longer periods will also provide a pool of persons who will have at least some experience of laboratory work. This can be of great value when the laboratory staff has to be extended or when a replacement is actual. It could also be advantageous to have an exchange of positions now and then for shorter periods, giving the laboratory engineer(s) some design experience and inversely.

It is in any case of fundamental importance that the laboratory chief and other future engineers at the laboratory get acquainted not only with the laboratory and testing technique, but also with the methods and problems of hydro power construction. The study tour of about one month to Sweden and Norway that is provided for the future laboratory chief by a United Nations fellowship will give a good start in this respect to grant a first-hand information. It should preferably be followed by another tour when the laboratory has been in operation for some months and he has a basic knowledge of some of the problems and difficulties that will arise in the work.

Many laboratories, and especially new ones, send their engineers to work on foreign laboratories and attend suitable courses that are arranged at technical universities or institutions. This will not be practical as long as there is only one engineer on the staff. The engineer, who is appointed a chief of the laboratory, has worked at the harbour laboratory in Copenhagen and thus has a basic knowledge in model experiments. What he lacks is experience in water power development and model testing in that connection. It is probably better to fill this need of futher training by frequent study tours to laboratories which are working in the water power field and to power plants under construction or in operation. In this way he will widen his knowledge of the problems and how they are solved and he will also be informed about such solutions, which have not worked so well and which are seldom described in the literature.

It would in any case be wise to send a young engineer abroad in a near future to work in a laboratory and attend a suitable course. He would then be available the day the technical staff of the laboratory has to be extended or when a possible replacement of the laboratory chief is needed.

It is essential that the technical staff of the laboratory follows the literature of their field. The engineer(s) should spend a considerable part of the time, in the first years, perhaps up to about one-third, studying technical literature and reports from different parts of the world. Some advice concerning books and technical magazines entirely or partly dealing with questions of interest to a hydraulic laboratory and not now available at the library of SEA was given.

Participation in technical organizations is another means of acquiring up-to-date information. The laboratory chief should be a member of the International Association for Hydraulic Research (secretary Professor H.J. Schoemaker, Raam 61, Delft, Netherlands), which for a comparatively low subscription offers a technical magazine, "Hydraulic Research", a semiannual list of all activitites of the world's hydraulic laboratories outside USA-Canada, congresses every second year and proceedings from those, etc. In special sections symposia or seminars are arranged. When the laboratory is well established it should apply for corporative membership in the same organization.

Construction and Operation of Hydraulic Models.

It may be of value to give a few comments on the performance of model tests. The theories and similarity laws can be found in the literature and are not treated here. It shall only by stated that it is practically always necessary to confine model-prototype similarity to a single force, which in most cases means a certain approximation. This must be remembered when the model scale is decided as well as when the results are evaluated. For models on open channel flow and water power plants the quite dominating force will be the gravity and the guiding similarity law is then Froude's law. The first condition is that the model flow should be turbulent as it in these cases is in practically all natural flow. A control that Reynolds number, based on the hydraulic radius, is larger than 2000 - which generally means that the flow is turbulent - shall therefore always be made when the model scale is decided.

When the theoretical limit is stated one has to consider the following points in thorough relation to what kind of questions the model is supposed to answer:

a) available time for model construction and tests
b) cost of model construction and probable larger rebuilding during the tests.
c) available space for the model. A sufficient part of the river upstream and downstream the plant must be included in the model to guarantee correct flow conditions within the areas where measurements and tests shall be made.
d) available water supply. As can be seen on fig 2 the water demand is increasing about 10 times when the scale is increased 2.5 times.
e) possibilities to carry out measurements with the required accuracy.
f) possibilities to manufacture model details smooth enough and to the required accuracy for the study of detailed design.

In cases when no dam is involved, e.g. for tests in a pure river model, distorted models can sometimes be used. This means that a larger vertical scale, and subsequently velocity scale, than the horizontal scale are used. Still maintaining turbulent flow conditions and still keeping the velocities high enough for accurate measurements, bed-load studies, etc. a smaller horizontal scale can then be used than would otherwise be possible. It is not advisable to use more than about 3-4 times distortion in ordinary cases, even if much higher values have very often been used. Distorted models always diverge from strict hydraulic similarity.and should only be used when economical or other strong reasons make it impossible to use an undistorted model in sufficient scale. If a distorted model is carefully calibrated against field data and proper allowances are made for the similarity limitations in the interpretation of the results, useful information can, however, be obtained from models of this type that would not otherwise be possible to obtain at a reasonable cost. Distorted models can never be used for dam or spillway studies.

