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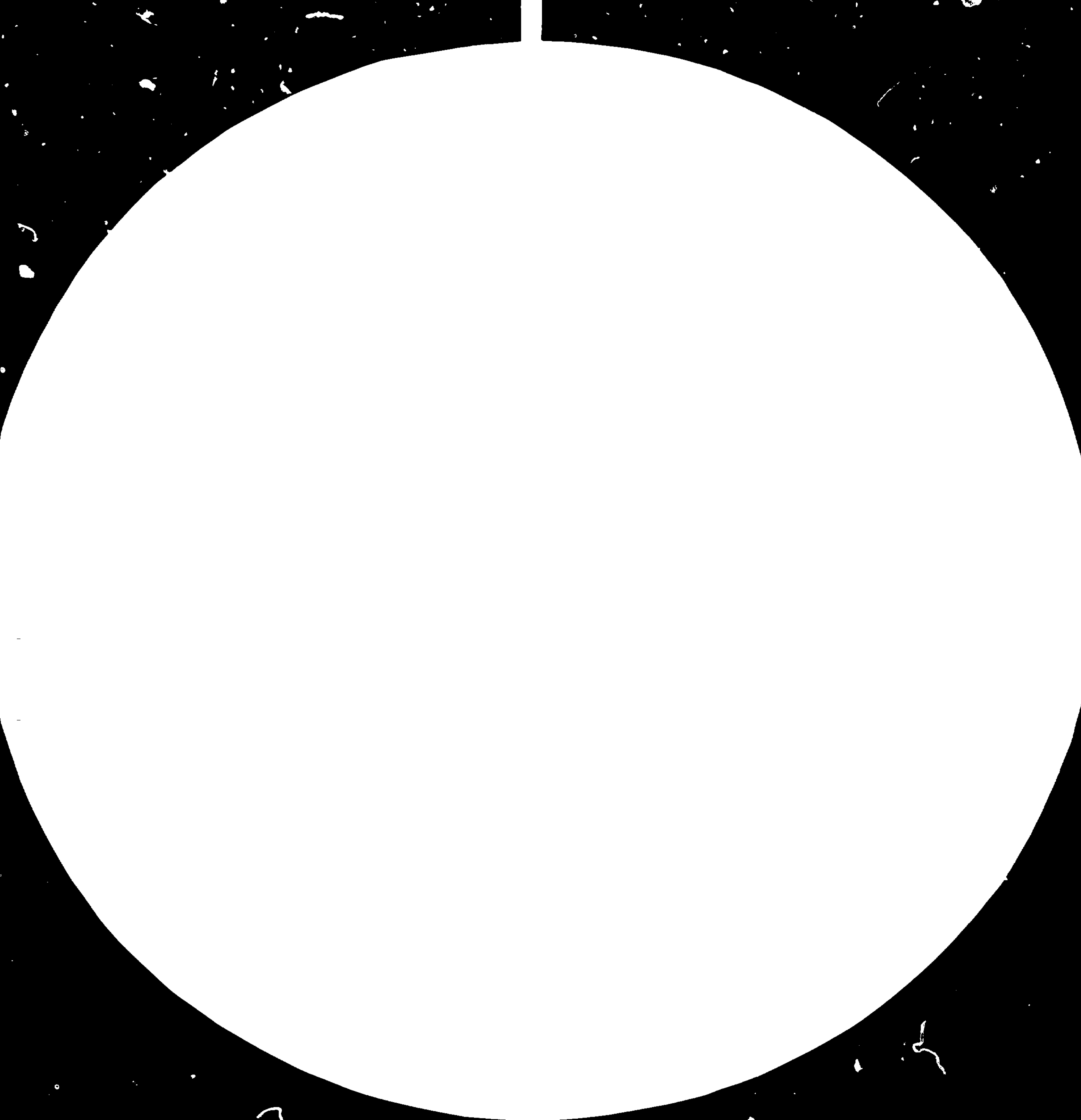

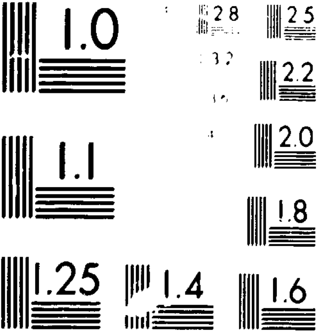
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Distr.
LIMITED

ID/WG.305/40
14 May 1980

ENGLISH

United Nations Industrial Development Organization

Seminar-Workshop on the Exchange of
Experiences and Technology Transfer
on Mini Hydro Electric Generation Units

Kathmandu, Nepal, 10-14 September 1979

HYDROELECTRIC POWER TECHNOLOGY IN NORWAY, WITH SPECIAL EMPHASIS ON SMALL SCALE POWER PLANTS*

by

Norwegian Water Resources and Electricity Board (NVE)
Oslo
Norway

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INTRODUCTION

by O. Gunnes, M.Sc. in Civil Engineering.
Director of The Water Power Research Department, NVE.

The history of Norwegian hydro-power in the meaning of electricity generation, began one hundred years ago. The first very small units were established for supplying electric light, and were built and utilized by private enterprises.

In the year of 1885 the first power-plant with the purpose of selling electric power, was established.

Although there were few power-plants constructed up to the turn of the century, this period has a particular place in the Norwegian electrification history. The construction of hydro-power plants during this period was mainly undertaken by mining- og papermill companies, and formed an important origin for the further development of industry in the country. Beside supplying electricity to the factories, the surrounding communities were provided with electric light.

The first electricity companies organized and owned by municipalities, grew up from around 1900. Their main purpose was domestic supply.

From 1907 up to about 1920, several big hydro power projects were constructed and put into operation. All of them with the purpose of supplying electric power to electrometallurgical and electrochemical industries established close to the power plants.

During the same period a large number of development carried out by municipalities also took place.

It is clear that around 1920 the basis for the industrial development of the country was founded, and it is obvious that water-power had a central place in that picture.

During the period from 1920 up to 1940 (the beginning of the second world war), a large number of power-plants were constructed. All of these were basically operating on limited local grids.

The table below shows the statistics from 1944 with all together 2,009 water-power stations:

Norwegian water-power stations per. January 1st, 1944:

Generating capacity	Number	Sum generating capacity
0 - 100 kW	1,463	37.1 MW
100 - 500 kW	270	93.4 MW
500 - 1,000 kW	85	57.8 MW
1,000 - 5,000 kW	116	237.7 MW
5,000 - 10,000 kW	30	216.6 MW
10,000 - 20,000 kW	19	250.3 MW
20,000 - 50,000 kW	16	472.8 MW
50,000 - kW	10	935.3 MW
Sum	2,009	2,301 MW

We recognize that a number of 1,463 stations, or 73 % of the total number, had a generating capacity of less than 100 kW. However, the total output from these 1,463 stations was only 1.6 % of the total generating capacity.

After 1945 a boom regarding development of large plants started. A countrywide development of a high voltage transmission line system began, and successively the small local powerstations became too expensive and unreliable to keep in operation compared to the safe and abundant supply from the new big system. Most of the small power-stations were therefore closed, or they were included in the development of bigger schemes.

In the next table the statistics over water-power stations per. January 1st, 1979 are shown:

Norwegian water-power stations per. January 1st, 1979:

Generating capacity	Number	Sum generating capacity
0 - 1 MW	ca. 250	ca. 75 MW
1 - 10 MW	195	736 MW
10 - 20 MW	57	898 MW
20 - 50 MW	85	2,717 MW
50 - 100 MW	40	2,942 MW
100 - MW	52	10,171 MW
Sum	679	17,541 MW

It is seen that out of 1,818 stations with a capacity less than 1 MW in 1944, only 250 are still in separate operation.

Up to 1976 little attention has been paid to the small units of hydro-power potentials, mainly because of an abundant supply of cheap electricity. However, as development of new large schemes are facing a growing resistance from groups of people and various organizations, it has become more and more difficult to find new schemes for providing sufficient electricity. Therefore the small potentials are again in focus, and at present a countrywide investigation is going on for registration of the small hydro-power potentials. Within 1979 a registration of about 500 power-plants, ranging between 300 kW and 10,000 kW will be completed. The total energy output from these plants is expected to amount to approximately 5 TWh mean annual production, which is 6 % of the hydro-electric potential already developed in the country.

A number of the small old stations, which have been closed some 20-30 years ago, are included in this investigation. However, a great number of the very smallest, potentials less than 300 kW, will be investigated and registered later on.

The cost limit for economic feasible power-plants is assessed to an investment of 0.40 US$ per. kWh annual production (cost level 1979, interest 7 % p.a., economic life 40 years).

A classification in strict terms of small stations versus medium and big stations, is rather difficult. There seems to be only one logical term limitation; the capacity of standardized units which are manufactured today. This limit is approximately 10 MW. There is no lower limit.

To make as many as possible of the small power stations economically feasible, is it necessary to emphasise the importance of standardized equipment and economic design, construction and operation. The large number of stations which may be built, make a comprehensive standardization possible.

In 1973, the Norwegian electricity supply system was organized in 535 separate units. Of these units 337 were responsible for distribution of electric power to domestic consumers. Most of them were owned by the municipalities or by the counties. Among these units most of the small hydro-power development is expected to take place.

Almost 30 % of the power production comes from stations owned by the State Power System, which is a directorate under the Norwegian Water Resources and Electricity Board (NVE). This directorate is planning, designing, constructing and operating their own system, and possesses all necessary functions for these purposes. The State Power System is normally engaged with the biggest power-plants and transmission lines, and is therefore of less interest regarding the small power-plants.

The small sources of hydro-power, should be considered as any other source of available energy. At which time the various small sources are to be developed, will depend on the development costs compared to the costs of other available energy sources.

The development costs for small hydro-power plants in Norway proves to range from about 0.20 US $ per kWh, up to the limit of economic feasible power, and even higher. This indicates that the development of the cheapest resources ought to be started as soon as possible, while the more expensive ones probably should be developed within 20 years or so.

However, one factor should be taken into account in this regard; the small plants are often located nearer the consumers than the big plants are, and should therefore be given some economic credits because of reduced transmission costs and losses.

The official policy in Norwegian electricity supply is, that the excisting electricity institutions shall operate their own existing power system as they do it now, either directly or in joint co-operation with other electricity companies. Furthermore, they ought to have responsibility for the development of the smaller water-power sources which are spread around the country. However, to promote a more efficient electricity supply, the policy is to work for a concentration of the smallest units in companies comprising a county, or if certain circumstances make this difficult, 2-4 units in a county.

For organizing the development of smaller water-power schemes, two models seem interesting.

- The county (or another bigger unit) is responsible for planning, financing and construction, and is also the owner of the plant. The local municipality is given the responsibility for running and maintenance of the technical equipment.

- The local municipality is the owner, and has the responsibility for running the plant, but has to join the bigger system through a power production co-operation.

Both models aim, as far as possible, to maintain a decentralized electricity organization system with units big enough to promote a strong economy and an efficient utilization of the energy resources.

As the small water-power plants are regarded as an integrated part of the total system, any special financial arrangement has not been proposed. The possibility of giving some economic support for promoting planning, excepted.

This will of course impede the small municipality units in developing their own plants, because they usually have the possibility of buying much cheaper electricity from the gross suppliers, for example the county. (The electricity price in Norway has been kept considerably lower than the cost of developing new power, caused by the great number of old depreciated water-power plants). The financial policy makes it necessary with units big enough to manage this financial problem.

From the outline above, it should be quite clear that the electricity from the small power-plants ordinarily will be intermixed with the power floating in the main grid. Only in particular cases, as for example in especially remote areas of the country, the power will be produced for a limited grid. It also seems to be of limited importance to keep the small power-plants as a reserve in case some parts of the main system should have a breakdown. This will require more expensive equipment, and is consequently a question of economy.

The articles in this paper intend to give an outline of modern Norwegian technology regarding design and development of small scale hydroelectric powerplants.

SMALL SCALE HYDRO POWER-PLANTS

- Development of local industry
- Controll and maintenance of the hydraulic equipment in hydro power-plants
- Small sized hydro power turbines
- Technical evolution and standardizing.

by W. Mjølner, Director and general manager

DEVELOPMENT OF LOCAL INDUSTRY

Hydro power development may entail significant contribution to local industry, primarily the civil works. However, through cooperation between contractor and local industry, production of small hydro turbines may also contribute to increased local activities.

The assumptions are as follows:

There must be a basis for development of a mechanical workshop milieu. Primarily, the work will consist of plate construction and welding operations, producing relatively uncomplicated parts as draft tubes, draft tube gates, fundament casings, supply machinery like trash racks and simplified gate constructions.

The material used in these constructions will be mild steel which is easy to weld. For low head plants, the production will also comprise penstocks, expansion boxes, manholes and turbine casings.

Today, most turbine parts consist of welded constructions. Consequently, turbine covers, guide vanes, guide vane arms and chains can be produced locally. However, demands for quality are more stringent when it comes to production of the vital turbine parts, especially for turbines which are intended for high head plants. This will often require use of non-destructive material inspection, i.e. liquid penetrant inspection, magnetic particle inspection, ultrasonic and X-ray inspection, and, of course, heat treatment facilities.

Further, it would require a machine workshop equipped with the most common machine tools in order to machine flanges, drill holes etc. Local production of turbine cylinders, distributors etc. requires precision tools in order to obtain satisfactory quality.

Assembley and fitting together of the products require a mounting shop, in which locally produced parts and parts produced by the contractor are fitted together, adjusted and exposed to pressure and function tests.

The possibility of training personnel for the various spheres will represent an important precondition. Training, primarily at the contractor's, is assumed to be both expedient and necessary. On the other hand, the contractor will need to have guarantees that delivery dates and quality requirements are met. From a contractor's point of view, this will often represent one of the main elements of risks. The problem may be solved if the customer is willing to share the risks to some extent, in order to promote local production.

Alternatives for development of local industry can be described as follows:

- Contractor establishes a subsidiary in the topic area.
- Contractor cooperates with an existing company, which will act as sub-contractor for specified products and services, or based on a joint-venture agreement.
- Contractor enters into licence agreement with an existing company.

It would take too long to describe these alternatives in detail, but it is obvious that exploitation of hydro power, through rational cooperation between customer, local authorities and contractor, would represent significant opportunities for transfer of new technologies and increased employment in the area involved.

CONTROL AND MAINTENANCE OF THE HYDRAULIC EQUIPMENT IN HYDRO POWER STATIONS

1. INTRODUCTION

The daily or routine maintenance of the equipment is usually described in the supplier's operating and maintenance instructions.

This will, however, in many cases make an insufficient basis for the long term preventive maintenance, which is due to many circumstances but espesially the fact that the operating conditions vary considerably from place to place. The purity of the water, physically (foreign material like sand and other solid substances) as well as chemically (degree of acidity, contents of chemical pollution, etc.) will be of vital importance when deciding how to plan the maintenance of the equipment.

The object of the maintenance will be in two parts:

- Main object is continuity of operation, which means that the plant will not be exposed to unintentional standstill because of breakages
- Water economy, i.e. optimal utilization of the energy supplied to the turbine, is of vital importance where water resources is a minimum factor. By measuring of old plants, it has been proved that the efficiency of the turbine deteriorates with time, the degree of deterioration depending upon mode of operation, construction and amount of maintenance performed.

Some of the most important factors reducing continuity of operation and efficiency are highlighted below.

2. CORROSION

Firstly, corrosion will lead to perforation of the material, thereby causing leakages. Outside the station, this will not cause immediate major damages. Inside the plant, however, even small leakages may cause major damages by exposing the electric control equipment and maybe the generator to direct water spurt. In cases when the operating mechanism of the shut-off valve is operated by water pressure from the penstock, special attention must be drawn to the pressure tubes in these control systems and also to the bypass line. When new, these tubes are dimensioned in the same way as the main penstock, but because of small diameter, the material is considerably thinner, and the interior corrosion develops just as quickly here as in the main penstock, provided approximate equal material quality. Usually, such leakages will be discovered at an early stage. Real danger will arise when the corrosion has been permitted to develop so evenly and to such an extent that the remaining material will not have the necessary strength. By increase of pressure during load rejection, this may result in sudden fracture, which primarily causes large water leakage and secondarily may entail unability to stop the machine when the water for the operating mechanism fails.

Our experience is that most of the damages relate from corrosion on vital bracket joints, which may not be so easy to inspect, but which may result in considerable damages. For instance, it frequently happens that stay and screw joints in the trash racks corrode, so that part of the trash rack are transported into the turbine.

Hydro power plants have an extraordinarily long span of life, and therefore, the problems in this field will undoubtedly increase considerably, also because of the fact that during the later years the materials have been utilized to a much higher extent than before. Special attention is required with regard to the gate constructions, which are of vital importance to the continuity of operation and which are often inaccessible for inspection and maintenance.

Moreover, valves, control devices, air inlet valves, etc. which are seldom in use, will be affected, because they may corrode so much that they cannot be operated. In many cases, it will consequently be impossible to make these components function when necessary, resulting in considerable interruptions of operation at the plant. This can be illustrated as follows: In many cases the penstock is provided with an emergency butterfly valve and an air inlet valve. If the air inlet valve has rusted in, draining of the penstock will result in complete compression.

Corrosion fatigue is another frequent phenomenon. This especially concerns the part of the turbine shaft in horizontal turbines exposed to water, i.e. in sharp transitions as keyways etc.

The stress level in such components is set low, and theoretically it is unlikely that fatigue will occur. But it is also known that when an horizontal shaft is exposed to corrosive surroundings, the danger of fatigue fracture will increase. This is among other things due to the fact that the surface develops corrosive holes where the stress level increases compared to the conditions existing when the shaft surface was not corroded.

As regards reduction of efficiency, the corrosion knots that normally develop in the water exposed areas of a hydro power plant where the material is of ordinary mild steel, will be of considerable importance. This applies to the total water way, inlet gates, trash rack, penstock, shut off valve, turbine and outlet. In Francis turbines, the spiral casing and stayring, distributor and runner are often very much corroded. To some extent, stainless material is being used in runner, guide vanes and the interior surfaces of the turbine cover. This increases the initial cost, but will prove profitable in the long run because of considerable reduction of maintenance costs as well as maintaining high efficiency.

3. EROSION

Erosion may often represent danger to the continuity of operation equalling those arising from corrosion. Considerable damages are often caused by sand in the water. In high-head plants with high water velocity erosion attacks may often be considerable. However, low head plants are also vulnerable. In horizontal Francis turbines we have seen that the shaft sealing bracket has eroded to such an extent that it broke and the plant was inundated. Usually, it will, however, start with a minor leakage. Erosion may result in vital bracket joints being destructed.

Erosion in the turbine distributor will highly affect the continuity of operation. Major leakage in the distributor because of abrasion may result in difficulties with regard to reducing the revolutions per minute sufficiently when the distributor is shut off, which in turn result in problems with regard to parallelling into the grid.

Leakage in the distributor may, in extreme cases, result in problems when operating of the shut-off valve is needed. If the plant is equipped with sluice valve, this will prove difficult to open, since the bypass valve will be unable to provide sufficient water on the downstream side of the main valve in order to obtain the correct pressure there.

Thereby, the friction power of the sluice will outstrengthen the the power of the servomotor. This will not apply to the spherical valves, but automatic operation is dependent upon a certain amount of pressure downstream the valve in order to make the main control valve function. Slide valves usually have oil hydraulics for opening and drop weight for closing, making the problems less prominent, but major leakage in the distributor may cause difficulties.

4. CAVITATION

As will be known, cavitation occurs in cases when, locally in the turbine, the water velocity is so high that the pressure decreases below the steam pressure, developing steam bubbles which in turn are condensed when they reach a zone with higher pressure. In this zone there will be fatigue of material, and the material will be destructed.

Cavitation damages which are allowed to develop will result in interruptions of operation. This especially concern runner and draft tube. There are examples on how Francis runners have had so large cavitation and corrosion damages that the runner ring loosened during operation, resulting in major damages. Our ordinary experience is, however, that cavitation damages may develop to a large extent before resulting in real major attenuation of continuity of operation.

It should also be noticed that there are many reasons for cavitation. The hydraulic design of the machine is of vital importance, but there are examples illustrating that local corrosion and erosion damages have changed the geometrical shape of the runner blades, which thereafter have been exposed to cavitation damages.

5. MECHANICAL ABRASION

Most parts having a relative movement are exposed to mechanical abrasion. This especially concerns the bearings, and it is important to use correct type of oil. There are many reasons for bearing failure. It is frequently caused by foreign particles and dirt in the bearings. It may be discussed how often the bearings ought to be dismantled and cleaned, but we have learned that at many plants this is done too seldom. Depending upon conditions of operation and type of bearing, we usually recommend dismantling and cleaning at 4 year intervalls. It is very common only to renew the oil, which of course must be done, but a great amount of the bearing failures that we have seen could have been avoided through dismantling and cleaning at an earlier stage, because the lubricating channels which are necessary in order to obtain sufficient oil film in the slide bearings, are slowly being clogged by dirt. Inevitably this results in breaking of the film, and the bearing will have a very quick rise of temperature. It is, however, a must that thorough cleanliness is shown while cleaning the bearings. For instance, traverse cranes are often used, resulting in particles sifting down on the bearing during assembley.

It is of vital importance that the cooling water system for bearings with water cooling is always intact. When cooling pipes are used, these are seldom clogged because the water is filtered (percolated), but in old bearings there are frequently water leakages in the cooling pipes, resulting in bearing failure.

For instance, when the penstock is equipped with an emergency closing butterfly valve, the result of an air inlet valve failure because of corrosion when draining the penstock will result in breakdown of the penstock.

This can be illustrated as follows: Draining of the penstock will require use of an emergency closing butterfly valve as well as the air inlet valve If the air inlet valve cannot move because of corrosion, this will result of complete compression of the penstock.

SMALL SIZED HYDRO POWER TURBINES
TECHNICAL EVOLUTION AND STANDARDIZING

Most suppliers of hydro turbines were in fact established last century. To begin with, they produced small-sized turbines, which gradually developed into the large units produced today for outputs up to several hundred MW per unit. This increase of size was primarily a result of a growing demand for low cost electricity to consumers. This is made possible through the large water power plants. Therefore, the demand for small-sized units has been minimal during the last 20 years, and consequently, the technical evolution in this field stagnated.

However, shortage of energy has now made the small-sized units an interesting alternative, provided that they are able to compete successfully with other forms of energy, such as oil, coal, nuclear power etc. Redevelopment has, however, been necessary. It is neither sufficient nor possible just to down-scale the dimensions of a large turbine. This would result in high-priced and inappropriate solutions. By analysing the cost-affecting factors, it has been found necessary to:

- Reconsider mode of operation
- Simplify and standardize the design
- Use standardized components

The most common types of turbines are the Francis, Pelton, Kaplan and tubular turbines. The Kaplan turbine and the tubular turbine are suitable for low heads and heavy discharge, while the Pelton turbine is used for high heads and relatively modest discharge. The area inbetween is covered by the Francis alternatives. The abovementioned types are all well suited for simplified mode of operation as described below:

Constant water flow/output through turbine

In cases of parallell operation of power stations where other units keep a constant frequency, the turbine can be designed with fixed guiding apparatus, and also fixed runner vanes on the Kaplan and tubular version. The unit is regulated only by the main valve in front of the turbine. This is also used for parallelling to the grid. After parallelling, the valve will be in open position. It is impossible to operate on partial load. However, it is to some extent possible to regulate a variable waterflow if the power plant is provided with an intake reservoir of adequate capacity and the pond level is allowed to vary between certain limits. The turbine is operated for a certain period of time on full-load, while the water level falls until it reaches a determined level, at which time the machine will stop. When the maximum level is resumed, the machine will start. This cyclus can be automized. Thus you will save the costs for adjustable guide apparatus, frequency governor and supplementary flywheel effect. Compared to a conventional turbine, the savings will represent approximately 25-30%, depending on the type of turbine involved.

Variable discharge/output through turbine

If it is required to adjust the water flow through the turbine, it must be equipped with adjustable guiding apparatus, which is controlled by a simple oil-hydraulic unit. This is suitable for control of intake reservoir and remote load control. It will reduce the costs for frequency governor as well as supplementary flywheel effect. In some cases it will also eliminate the costs of safety valve and surge chamber.

This presupposes employment within a large grid system. Further, it must be ascertained that there will not be an unacceptable pressure rise as a result of the fact that this simplification (low flywheel effect) in most cases will entail runaway speed of the turbine at load rejection. When this alternative is suitable, it will represent a cost reduction of 10-20% compared to a conventional turbine.

Variable power take-off from generator

When operating either periodically or continually on a separate network, the stability of the system must be considered. As a minimum the turbine will have to be equipped with a frequency governor of electro-hydraulic or mechanical-hydraulic construction. Considering the amount of maintenance involved, the mechanical-hydraulic type will often be preferred, but this is also very much dependent upon the competence level of the staff responsible for operation and maintenance of the equipment.

Usually, it is necessary to have more supplementary flywheel effect than what is built in by natural means in generator and turbine runner. Pelton turbines will normally require water jet deflector. Francis turbines will sometimes require pressure relief valve. Kaplan/tubular turbines will require adjustable runner blades and guide vanes in order to obtain maximum efficiency for a large load range and capability to perform with stability on a separate net.

The above three alternatives have in common the requirement for minimum inspection and maintenance. Consequently, the turbines are equipped with control and safety devices resulting in automatic stop in the event of the more ordinary failures. However, the equipment is not as comprehensive as it will have to be for a large unit where failure consequences will be much more calamitous. (Such units are therefore equipped with a much larger number of control devices). Further, the units are normally equipped only for manual start, because the necessary ancillary equipment for the automatic start procedure will represent a considerable increase in price.

Simplifying and standardizing of design/construction

In order to minimize costs it has been necessary to simplify the design as much as technically possible without reducing the demands for safety of operation and maximum output. It was particularily necessary to use welded details instead of cast details. Today's welding technology and range of material ttypes have strongly contributed to reducing the production costs. It is essential that choice of material quality is made from a maintenance point of view. On a long term basis, it may prove extremely profitable to use stainless steel in some of the vulnerable elements of the construction, even if this will increase the initial costs. Most of the small-sized turbines are designed with horizontal shaft. Today, we do not have turbine shaft or bearing for these turbines, see figure 1 and 2.

The runner is mounted directly on to the generator shaft by means of a shrinkage joint by the oil pressure method. This simplifies the dismantling and erection, shaft keyways are avoided, thereby reducing the danger of fatigue fractures in the shaft. However, the axial forces of the turbine will have to be absorbed by one of the generator bearings. On the other hand, the unit will have only two bearings. Further, the shaft sealing box is designed so that it does not touch the shaft. Previous grease-lubricated bearings and bushings are today replaced by self-lubricated bushings. If additional flywheel effect is required, a flywheel is mounted on the generator shaft on the opposite side of the generator.

It is further necessary to standardize as much as possible in order to minimize the costs. There are, however, so many factors to be considered when designing hydro turbines that only a certain extent of standardization can be obtained. Apart from head and discharge, revolutions per minute and suction head (for Francis and Kaplan/tubular turbines) will be essential for the applicability of a given turbine design for various combinations of head and discharges. For one thing, the output will be considerably reduced if a turbine designed for a specific combination is operated under other conditions.