The construction cost of a model is many times the main cost of the investigation. It is therefore important to use a construction method and construction materials that will make it as cheap as possible. However, the principal properties always to be maintained are:

a) it shall be an accurate replica of the prototype in all pertinent details.
b) it must retain its accuracy of construction and not deform or settle.
c) it shall be easy to change in details. This after all, is the aim of the work.
d) it shall be equipped with devices for control and measurements of flow and water levels.
e) it shall be suitable for observation of flow conditions and for measurements and photographic recording of interesting data.

Every laboratory develops its own methods of model construction, adopted to the local conditions, available equipment, comparative costs of different materials etc. To give an idea of the work procedure the method used at Swedish State Power Board's laboratory for ordinary power plant models will be described.

The external walls of a model are constructed of concrete blocks, 30x20x16.5 cm, mortar often used only for the top layer. Guide beams of wood or L-steel are erected along the model sides, at greater width also in one or more lines within the model, to be used for hanging templates, measure lines etc. The concrete blocks can be used several times.

Between these walls a filling of sand or gravel is placed to about 4 cm below the planned level of the finished model bottom. This filling is well compacted by watering and vibrating. If possible the model and the walls are so built that filling can be broughtright to the spot in trucks. Male templates, sawn from woodfibre sheets, are used.

A layer of concrete about 4 cm thick, which exactly follows the contours of the templates, is then laid by hand and forms the definitive bed of the model. This concrete shell must be laid very carfully in order to ensure that the model is watertight and exact.

When a certain surface roughness is needed this is made by patterning the surface with a special roller before the concrete has stiffened. To pattern a very rough river bed the concrete layer is sometimes placed 5-15 mm below the final level. Then a gravel and stone lining is glued to the bottom by a thin concrete layer. The later type of roughness is purposely somewhat exaggerated from the beginning so that it can be smoothed during the calibration by knocking away some of the coarser stones until the flow picture of the nature is verified.

The use of male templates has two main advantages compared to female templates, which are also much used at many laboratories. Firstly they give a continuous and watertight model surface not broken by the templates. Secondly it is possible to rebuild the model to the original appearance using the same templates at any time during the tests, when radical changes may have been done, (If they are saved the model can even be rebuilt in the future when needed).

Other component parts such as piers, gates, intakes, walls, etc., are made of concrete, light-weight concrete, steel-plate, brass, perspex, glassfibre-reinforced plastic or wood, depending on the requirements and manufacturing facilities in each particular case.

Wood is avoided as far as possible in model parts of more permanent nature because of its instability in dimensions due to water content. Some wood-fibre and plywood qualities are made waterproof in the manufacturing process and can be used without too great difficulties. The same is valid for some types of hard and dense wood. For temporary works during testing, wood is very suitable.

Plastic glass is an excellent material for models as it can be moulded to nearly any shape after heating. It makes it possible to study flow conditions both in enclosed sections and from the side or bottom of open waterways. When perspex parts are connected a very vaporous glue with some sharp ingredients is used. The same is the case when glassfibre-reinforced plastic pieces are manufactured. The workingplace for these work must therefore be well ventilated. When possible it is advantageous to use hot-air welding in stead of glueing for perspex works.

During the tests it is necessary to keep down the unavoidable waiting time for concrete stiffening. Therefore calcium chloride-solution is often used partly or totally replacing the water. Other additives may in other cases be used to retard setting to give a longer available time of workability or to give a mortar that can be cut and patched also after the setting. Such materials are gypsum and opalite which then replace a smaller or larger part of the cement in the mortar.

The reproduction of structures shall be characterized by accuracy in detail and smoothness of wetted surfaces. To maintain the smoothness it is necessary to protect steel structures by painting or in other ways.

The operation of a model may be divided into adjustment, verification, tests and preparation of reports.

The adjustment includes the minor changes that might prove necessary to insure satisfactory model performance and adjustment tests should indicate that the model is adequate for the purpose it was designed.