For units less than 1 MW and where the Francis turbine is a suitable alternative, we have designed 8 standardized versions as shown in the head-flow diagram, see fig. 3 and 4. It will be necessary to change the revolutions per minute if one standard turbine will be used for various combinations of head and discharge.

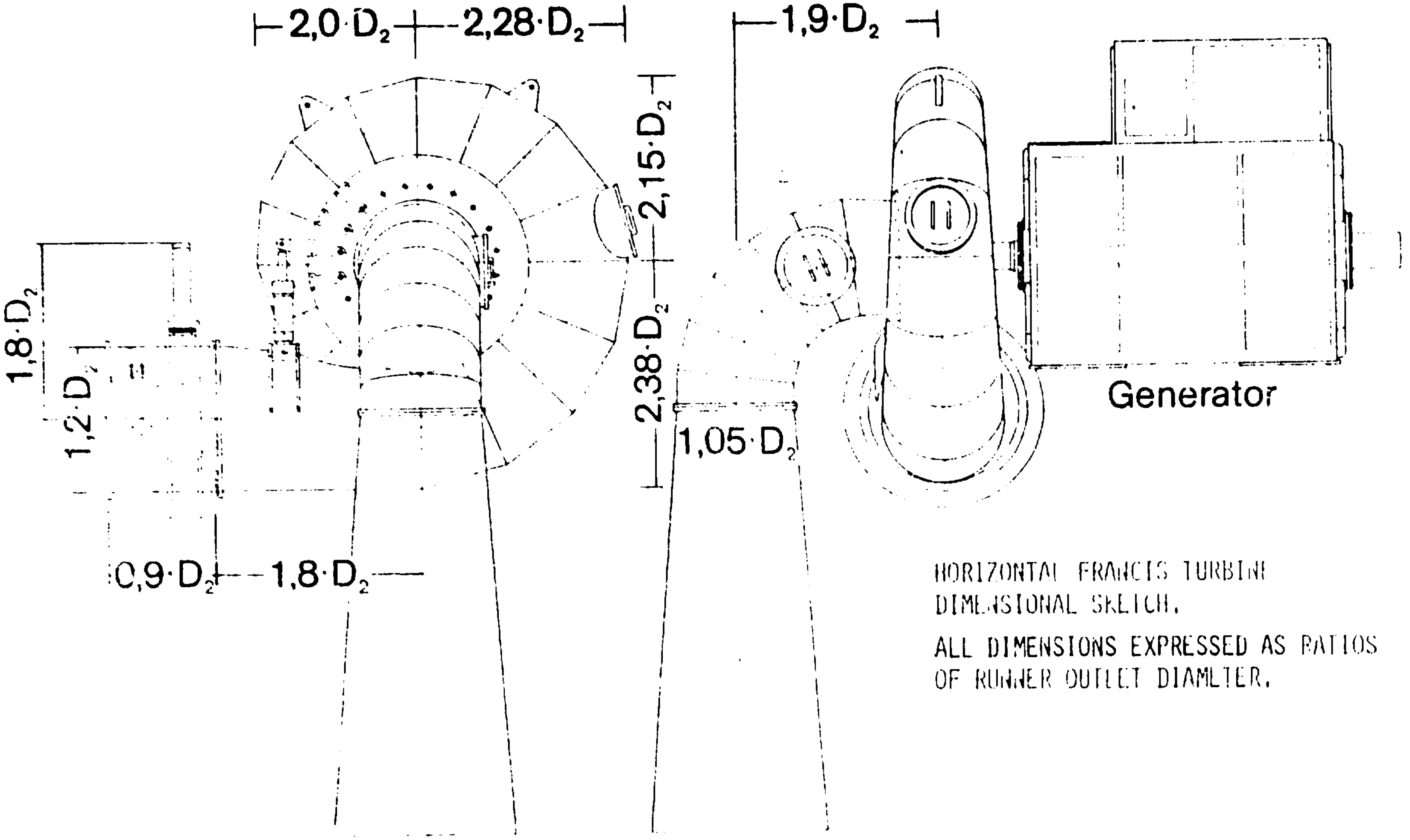
Regarding turbines with outputs up to 10 MW, we have prepared a standard arrangement for the constructions in order to reduce the engineering work and thereby the costs, without reducing the demand for maximum output for the plant in question. For instance, data for output, revolutions per minute, runner diameter and suction head have been systematized in the head-flow diagrams.

From these diagrams, the main dimensions of a turbine for the desired combination of head and discharge can easily be found, since all main data are stipulated as a function of the runner's discharge diameter. This will primarily reduce the pre-feasibility work.

Extensive use of mass produced components is also a cost reducing factor. This will primarily apply to the control system elements. The use of such elements, however, requires previous evaluation and testing. It is of vital importance to ascertain that the often prevailing disadvantageous surroundings (humidity, vibrations, pressure oscillations etc.) will not destroy the functional characteristics of such elements.

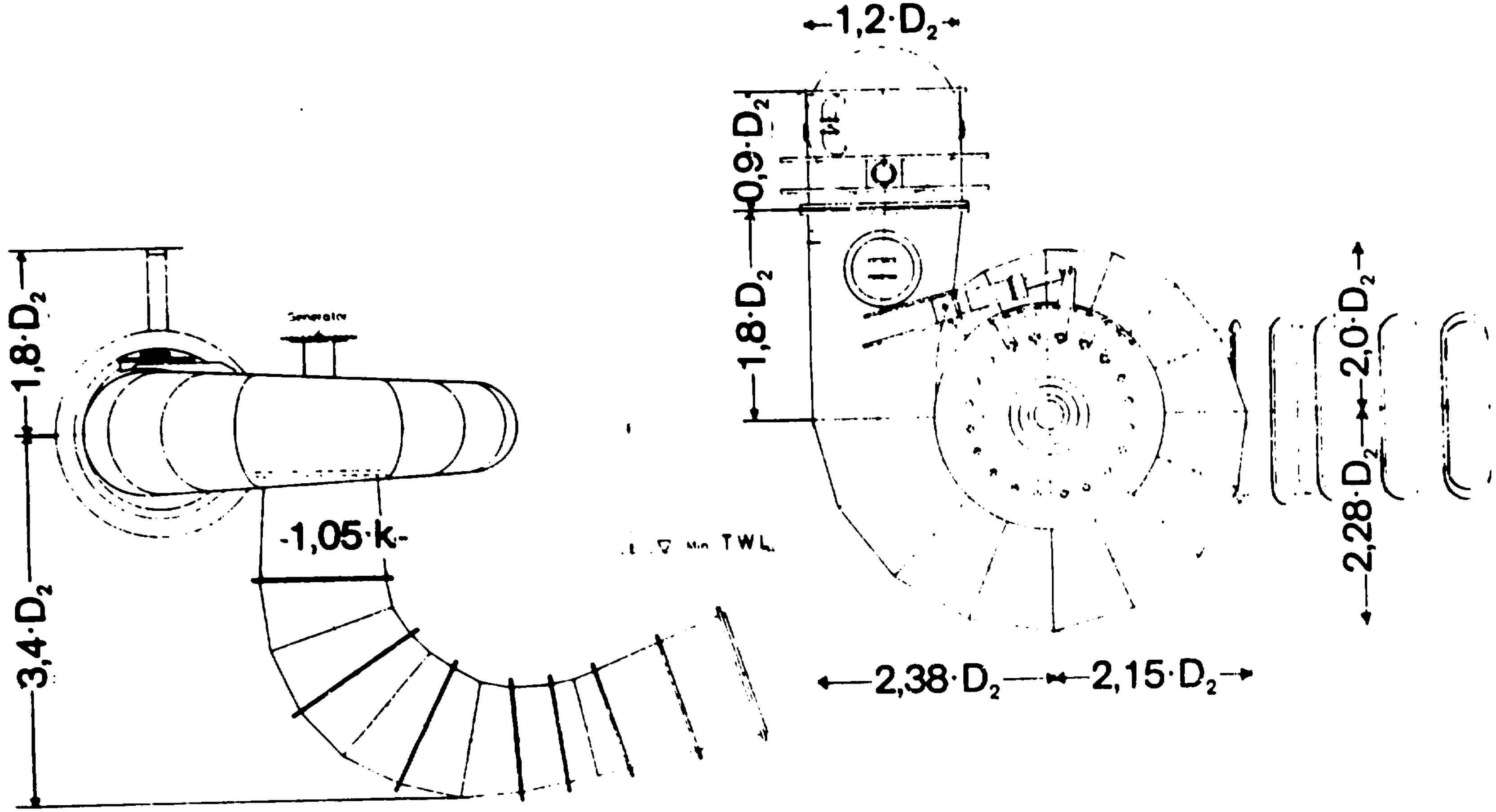
Finally, I would like to stress the importance of standardizing the purchase specifications for small-sized hydro units. Large units will normally require detailed specifications.

Detailed specifications for small-sized plants will often make it impossible for the suppliers to offer their standard versions. Studying of such specifications and trying to adapt the standard versions that are developed will also be time-consuming and expensive, resulting in an unintentionally high-priced solution.

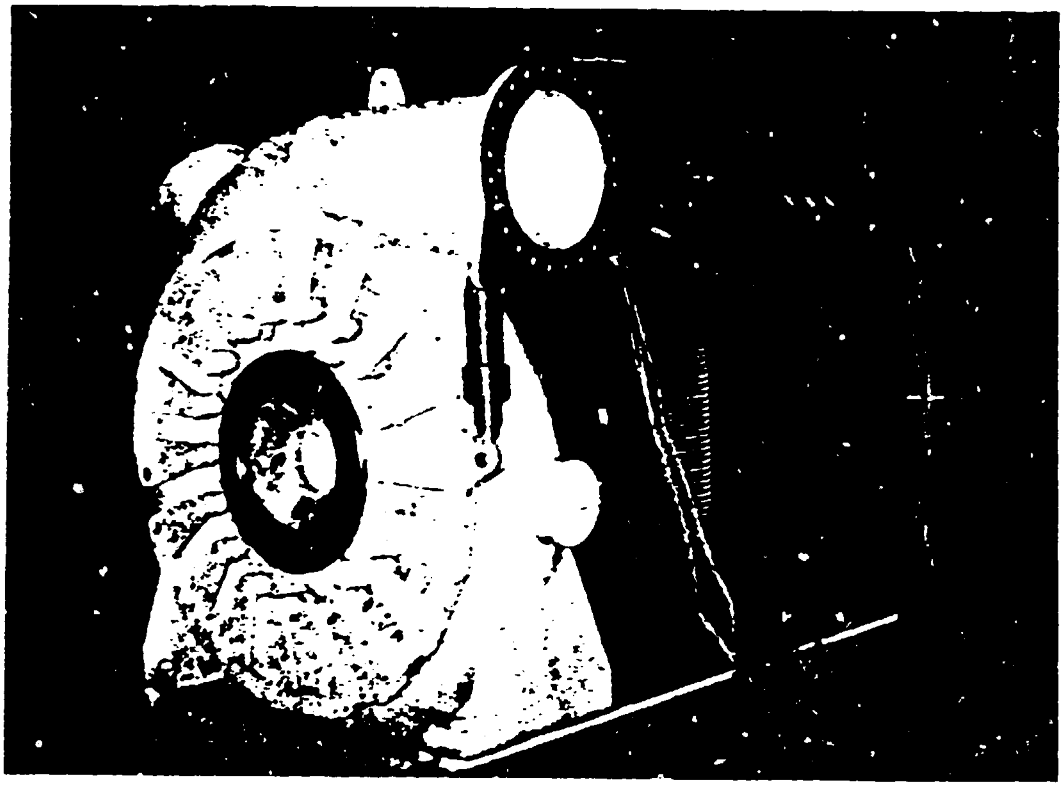


HORIZONTAL FRANCIS TURBINE
DIMENSIONAL SKETCH.

ALL DIMENSIONS EXPRESSED AS RATIOS
OF RUNNER OUTLET DIAMETER.



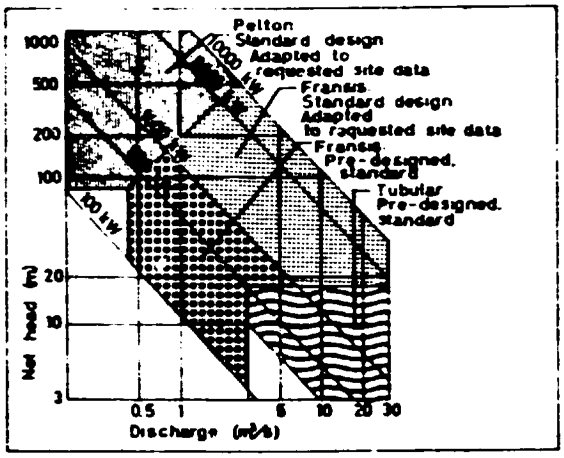
VERTICAL FRANCIS TURBINE DIMENSIONAL SKETCH
ALL DIMENSIONS EXPRESSED AS RATIO OF RUNNER OUTLET DIAMETER



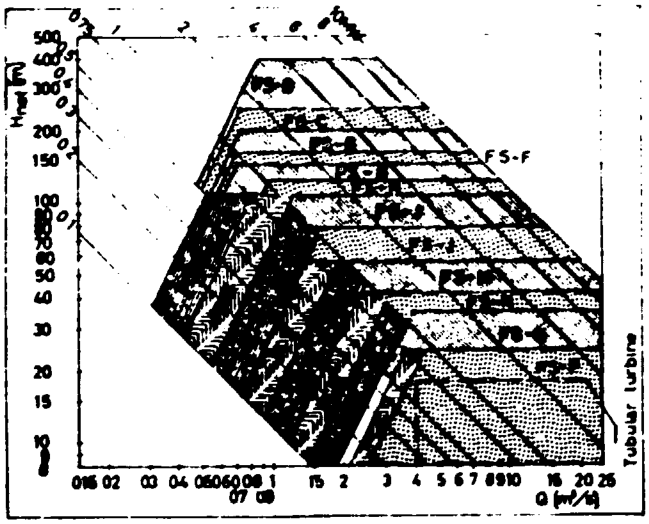
FRANCIS TURBINE
OUTPUT: 1000 KW
SPEED: 1000 R.P.M.
NETHEAD: 144 M

NEW TURBINE IN OLD HYDRO POWER PLANT.

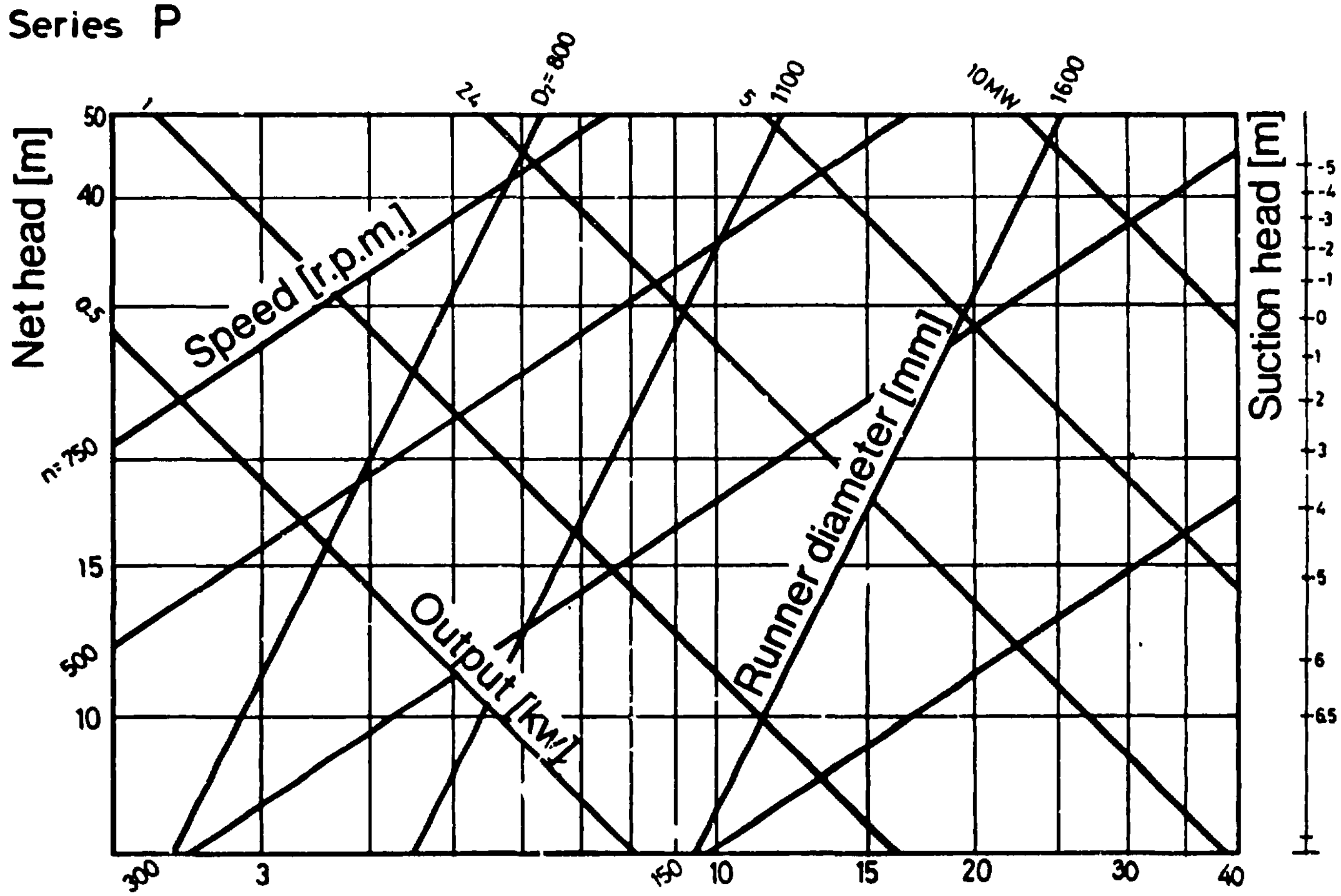
FRANCIS.
OUTPUT: 1900 KW
SPEED : 500 R.P.M.
NET HEAD: 37 M



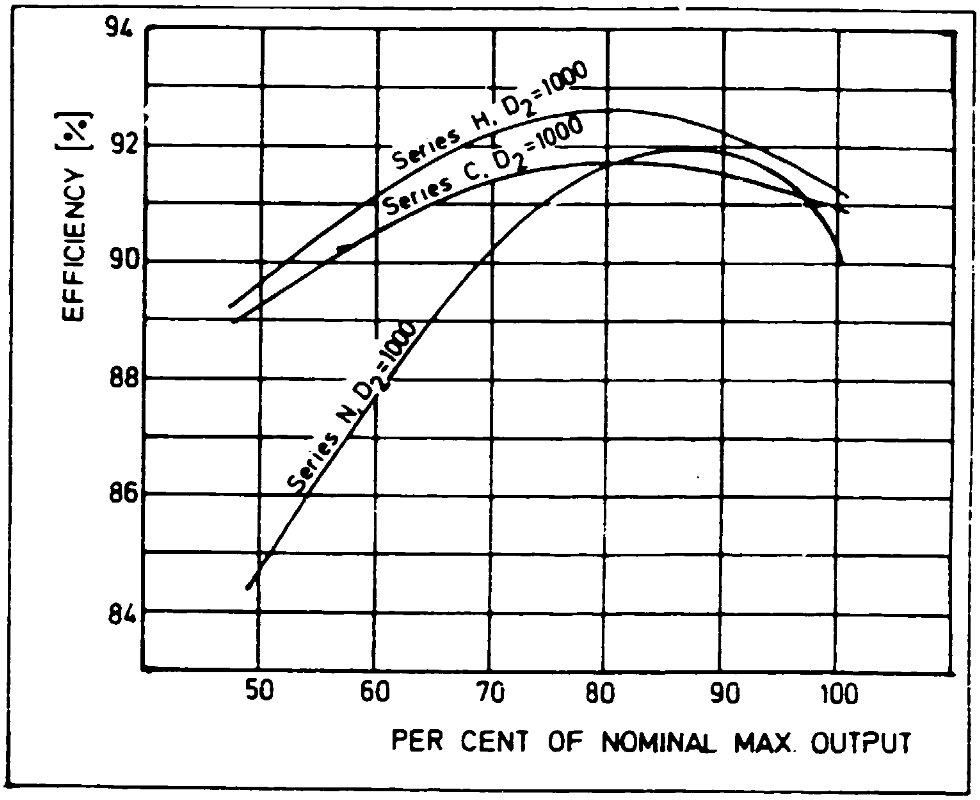
APPLICATION AREA SMALL SCALE HYDRO TURBINES



APPLICATION AREA, FRANCIS TURBINES,
TYPE FS AND FC.



PRINCIPAL DIAGRAM (SIMPLYFIED) OF FS FRANCIS TURBINE
THE DIAGRAM SHOWS WHICH CHARACTERISTICS THAT CAN BE DETERMINED
WHEN KNOWING THE NET HEAD AND FLOW



FRANCIS TURBINES
EXAMPLES OF EFFICIENCY FOR 3 DIFFERENT SERIES OF
FS TYPE

ELECTRICAL EQUIPMENT FOR SMALL SCALE HYDRO POWER-PLANTS.

- The Generator
- Switchgear and control system

by J. Bergseng, M.sc. Elec. Eng.
Sales manager
Energy production and Distribution

The Generators

The main task of a small scale hydro power plant is to produce kWh

An induction generator with squirrel cage rotor is thus suitable for such a power plant providing that a grid - fed by synchronous generators - is at hand.

There will be occasions where it is desirable to maintain operation of such a plant in the absence of the grid - e.g. for supply to a small local community or industrial plant necessitating a more costly solution by applying a synchronous generator and speed regulation of the turbine

Upon reflection of a small scale power plant and its uses one would briefly define its design philosophy as

- Simplicity
- Limited use of components
- Standardization
- Unmanned operation
- Manual starting up

Both synchronous and induction machines have their advantages and drawbacks in small scale power plants. The synchronous generator covers all types of operation whilst the induction generator with squirrel cage rotor must be connected to a grid fed by synchronous generators. This is due to the fact that it must draw its magnetizing current from the grid. Voltage regulation is not possible.

The induction generator acts as a reactive load on the grid and part of the magnetizing current of the generator must be compensated by means of a condensor battery.

Complete magnetization of an induction generator with a condensor battery is conceivable. Single operation - in any case, with constant output - is thus possible. However, this is a theoretical aspect.

A summary of possibilities for the use of synchronous or induction generators is given in Fig. 1.

Due to costs and delivery time, the generators must be taken from standardized machine series. This implies that, in the case of the induction generator, it would be taken from the industrial motor series and, in that of the synchronous generator, from the generator series for combustion motors.

Demands on a generator in a hydro power plant differ from those in a diesel power plant or on a motor in an industrial plant. Modifications are, therefore, necessary. This applies, in the first instance, to strain on bearings, strain in connection with runaway speed as well as control of critical speed.

Synchronous generators are delivered as brushless generators. They are fitted with AC magnetizing machine and rotating diodes. The voltage regulator is situated on top of the generator. The latter is also equipped with the necessary measuring transformers for the regulator. The generator with magnetizing and regulating system is thus a package delivery.

The voltage regulator effects the following functions:

- Voltage regulation
- Sharing of reactive power between generators operating in parallel
- A compound circuit maintains the necessary current in the event of short circuit so that protection may function
- Voltage build-up with the aid of residual magnetism from the generator

The system is not dependent on outer sources of voltage.

The magnetizing machines and voltage regulators are dimensioned for a wide field of operation - a small number covers the entire range of generators.

SWITCHGEAR AND CONTROL SYSTEM

The design and system criteria for the switchgear and control system of a small scale hydro power plant may be summarized in a few words:

- Simplicity
- Standardization
- Automation to a certain extent - i.e. unmanned operation but manual starting up
- Remote control should be avoided but is, of course, possible.

<u>Protection System</u>

Choice of protection for any generator demands a clear outline of the strains to which a generator is exposed during operation - which would comprise:

- Electrical overvoltage affecting insulation
- Mechanical forces as a result of runaway or short circuiting
- Heating as a result of overload or lack of cooling

The object of the protection system may be described as threefold inasmuch as:

- its nature must be preventive - i.e. an abnormal condition must be detected at the earliest possible moment
- it must instantly leave the faulty point currentless in cases where the fault develops rapidly
- it must be able to guard against faults in the grid to which the generator is connected

This may lead to a relatively comprehensive system and, for small power stations, a compromise is necessary.

The majority of faults result in inadmissible rises in temperature. The obvious solution is to install temperature sensors in all bearings and in the windings of the generator. Fig. 2 shows the characteristics of semi-conductor elements used in low voltage generators.

Elements may be supplied with Curie point adapted to limit temperatures for the bearings, windings and the insulation class.

Good heat contact between winding and sensor is essential for safe and satisfactory function as the sensor reacts to gradual rises in temperature. The sensors are less suited to high voltage generators as the winding insulation is considerably thicker than that for low voltage.

For high voltage generators, PT 100 elements may be used. Connected to a control unit, the relevant temperatures may be measured, a pre-warning signal given and, when the upper temperature limit is exceeded, tripping is carried out.

Furthermore, for high voltage generators, thermal relays with suitable thermal time constant may be utilized.

By installing overcurrent time relays with instantaneous short circuit release, reliable protection is attained against:

- Overload
- Prolonged overcurrents
- Short circuits

In the event of short circuit in the winding between two phases in the generator, the point of short circuit will be fed from the grid.

To which extent the overcurrent time relay will afford any particular protection (release the breaker) depends upon the location of the short circuit in the winding - in other words, the magnitude of the current from the grid.

However, dependent upon conditions as well as the size and voltage of the generator, the use of differential relay as a safeguard against internal short circuit should be considered.

Frequently, a winding short circuit will originate as a stator earth fault.

A winding short circuit between two phases always entails considerable damage to the generator and costly repair. The main objective must therefore be to prevent a stator earth fault from developing into a winding short circuit. Thus it may be quite as important to use a stator earth fault relay rather than a differential relay.

Overvoltage may occur both as a result of defects in the voltage regulator - magnetizing system - and of runaway. Overvoltage protection is therefore included as standard equipment. Overspeed protection is also included - as in all other power plants.

A summary of faults and faulty components is given in Table 1.

Automation and Controls

Bringing to a standstill:

As a main rule and due to the fact that the plants are normally unmanned, any fault will result in automatic disconnection of the generating unit from the grid and, furthermore, the unit will be brought to a standstill.

However, depending upon the location of the plant and the nature of the fault, it may be reasonable to keep the plant running but disconnected from the grid. This is especially important in areas where temperatures below 0°C (or 32°F) are to be expected. Otherwise, the penstock may freeze. If necessary, arrangements for by-pass of the water may be made.

The unit is disconnected from the grid and brought to a standstill by the built-in automatic control, the general procedure being:

- the turbine is de-loaded
- the valve in front of the turbine will close
- the circuit breaker trips time delayed.
  The delay is adjustable.
- in the case of a synchronous generator, it is demagnetized.