The verification tests involves such modifications and completions of the model that a flow picture known from field investigations can be correctly reproduced in the model. For a power plant model, these tests have often to be carried out before the dam or any canal excavation etc. is introduced. The verification should include the general flow picture at a couple or more different discharges within the region of interest of the coming tests. It is very valuable to have field velocity measurements over some cross-sections for this comparison and it is almost inevitable to have water level observations at some discharges along the river stretch to make adjustments of the surface roughness possible.

When a model totally or mainly consists of structures and artificial waterways there is of course no meaning of a calibration against known flow picture for the natural river.

In such cases it is only a question of finding the correct model roughness for different components. Also in this case field data concerning the roughness of the natural river bed in the same material will, however, be of value for the calibration.

It is of uttermost importance that the field investigations from the very beginning are carried out in such a way that the data obtained are usable and sufficient for the model tests when the plans arrive at that stage. Therefore field investigation programs should be settled also with the aim of possible future model tests and the laboratory should have the possibility of giving its advice and desires on these programs. Then costly complementary and time-consuming investigations can in many cases be avoided in direct connection to the start of the model tests.

For a model designed to investigate problems dealing with bed-load transport problems, the verification may consist of changes in bed configuration between known dates obtained by hydrographic surveys. The verification of such models presents great difficulties, mainly due to the difficulties in finding a bed material for the model giving an exact similarity in movement to the prototype. In attaining verification of such a model it is therefore often necessary to forego precise satisfication of the Froude law for the discharge, and even to forego strict linear scale ratios.

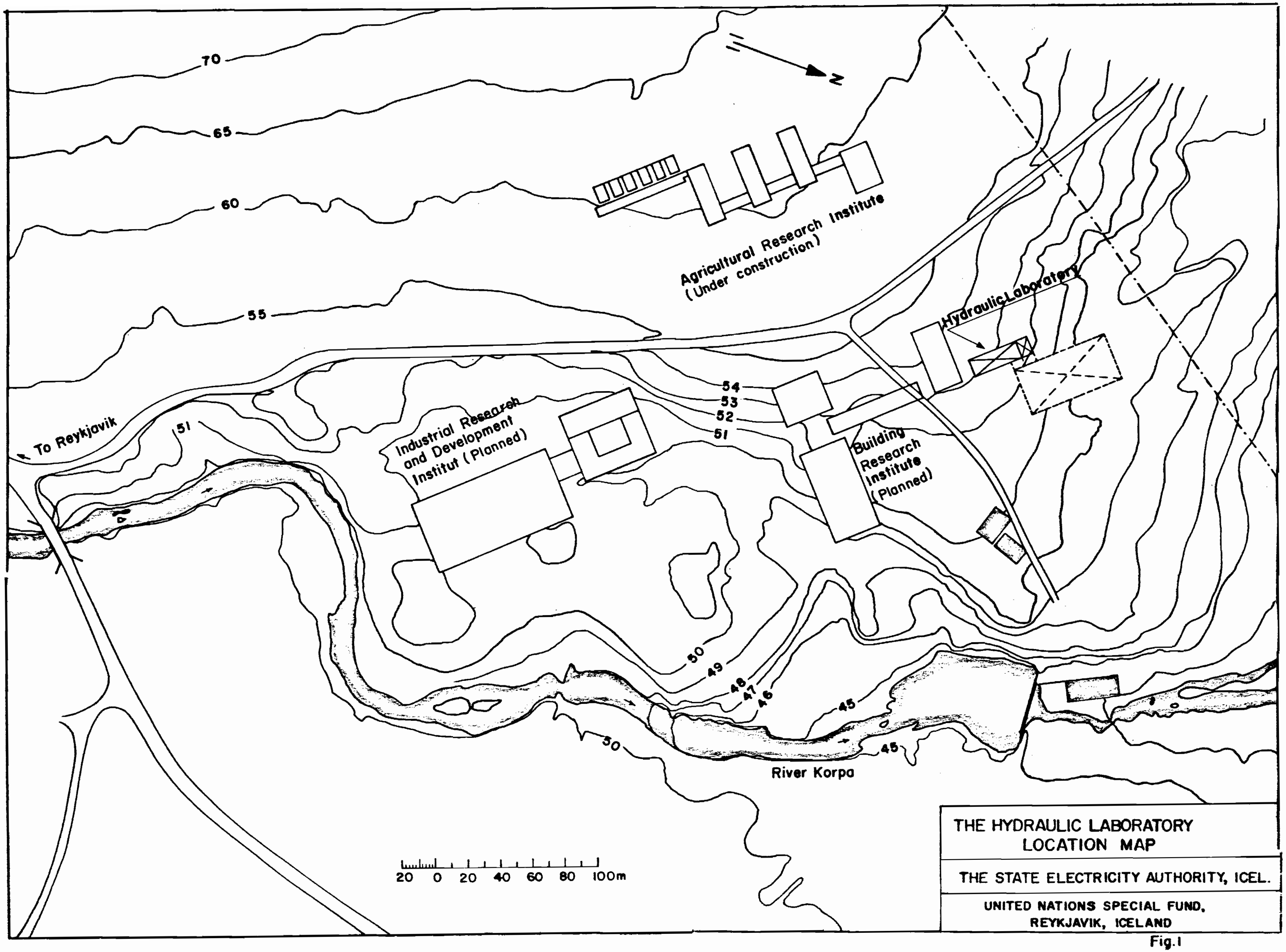
In this connection it may be mentioned that an Icelandic type of rock - Perlit, somewhat related to mica - after grinding to different grain size could be a very useful material for bed-load tests. The density of this material can be changed by heating,after what is said within a rather large region. For bed-load and similar investigations a fine and light material is desired and many different and rather expensive methods and materials are used to obtain that. Could this material be used to manufacture a reasonable variety of grain-size and density it could certainly be sold to a great many laboratories all over the world. It would therefore be worth while to take up an investigation of these possibilities at the laboratory.