Start procedure:

In order to start, certain conditions must be fulfilled. Furthermore, the presence of the operating crew is required in order to initiate the starting and to control it.

Once initiated, the starting procedure runs automatically.

- Manual starting of the oil pump to build up the oil pressure of the hydraulic system to the required level.

- Manual setting of the automatic to operating position. If any fault exists within the system, an alarm will now be given and the fault may be identified on the alarm panel. The starting procedure is automatically discontinued until the faulty component has been repaired.

- Following the setting of the automatic, the various elements of the turbine are brought to start position and, upon opening of the valve, the turbine starts and accelerates to nominal speed.

In the event of an induction generator being employed, the circuit breaker will close when synchronous speed is reached. The closing command is given by the speed control equipment and the generator is instantly ready to deliver rated output. In order to achieve this, however, a grid must be at hand and the generator driven at an over-synchronous speed of approximately 102% of synchronous speed. The turbine regulator will provide for this speed.

A synchronous generator must be treated somewhat differently.

a. Connection to a grid, parallelling:

In this event, the unit is being accelerated to synchronous speed and, in order to avoid switching error and relieve the operating crew, parallelling as well as magnetizing of the generator are carried out automatically.

The parallelling apparatus - Synchrotact - consists only of solid state components. It is connected to the voltages on either side of the open circuit breaker and controls the following:

- Slip of the rotor and thereby the frequency
- Voltages on either side of the open circuit breaker
- Phase angle

The closing command is given when the set maximum slip is reached. Consideration must be given to the breaker closing time.

When connected to a grid, the frequency is determined completely by the grid - and thereby the speed of the unit. Frequency regulation is, therefore, not necessary.

b. Single operation:

Compared with an induction generator, the synchronous generator may produce reactive power as well as sustain its terminal voltage. The synchronous generator is thus suitable for single operation.

Start-up and closing of the circuit breaker do not differ from the procedure for an induction generator. However frequency regulation must now be possible and a turbine with adjustable guide vanes and runner vanes must be employed.

Excitation System and Voltage Regulation

Slip-rings and brushes always require a certain amount of maintenance. They may further be one of the weakest points with regard to reliability.

The modern synchronous generator for the small scale hydro power station is therefore of the brushless type. The rotating diodes as well as the AC exciter are mounted on the generator shaft inside the stator frame.

The voltage regulator is of the solid state type and mounted on the top of the generator, as are also the current transformers for feeding of the regulator. Fig. 3.

The generator, excitation and voltage regulating equipment thus form a complete unit.

Voltage regulation:

Fig. 4 shows the regulator principle of an autonomous generator system. The unit has a number of functions

a. Automatic voltage regulation

Under normal circumstances, the voltage is automatically kept constant and at a pre-set value. The reference level of the generator voltage is adjustable.

Furthermore, the automatic voltage regulator is equipped with a quadrature current voltage droop circuit. Should the reactive output of the generator increase beyond the value corresponding to the nominal power factor, the circuit will decrease the voltage in order to sustain the correct reactive output.

b. Voltage build-up

The voltage is built up by the residual magnetism of the generator, which provides for an automatic voltage build-up. When the terminal voltage has reached 30-40% of nominal voltage, the automatic voltage regulator takes control and regulates the voltage to the desired value.

c. Compounding circuit

The necessary excitation current during a short circuit condition is provided for by a compounding circuit. This will maintain the short circuit current for a sufficient period of time to allow the relevant relays to operate.

Water Level Regulator

As small power plants are designed for unmanned operation, automization of the turbine admission is therefore necessary.

The following modes of operation warrant automation

a. Water supply to the reservoir varies throughout the day or the week. The variation may be within the output range of the turbine but outside the capacity of the reservoir. This is especially true for power plants with small intake chambers or run-of-river power plants.

b. The inlet to the penstock at the intake chamber may be blocked by foreign bodies.

c. Power plants where regulation of the water level of the intake chamber is desirable.

d. To ensure the utmost exploitation of varying water supply by maintaining constant level in the reservoir.

An electronic water level regulator has therefore been devised - simple in construction but nevertheless operationally reliable.

Instead of water level sensoring in a reservoir, which often entails costly transmission of the sensor signal - e.g. icing problems etc. pressure is sensored at the intake in the power plant as well as the distributor opening. With the aid of these two criteria, measurement is attainable of the static water level or the water-line in the intake reservoir. For adjustment of the wicket gates (or - in the case of a tubular turbine - the runner blades), the servo-motor of the turbine control system may be used. A principle sketch is shown in Fig. 2.

As a secondary function, the regulator also monitors the pressure in the turbine. In the event of the water supply being completely or partly blocked, the regulator will register this as loss of pressure and react in accordance with low water level - adjusting the turbine output until satisfactory pressure has been restored. Emptying of the penstock and subsequent release of the under-pressure protection may thus be avoided - the generator remains connected to the grid but with reduced output. Upon removal of the obstacle, operation reverts to normal once again.

Connection to the Grid

Apart from the equipment directly related to the generators (synchronizing, voltage regulation etc.), the main power circuits for an induction generator are similar to those for a synchronous generator. However, the power circuits for high and low voltage generators are somewhat different - Fig. 6.

For a low voltage generator, the circuit breaker is located between the transformer and the generator and, in the case of a high voltage generator, between the transformer and the high voltage bus bar.

The generators in question may be designed for operational voltages up to 13.2 kV. However, since the grids to which the small scale power plants are to be connected normally have higher voltages, step-up transformers are necessary.

Furthermore, in the event of a short circuit - for instance, on the generator terminals - the short circuit current from the grid can reach a considerable magnitude. The impedance of the transformer will limit this to a more suitable magnitude, reducing the strains to which the equipment otherwise could be exposed.

The magnetizing current of the induction generator is supplied from the grid. The generator is thus unable to regulate its terminal voltage - i.e. the terminal voltage is completely governed by the grid. The grid voltage may fluctuate over the day/night and, since the output of an induction generator - keeping the current constant - is proportional to the voltage, it is important to know the magnitude of these fluctuations. Otherwise the output will be reduced when it is most needed - i.e. when the load demand is high and the grid voltage at its lowest value. Careful consideration must therefore be given to the ratio of transformation and the transformer must be equipped with the correct tappings.

Table 1

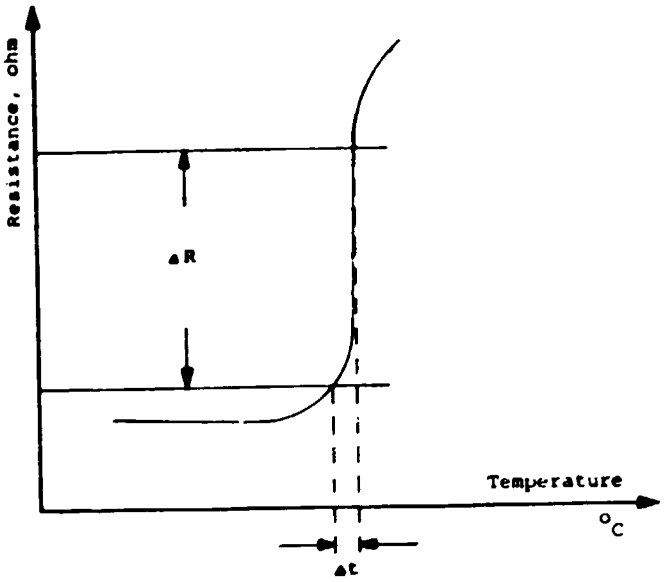
PROTECTION AND ALARM SYSTEM

Faults	Faulty items								Remarks
	Induction generator		Synchronous generator		Gear	Turbine Reservoir	24 DC supp. Aux. circ.	Transf.	
	Low voltage	High voltage	Low voltage	High voltage					
Winding temp. too high	x	x	x	x					
Bearing temp. too high	x	x	x	x	x	x			Tubular turbine bearings only
Overload (thermal)		(x)		(x)			x	x	High voltage fuses
[illegible]	x	x	x	x					
[illegible]	(x)	x	(x)	x			x		
[illegible]	(x)	x	(x)	x					
[illegible]							x		
[illegible]						x			Francis- and tubular turbines
[illegible]						x			
[illegible]					x	x			Turbine governor Circulation pump
[illegible]						x			Turbine governor
[illegible]								x	
Flood						x			Start drainage pumps
Min. water						x			
Internal short circuit	(x)	x	(X)	x					
[illegible]								x	

Type of generator	Suitability	Parallel operation				Single operation			
		a	b	c	d	a	b	c	d
Induction generator	Most suitable	☒							
	Very suitable		☒						
	Not very suitable					☒			
	Unsuitable			☒	☒		☒	☒	☒
Synch. gen.	Suitable	☒	☒	☒	☒	☒	☒	☒	☒

a: Operation with constant output
b: Operation with varying output
c: Operation with varying load and constant voltage
d: Operation with varying load and production of reactive power

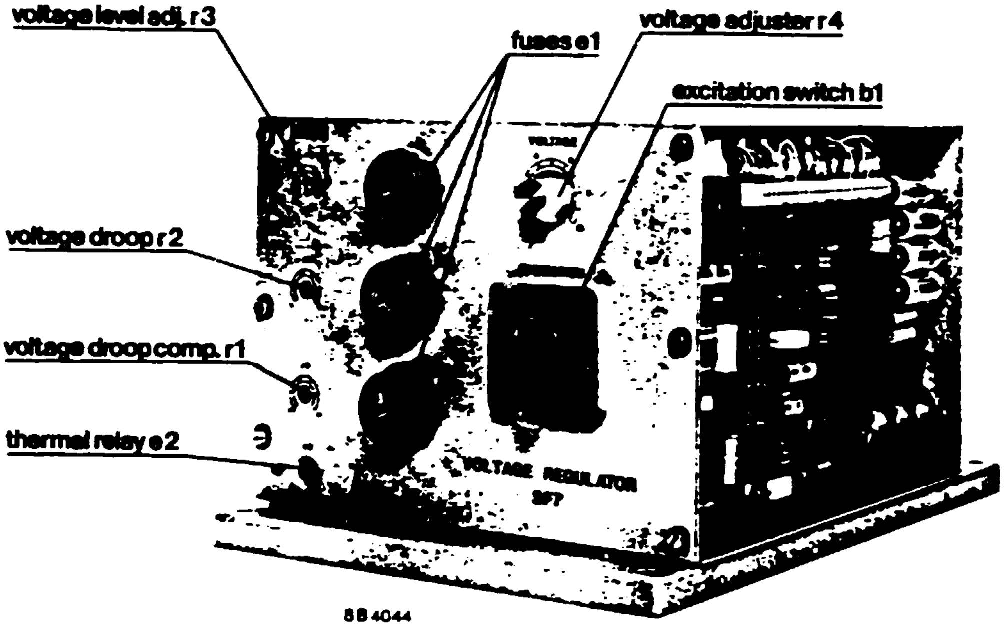
Fig. 1



At normal temperatures, resistance of the element is practically constant whilst a minor temperature rise from a certain point yields an increase in tenth powers in element resistance. It acts as a breaker and may interrupt a static circuit.

Fig. 2

Voltage regulator SF7. Front view.



Voltage regulator SF7. Top view.

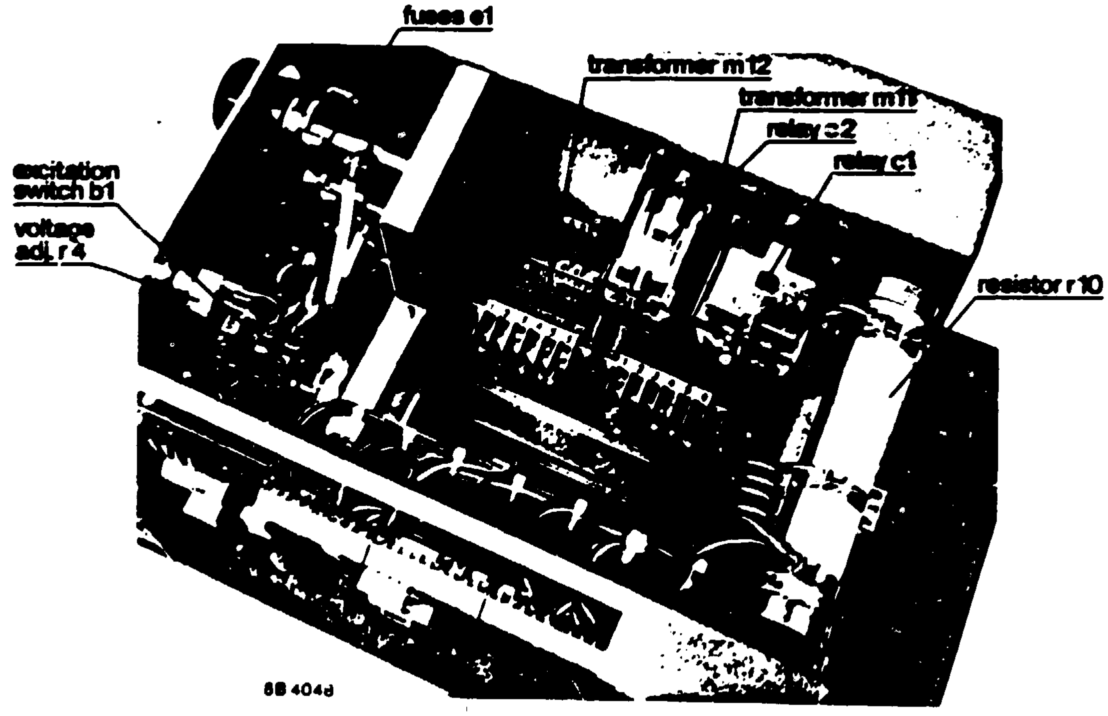
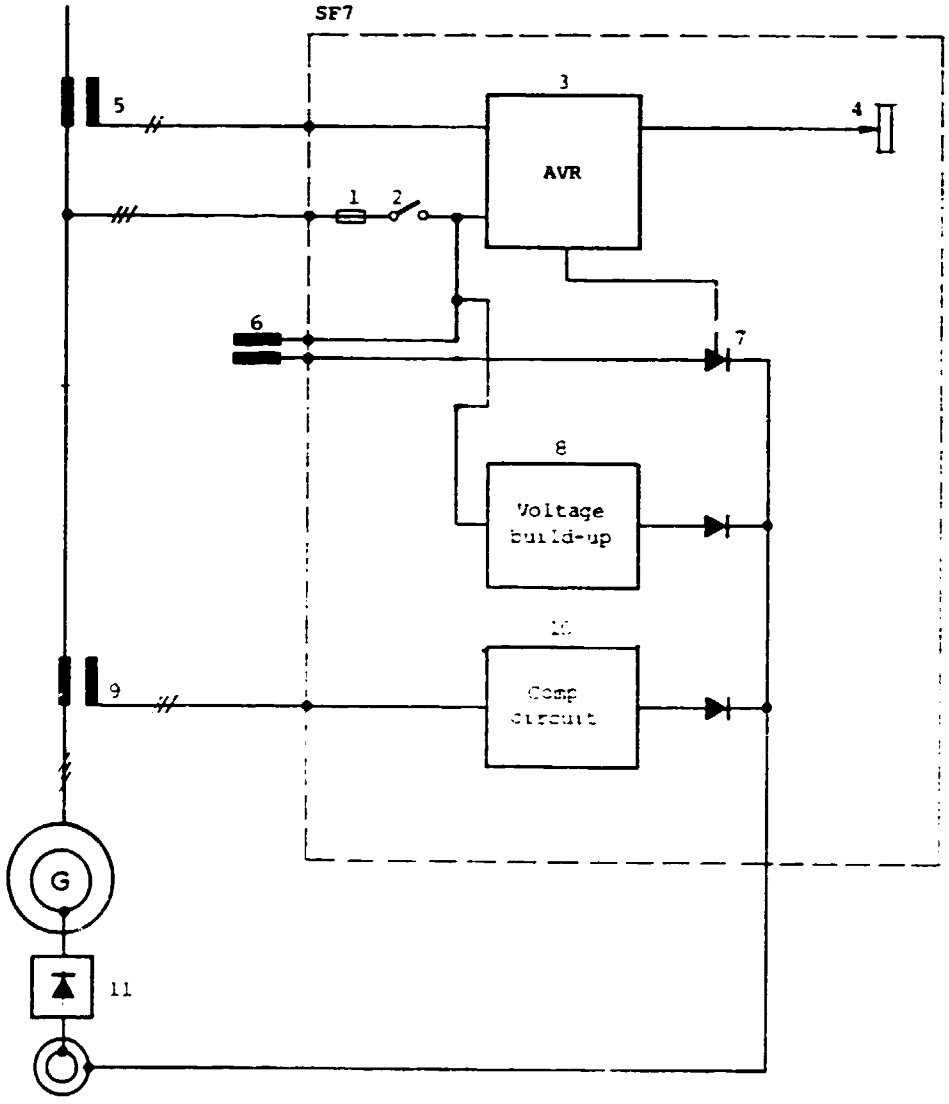


Fig. 3

Automatic voltage Regulator SF7

Block Diagram OE-S 77/52



1. Fuses
2. Excitation switch
3. AVR unit
4. Voltage adjuster
5. Current transformer
6. Reg. supply transformer
7. Thyristor bridge
8. Voltage build-up circuit
9. Compounding transformer
10. Compounding circuit
11. Rotating diode bridge

Fig. 4

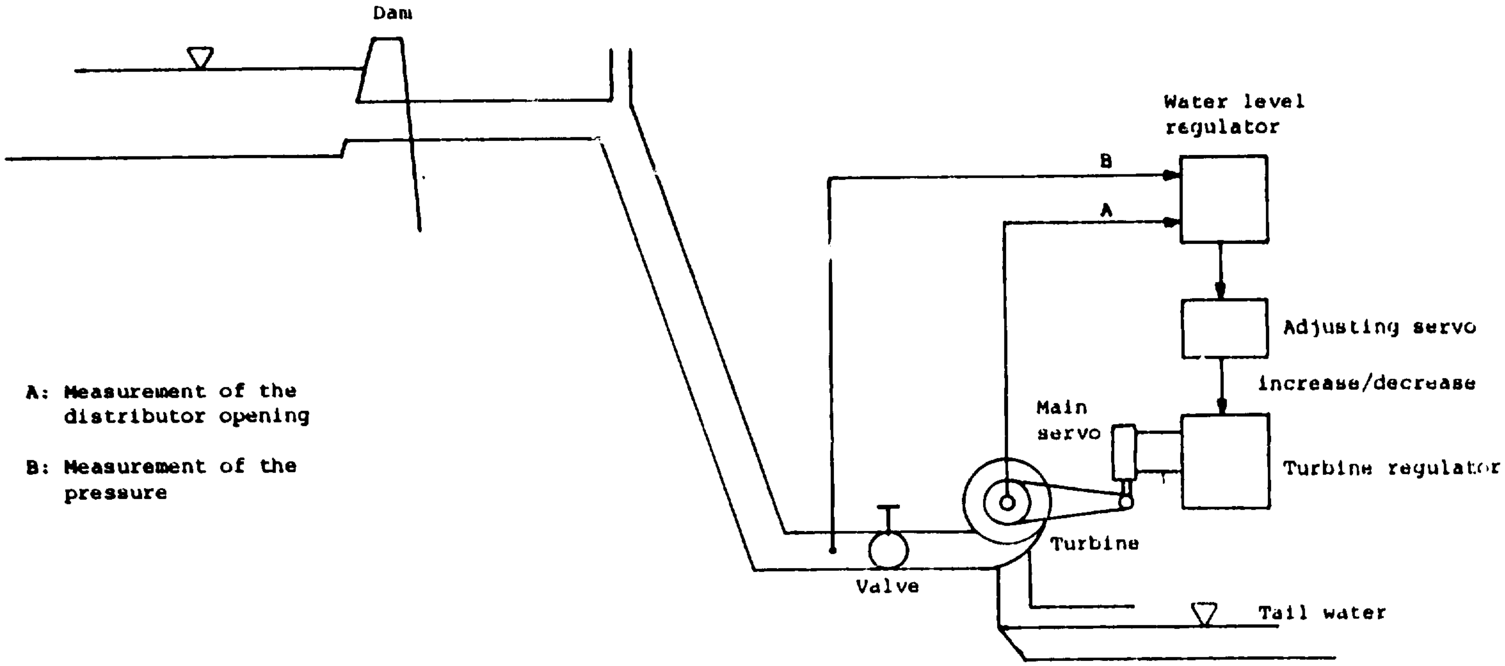


Fig. 5 Schematics of the water level regulator

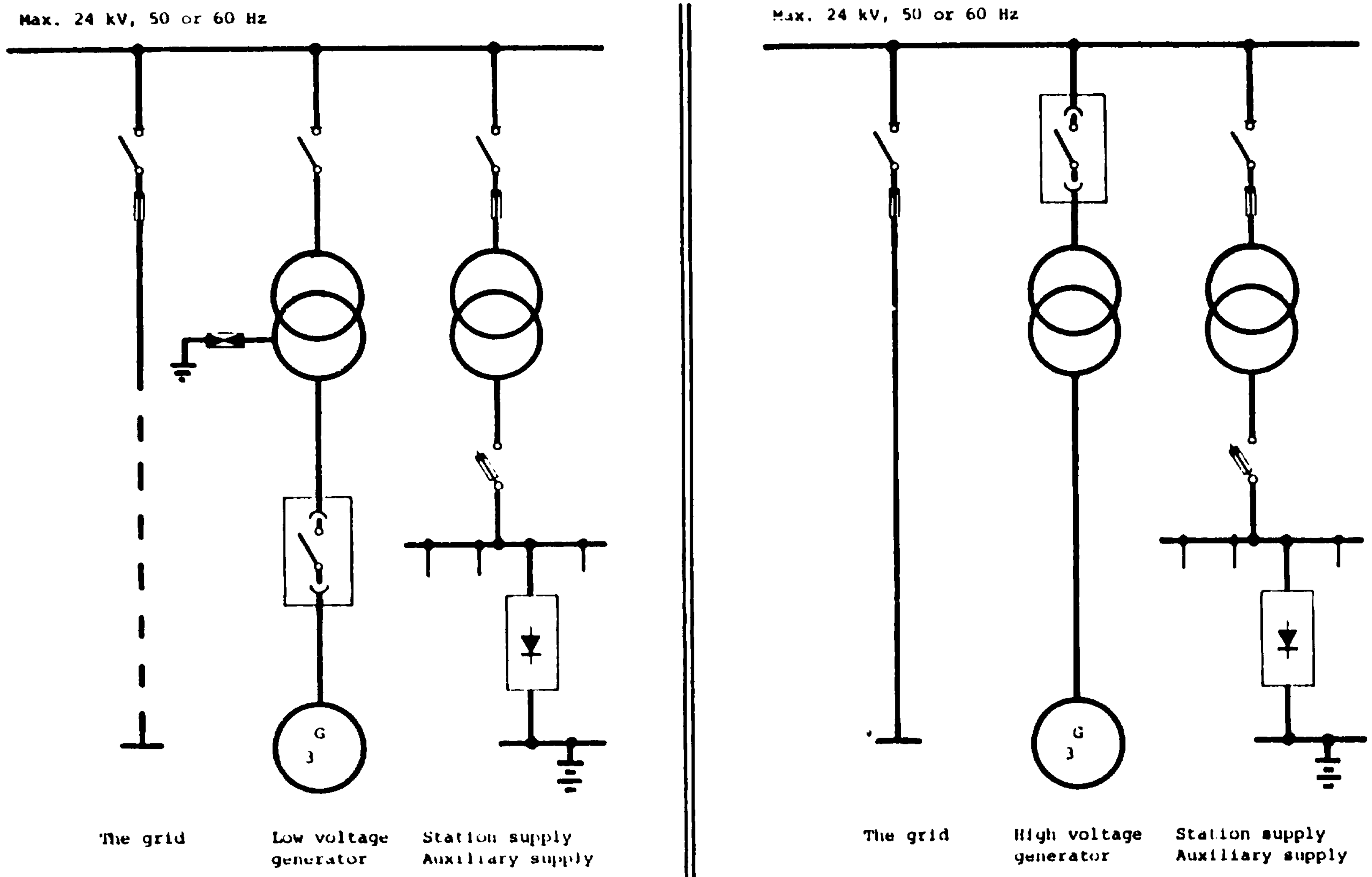


Fig. 6 Principle diagram of small scale hydro power plants

WATERWAYS, DAMS AND POWER BUILDINGS FOR SMALL SCALE POWER-PLANTS.

by T. Jensen, M.Sc. in Civil Engineering. Water Power Engineer.
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Waterways

Waterways for small power-plants often represent a big item of expenditure, both in view of constructional- and running expences. It is therefore of the utmost importance to examine the conditions of the terrain, and also the geological conditions (maps, surveys). Principally, three different waterway systems are to be found: Under-ground (tunnel, shaft), and overground, penstock and/or channel.

Rough ground projects

Usually, tunnel and/or shaft systems will be most profitable when great quantities of water must be transported. These systems are also of interest where the topographical conditions naturally favour under-ground systems, that is, where these systems increase the head of water and/or shorten the waterway.

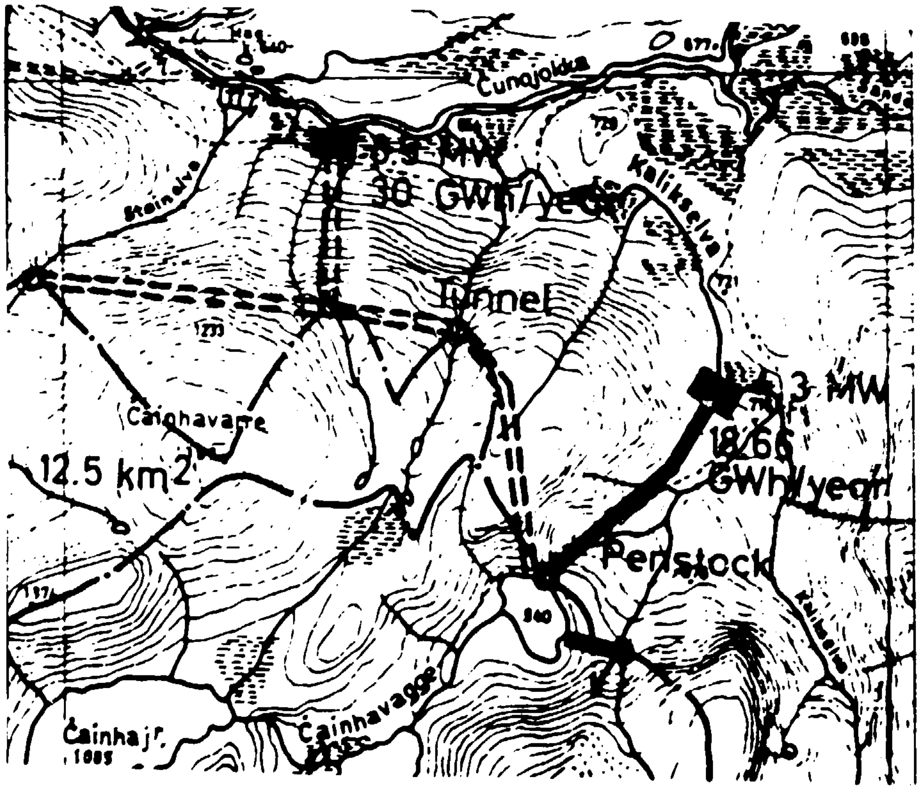


Fig. 1

Fig. 1 shows in principle a project where tunneling probably will be more favourable than penstock. The main difference lies in the fact that tunneling opens up possibilities for a larger catchment area, while laying a penstock line is expensive in this terrain, where deep moraine causes expensive points of support.