Planning and conducting of the tests must be made with great care to ensure reliable results in shortest possible time. A systematical test plan with intermediate goals allowing a current analysis and recording of the results is needed. Especially when different alternatives are tested and compared it is of greatest importance that a test method giving an evaluation of the results on one and the same basis and as little subjective as possible is adopted.

During the tests there must be close liaison between the laboratory and the design engineers. All practical plans that can be applied should be discussed and the selection of those to be tested shall be made in co-operation, thus avoiding that much work is wasted on plans that are impractical for some reasons. The sequence in which different parts of a plant should be studied should also be decided in co-operation so that the laboratory and the designer and constructor can work hand in hand in the best concord.

It should be observed that the additional cost of a test is rather insignificant when the model once is constructed and verified. Therefore the model should be used to test all the problems or components that are of interest although the model perhaps from the very beginning was constructed only to solve a certain problem.

Reports constitute in most cases the chief instrument whereby the benefits of the model study are transmitted to the designer or sponsor. They must be complete, accurate and timely and should be characterized by unity, coherence and emphasis.

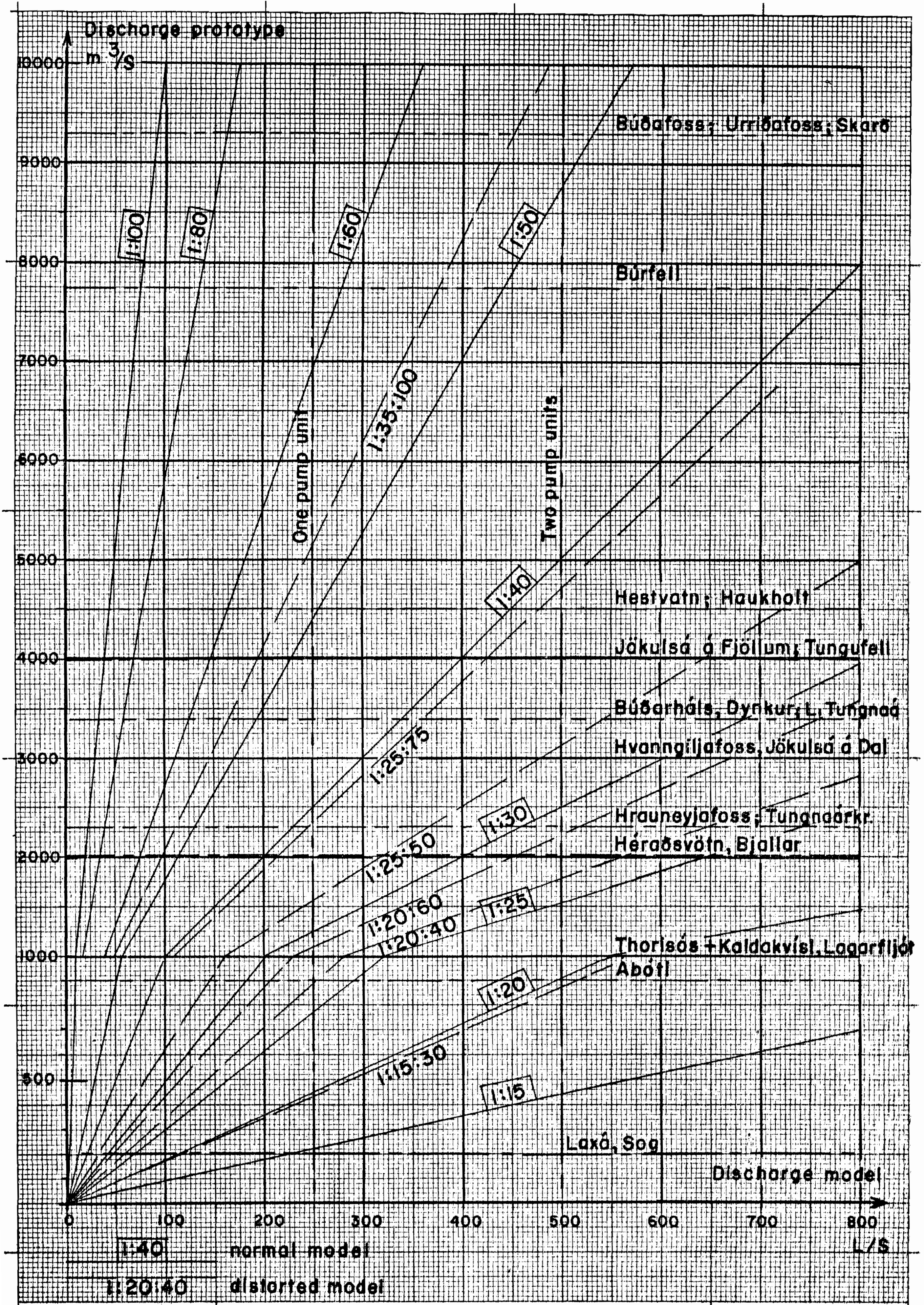


THE HYDRAULIC LABORATORY
LOCATION MAP

THE STATE ELECTRICITY AUTHORITY, ICEL.

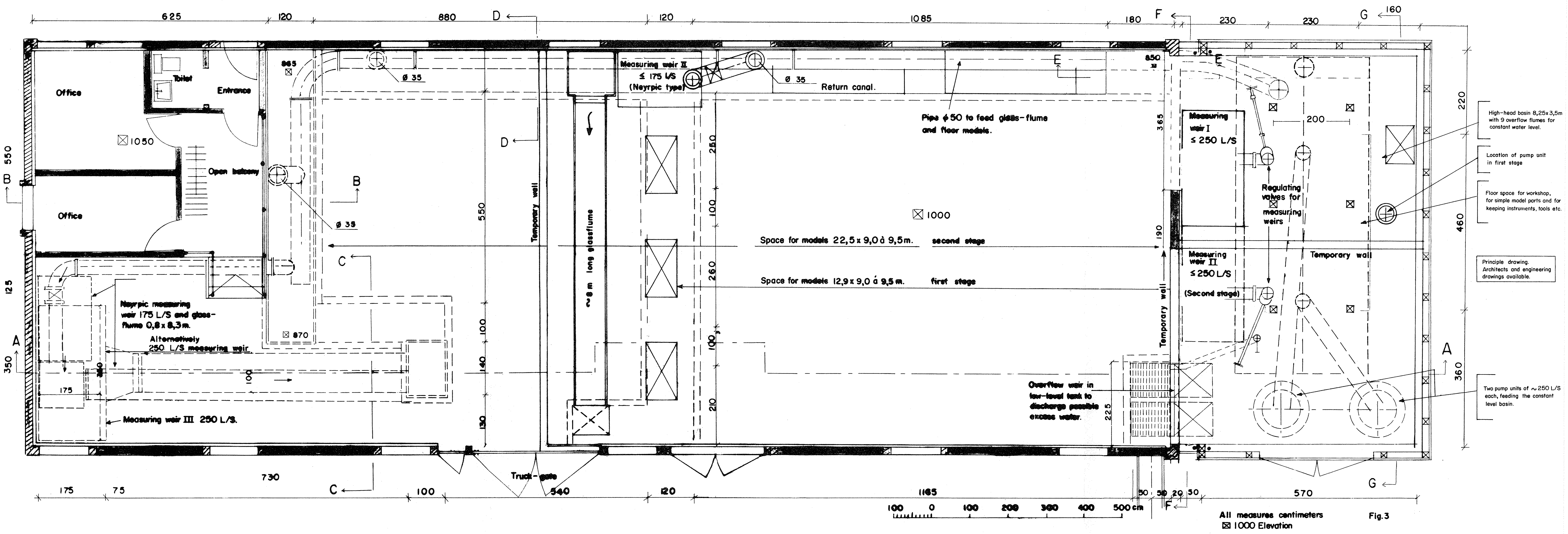
UNITED NATIONS SPECIAL FUND,
REYKJAVIK, ICELAND