It is important to note that work in rough grounds largely depends on the quality of the species of rock. Unsound rock demands a high degree of securing and concreting. This may add to the cost of the counstuction, and make it more expensive than a penstock alternative. For this reason, geological examinations (seismic measurings, studies of rock structure etc.), are necessary before commencing on a rough ground project.

For tunnels and shafts it is important to have sufficient overburden, to prevent that pressure, which may come up in the waterway, results in leakage or total break down.

Tunnels

At present there are two possible methods for getting approximately horizontal running. Conventional running, use of boring and blasting, and full profile drilling. In soft rock, and rock holding small quantities of quartz, is full profile drilling the best alternative, in deference to a smaller cross section of tunnel. Conventional tunneling is better adapted to hard rock.

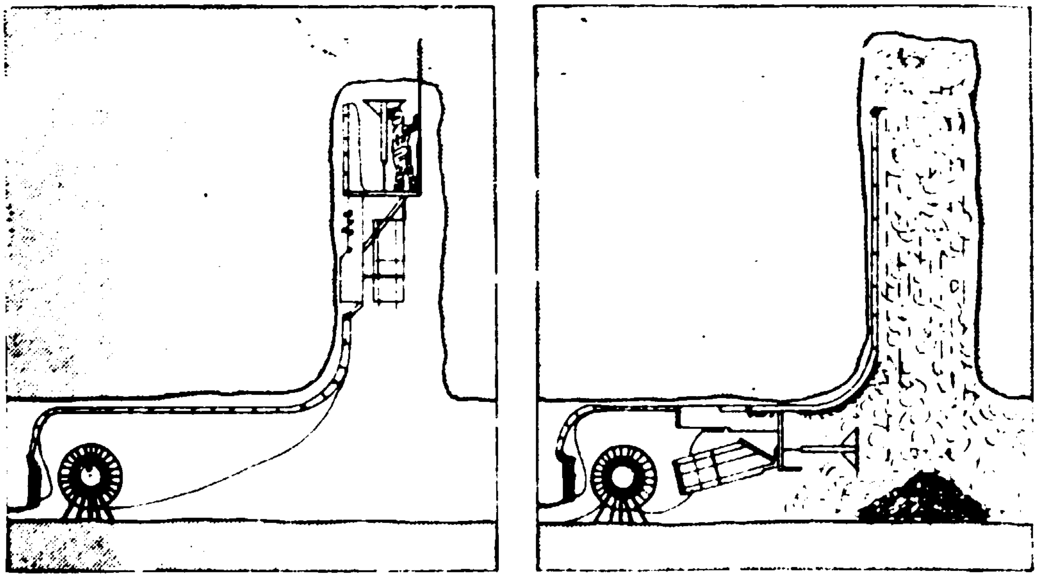
Large cross sections are unnecessary for small power-plants. Full profile drilling may be operated down to 3-4 m^2, while conventional tunnel running has 5-8 m^2 as lower limit, dependent upon available mechanical equipment. Common for all rough ground projects is the great cost of rigging. This favours long tunnels, but not too long, because transport of earth masses may be expensive. For smaller cross sections rail transport is usual, while for cross sections exceeding 15 m^2, wheel transport is preferable.

Enclosure 1 shows development of cost as a function of length, and cost as function of cross section.

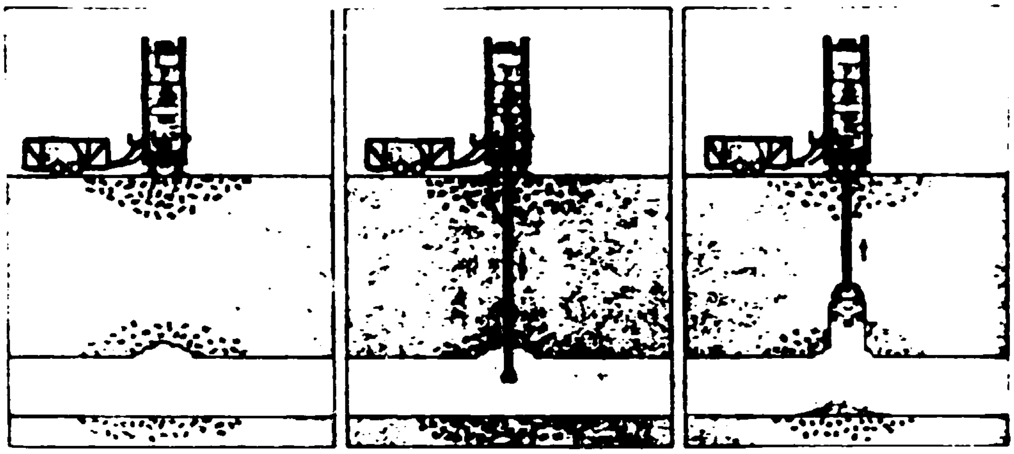
Note that change to wheel transport cause a fall in the costs. The reasons for this decrease are more effective equipment for all larger cross sections, and the elimination of the great rigging costs for rail transport. It is important to be aware of this, because where both types of equipment are available, a larger cross section may be attained without additional cost. This gives less loss of head in the tunnel, which again results in better utilization of the water.

Shafts

Two possible methods of running will be described. Running with Alimak hoist is a well-known method in Norway, and this method has shown some good results. Another method is full profile drilling, where first a pilot hole is drilled, then a rotating disc is pulled through the hole. (see fig. [illegible]). This method is only recently in use, and where small cross sections are adequate, great results are expected.



The Alimak method, with drilling and air injection after blasting



Principle for profile cutter.

Drilling a pilot hole

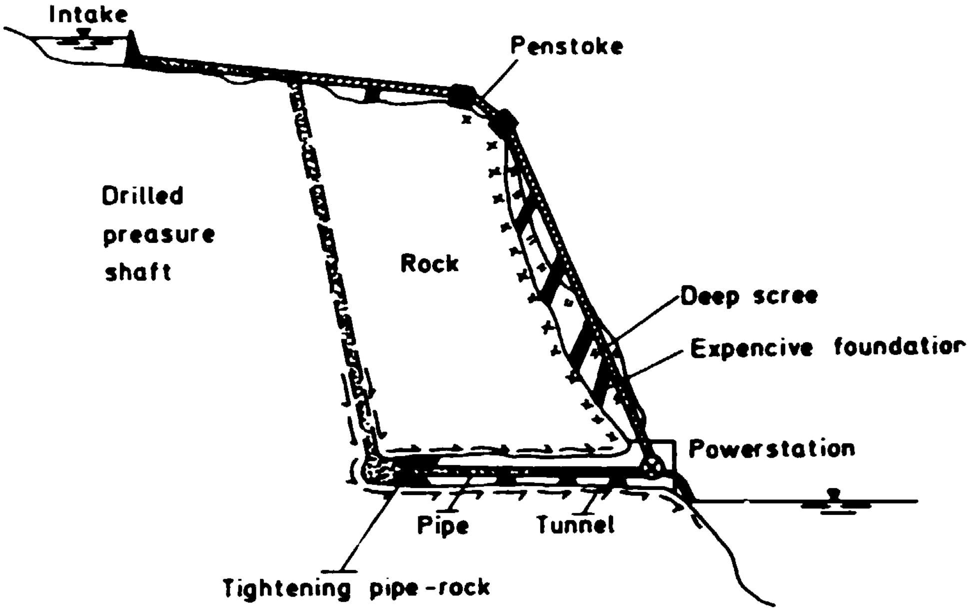
Operating the profil cutter.

Fig. 3

Because of slides after blasting, most of the shafts are drained with a 90° or 45° incline (by using Alimak stool). Minimum cross section is calculated to approximately 4 m² and normal price to ca. [illegible] Nkr/m (1.1.79), rigging included, taxes excepted. A drilled shaft has, so far, a maximum diameter of 1200 mm (1,1 m²), and the length is limited to 150-200 m. A hole measuring 300 mm and with a length of 100 m, costs 2700 N.kr/m, total construction costs included (1.1.79).

It is supposed that small power-plants which utilize high heads, where penstock becomes too expensive because of terrain conditions (moraine etc.), and where conventional shaft running also is too expensive, will become more interesting in view of the new drilling method.

Fig. 4 indicates this.



The tunnel is necessary to obtain sufficient overburden for the pressure shaft.

Fig. 4

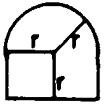
Because of the necessary size, will loss of head often be low in tunnels. Manning's formula is often used.

Manning's formula $h_f = \frac{V^2 \cdot L}{M^2 \cdot R^{4/3}}$

$V = \frac{Q}{F}$, R (hydraulic radius) $= \frac{F}{A}$ $\frac{\text{surface}}{\text{periphery}}$

The formula shows that full profile drilling may have a lesser cross section at the same loss of head as is usual in conventional tunnels. Consequently, development of profile drilling machinery will be of importance for small power-plants.

A rough calculation shows loss of head per 100 m tunnel to be:

Blasted tunnel  $hf = 0{,}6 \cdot q^2 \cdot F^{-9/3}$ m

Drilled tunnel  $hf = 0{,}11 \cdot q^2 \cdot F^{-8/3}$ m

This shows that drilled tunnel with a circular cross section gets approx. 3,5 times less loss of head than blasted tunnel. Practically, this means that a necessary tunnel of 16 m^2, may be reduced to 6,5 m^2 when drilled, assuming the loss of head to be 0,1 m/100 m. The reason for this lies in the fact that a circular cross section has a better hydraulic shape, and also that a drilled tunnel has a smoother surface): higher Manning number.

For unlined pressure tunnels it is normal-economic to calculate the loss of head to 0,1 -0,35 m/100m, which equals approx. 0,5 m/sec. - 1 m/sec. for cross sections from 5 m^2 to 16 m^2.

Summary. Advantages and disadvantages.

	kr/m	Cross section m^2 minimum	Cross section m^2 maximum	Manning's number M	Influence on rock
Tunnel: Conventional running L = 3000 m	3,200,-	5-8		28-35	Blasting causes shock wawes in rock. May cause more securing. Stones may be used for road base and filling of dam.
Full profile drilling L = 3000 m	2,800,-	4	4	70	Small vibrations in rock Produce fine mass, which is not fit for dam filling or road base. Utilization possible if other materials added
Shaft: Alimak, blasting	6,000,-	3,5-4		30-35	Same as for tunnel.
Drilled	3,700,-		1,1	70-80	Must be accessible from base to top.

Over-ground projects

The topography will decide the solutions in all terrain work. An over-ground waterway consists of canals and pipe constructed of various materials (steel, ductile iron, reinforced plastic, wood)(impregnated timber)). Solutions will differ from project to project, and every conciveable combination, both between different pipe types and pipe/channel systems, may be found. High head plants often have headraces. However, in steel pipe, while low head plants often have headraces. However, in some cases it may be of advantage to use channels for high head plants, too.

Fig. 5 shows 3 different solutions for over-ground projects.

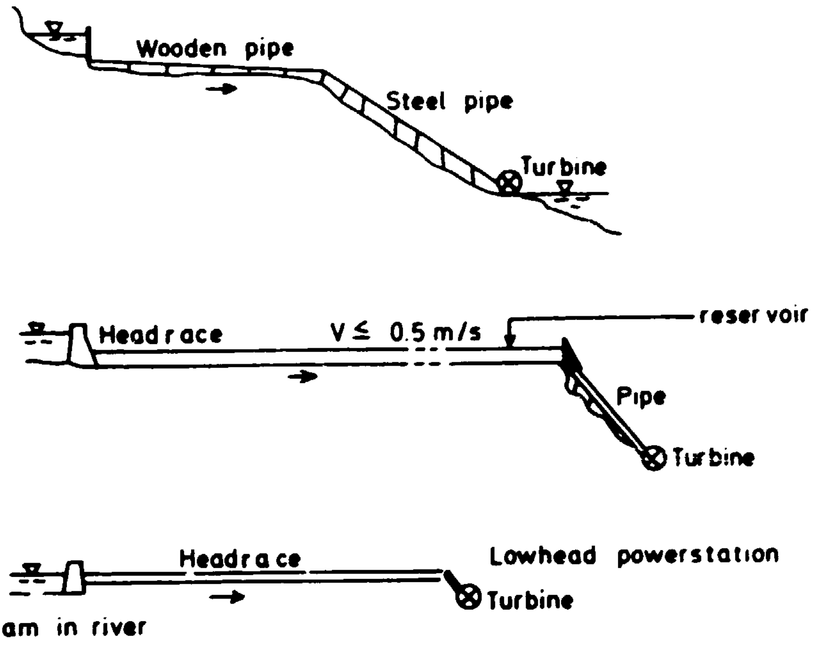
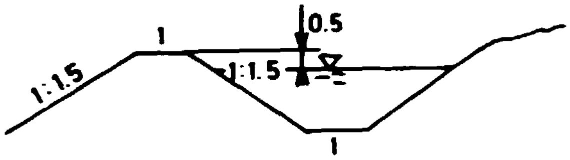


Fig. 5

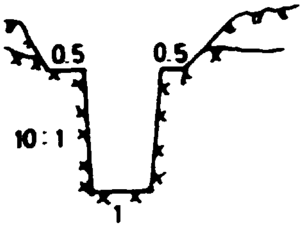
2. Channels

Canals are of present interest in sloping grounds consisting of deep moraine, but they may also be used successfully in rough grounds. Canals are especially of interest where great quantities of water and low head are concerned. The longer the distance between intake and power-plant, the more favourable is the use of canals, compared to other systems. For this reason, canals may profitable be used to transport water from the reservoir to a suitable penstock line (see ex. 1).