Fig.1



THE HYDRAULIC LABORATORY.	STATE
MODEL–PROTOTYPE RELATIONS OF DISCHARGE.	ELECTRICITY
DESIGN FLOW FIGURES ACCORDING TO SEA.	AUTHORITY
UNITED NATIONS SPECIAL FUND, ICELAND	REYKJAVÍK

Fig. 2



High-head basin 8,25 x 3,5 m with 9 overflow flumes for constant water level.

Location of pump unit in first stage

Floor space for workshop, for simple model parts and for keeping instruments, tools etc.

Principle drawing.
Architects and engineering drawings available.

Two pump units of ~ 250 L/S each, feeding the constant level basin.

All measures centimeters
⊠ 1000 Elevation

Fig. 3

THE HYDRAULIC LABORATORY
LABORATORY BUILDING

THE STATE ELECTRICITY AUTHORITY, ICEL.

UNITED NATIONS SPECIAL FUND,
REYKJAVIK, ICELAND

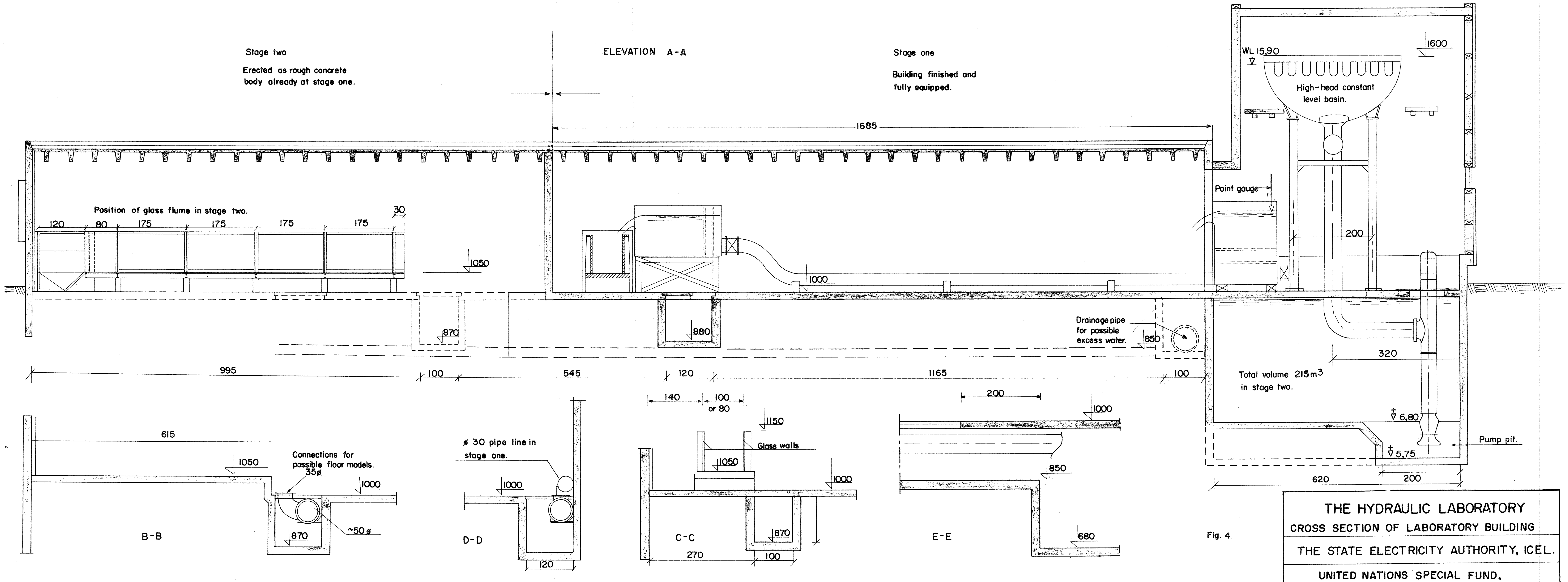
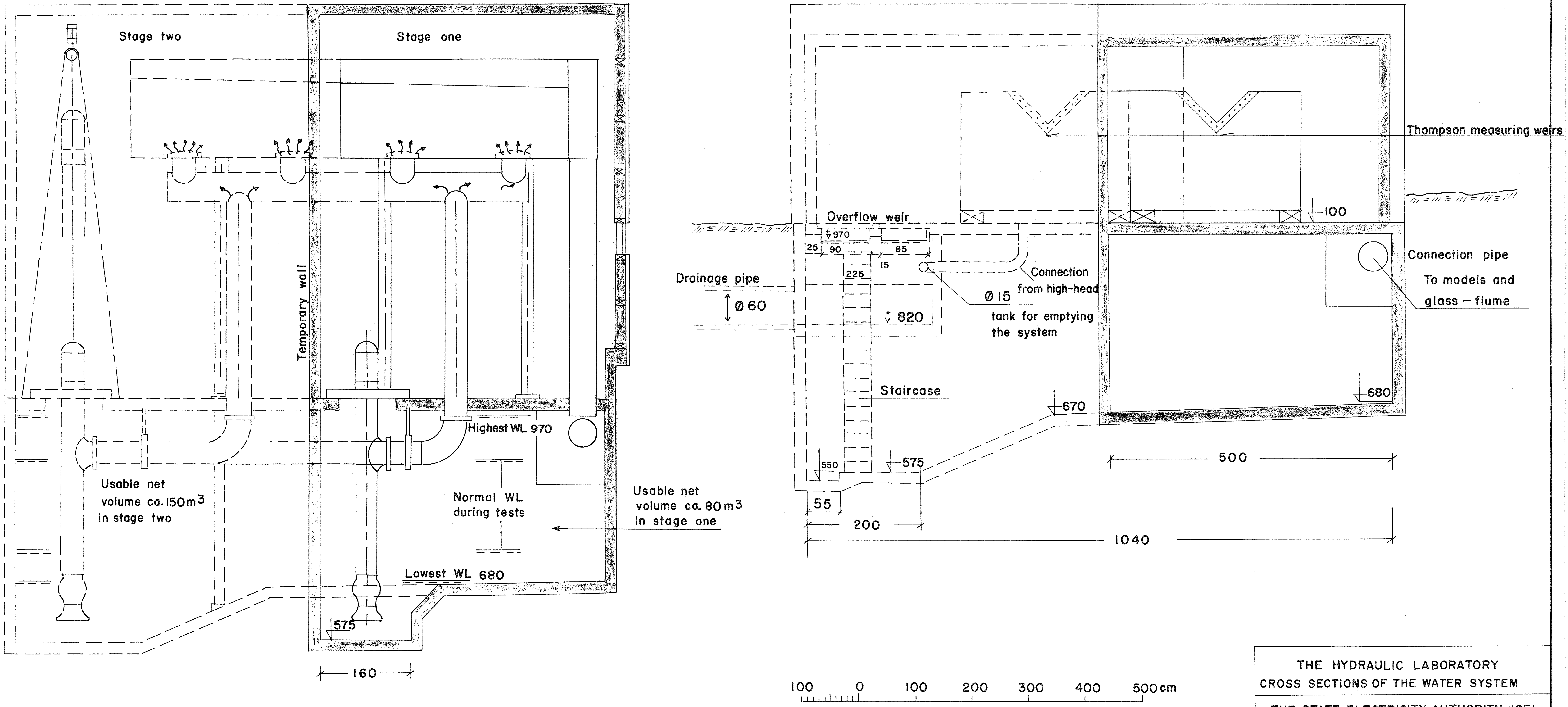


Fig. 4.

THE HYDRAULIC LABORATORY
CROSS SECTION OF LABORATORY BUILDING
THE STATE ELECTRICITY AUTHORITY, ICEL.
UNITED NATIONS SPECIAL FUND,
REYKJAVIK, ICELAND



THE HYDRAULIC LABORATORY
CROSS SECTIONS OF THE WATER SYSTEM

THE STATE ELECTRICITY AUTHORITY, ICEL.

UNITED NATIONS SPECIAL FUND,
REYKJAVIK, ICELAND

Fig. 5

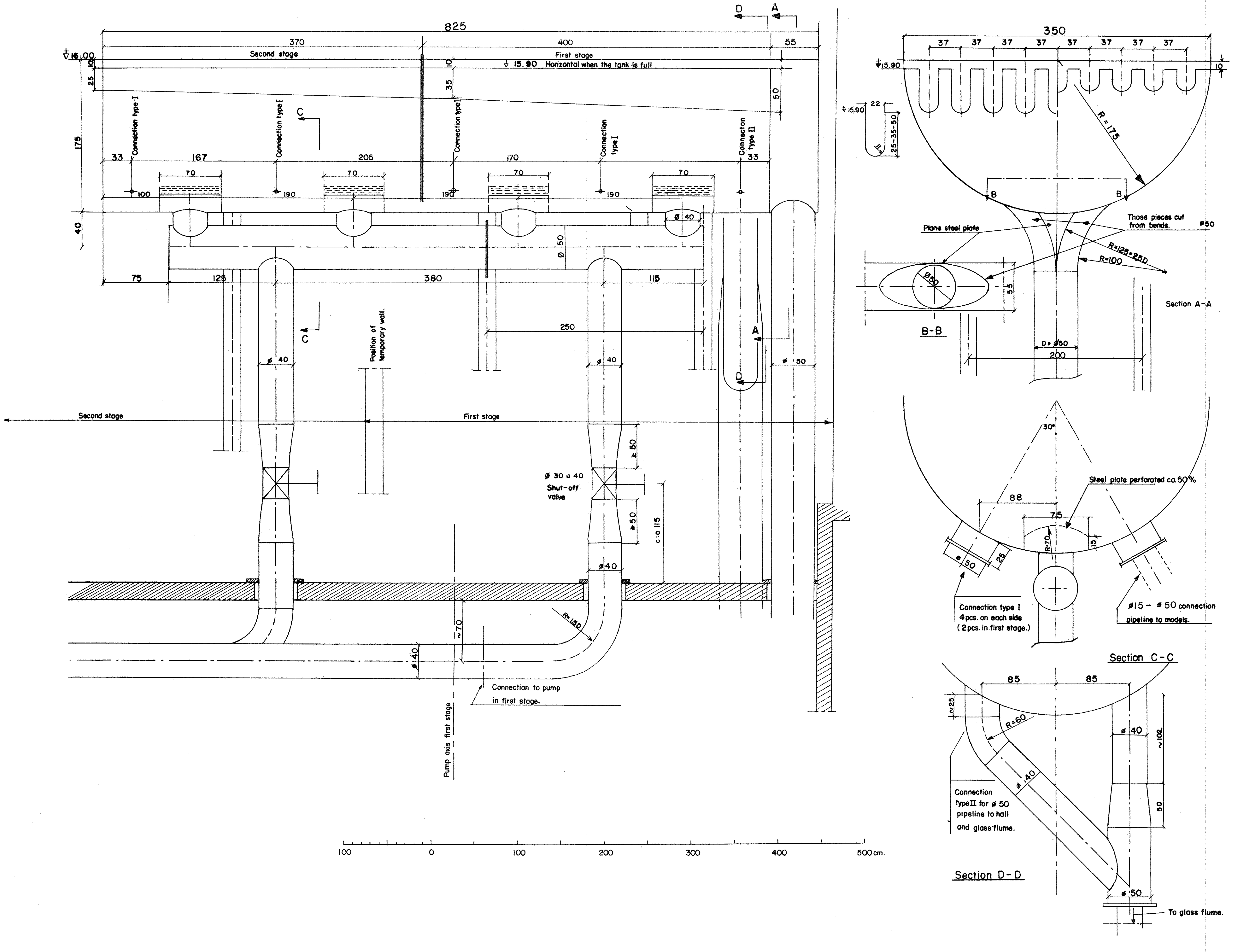


Fig. 6

THE HYDRAULIC LABORATORY
THE HIGH-HEAD TANK

THE STATE ELECTRICITY AUTHORITY, ICEL.

UNITED NATIONS SPECIAL FUND,
REYKJAVIK, ICELAND