Canal in moraine

Fig. 6



Canal in rock

Fig. 7

Canal tranporting water from reservoir to penstock should have a smaller reservoir at the end of the canal. Canals in low head plants are normally of such a size that this is unnecessary.

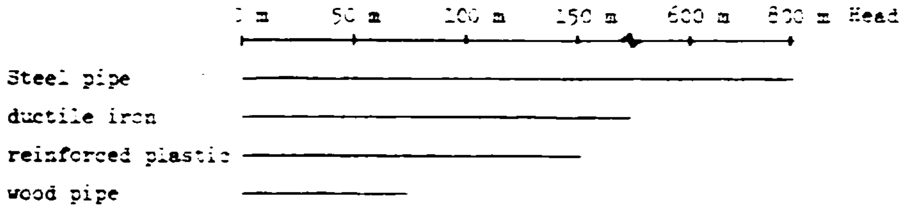
Compared to closed waterway systems, canals often demand inspection dependent on vegetation conditions and climate. Experiences from Norway show that canals are easily clogged up by rubbish, especially in forest grounds.

Because of fragile ice formation during winter, it must be possible to ice-cover the canals in frost periods. Fragile ice blocks up the intake gates, thus making av stoppage. For this reason, the velocity of the headrace ought not to exceed 0,5 m/sec in areas exposed to frost in periods. In other areas the velocity will be determined by the pitching materials used in the canal. Enclosure 2 shows cost and gradient for small canals. In spite of more inspections, canals may favourably be used in sloping ground instead of penstcoks. The reason is found when comparing cost and gradient for small canals with the cost of pipe.

Pipe

Generally

As mentioned above pipes constructed from various materials may be used. Different types and sizes of pipe may be combined to get optimal solutions. The account below shows the domains where the different types of pipe may be used. Here must be mentioned that steel pipe becomes expensive for lesser discharged heads, because the wall-thickness on this pressure level is not determined by the discharged head, but of rust and wear.



In connection with penstocks is it important to realize that the pipe cost often is a small item. Penstocks to power-plants must be laid over longer level ranges. This means foundations and levelling. In rough terrain, expences concerning this by far exceeds the cost of pipe.

The constructional cost, which not only increase with terrain conditions, but also with a larger diameter, are compared to the loss of head in the penstock, which reduces the energy production. Principally it is usual to make an estimate as shown below, to find the correct dimension of the penstock.

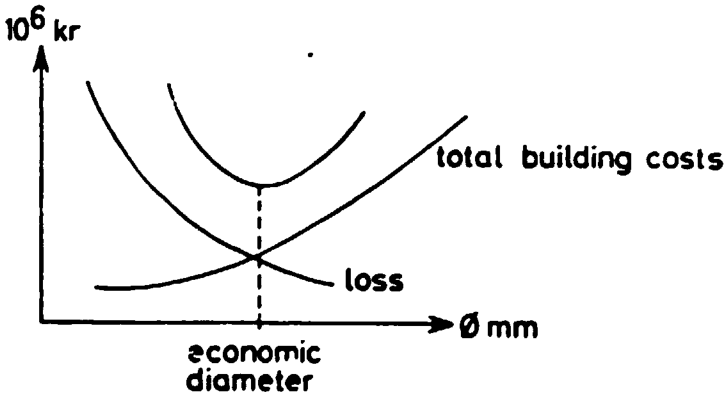


Fig. 8

Loss of head for pipe may be found by using Darcy-Weisback's formula:

$$h_f = f \cdot \frac{L \cdot V^2}{D \cdot 2g}$$

D = interior pipe diameter

V = water velocity [Norway has today approximate economic velocity (steel 3,5 m/sec. $< V <$ 5,5 m/sec.), (reinforced plastic 2,5 m/sec. $< V <$ 4,5 m/sec.), (wood 1,5 m/sec. $< V <$ 3,5 m/sec.)]

f = friction coefficient dependent on relative roughness, $\frac{\varepsilon}{D}$ and Reynold's number $R = \frac{D \cdot V}{\nu}$. f is best found in a Moody-diagram.

The friction coefficient will vary over time, especially for steel pipe, (corrosion, overgrowth etc.). The friction coefficient for steel, wood and reinforced plastic is indicated below. Welded, smooth steel pipes have least friction (this also apply to reinforced plastic). However, the friction increases with junction of rivets, and with corrosion. As a rule for rough valuations, the following estimate may be used: f steel = 0,020, f reinforced plastic = 0,014, f wood = 0,015, f ductile iron = 0,017.

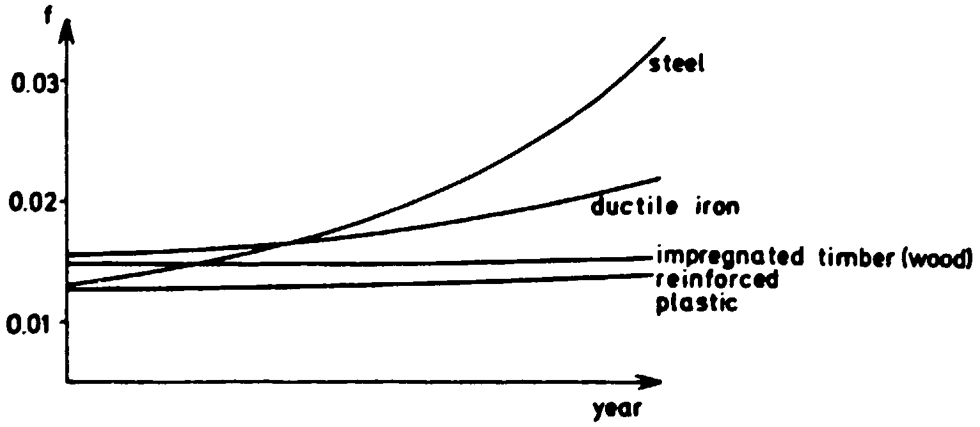


Fig. 9

When maintained, wood pipe may last approximately 30 to 40 years. Reinforced plastic pipe over-ground will probably last for a shorter period than earth covered pipe. Ductile iron will last as long as earth covered reinforced plastic pipe under the same conditions. Steel pipe over-ground will last approximately 40 years. In this connection the condition of the water (percentage of acid, sediment transport etc.) is very important. Steel is the best material when strength to withstand the wear from sand and gravel is considered, but it is less resistant against chemical substances and water with a low PH. Reinforced plastic and ductile iron have a better chemical resistance, and approximately the same durability regarding wear of sand and gravel. Wood (impregnated timber has less resistance against chemical wear, but a high degree of resistance against substances usually found in waterways.

Pipe costs

As mentiones before, the pipe cost may be a small item in the total penstock cost.

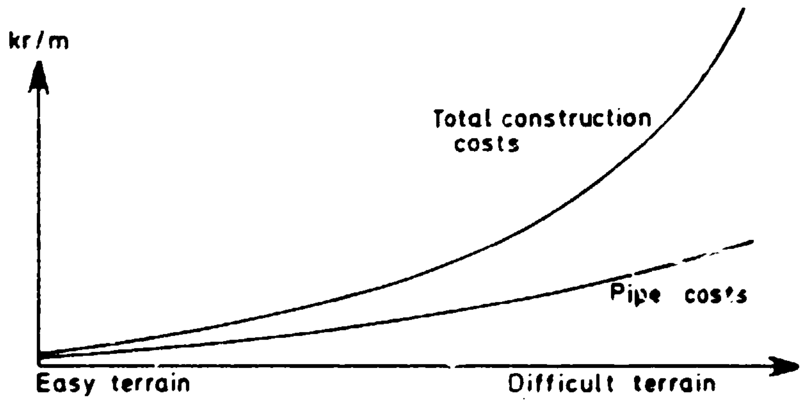


Fig. 1[illegible]

The figure shows in principle the proportions between pipe costs and total building costs.

With low heads and easy terrain, the type of pipe will have a strong influence on the cost figure. This is the reason for the current interest in Norway for wood pipe over-ground, if conditions for earth covered pipe are not especially suitable, in which cases reinforced plastic may be used. By using trenches, the number of supporting points may be reduced, because use of supporting points enhance the price of the penstock.

Enclosure 3-4 shows the cost figure for over-ground pipe and earth covered pipe.

Use and placement of pipe

The penstock line should be constructed in such a way that use of down-grades near the power-plant is possible. The higher the pipe is placed, the more the pressure is diminished and thereby the cost. This solution is limited by the line length, because increased length entails added cost and stability problems. Usually combinations of pipe types (wood, steel), is employed.

The stability of waterways often demands surge tank and flywheel effect (on turbine axle), especially by long penstocks or tunnels. If an ordinary surge tank cannot be constructed (difficult terrain etc.), it is possible to construct an air-filled surge tank. For penstock this will often increase the cost, and that is another reason for adapting the waterway to the terrain as shown in fig. 11.

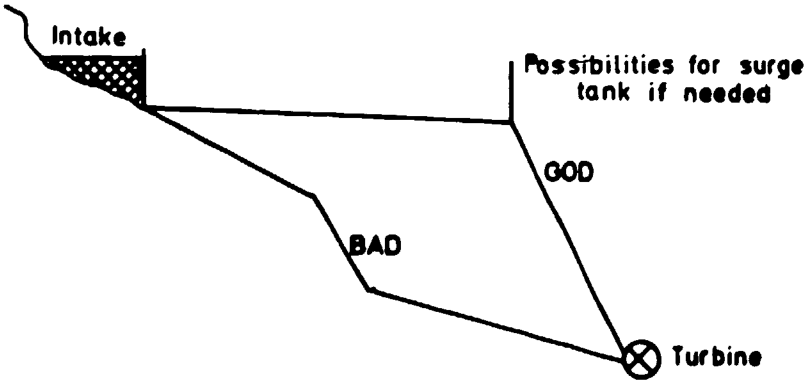


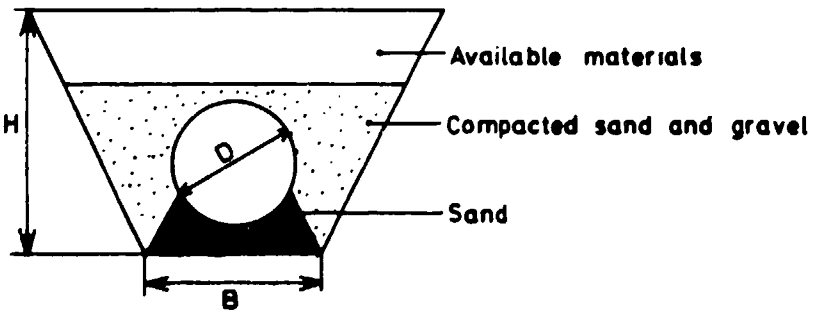
Fig. 11

The wall-thickness of the pipe must equalize the static pressure, and pressure variations by on/off switches. Pressure changes by on/off switches increase with velocity and length of pipe. For short lengths of pipe, (L < 100 m), the following calculation may be used: h = 0,1 H + 20 m. Necessary measurement will then be static pressure plus maximum pressure gradient, and this must not be exceeded.

To reduce the cost of pipe, the wall-thickness is adapted to the necessary dischared head.

For the operation of power-plants, producers of equipment prefer pipes with a high elasticity module. This favours the use of steel instead of reinforced plastic and wood, because pressure variations will not reach the same extent in these materials. The pressure waves will be absorbed by the pipe material, thereby not lasting long enough to influence the turbine regulator and thereby the net stability.

Reinforced plastic pipes and ductile iron are suited for earth covering. As mentiones before, it may then be possible to reduce the number of foundations and thereby the costs. With low heads the friction against the ground will function as a continous point of support. Earth covered pipes are not as easily exposed to wear, heat etc.



H = D + 1.5 m, B = D + 1m Earth covered pipe.

Fig. 12

For pipes on ground (mostly steel and wood, but also reinforced plastic), it is necessary to use points of support in deference to the weight of water and pipe, temperature variations (friction force), dependent on the friction coefficient f(which may be reduced by using pasteboard) (fig. 14), and the net weight of the pillars. The pillars have to be rock-fastened, because founding on moraine demands expensive supporting points. The spacing of steel pillars is ca. 8 to 10 m (dependent on pipe length), for wood pillars ca. 3 to 4 m.

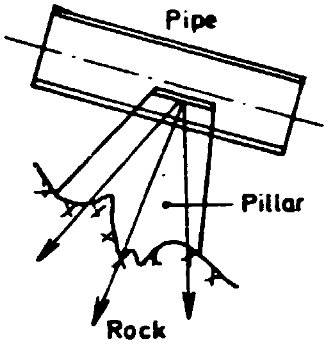


Fig. 13

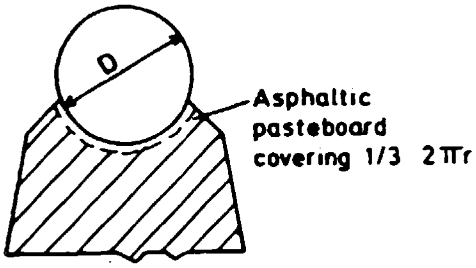


Fig. 14

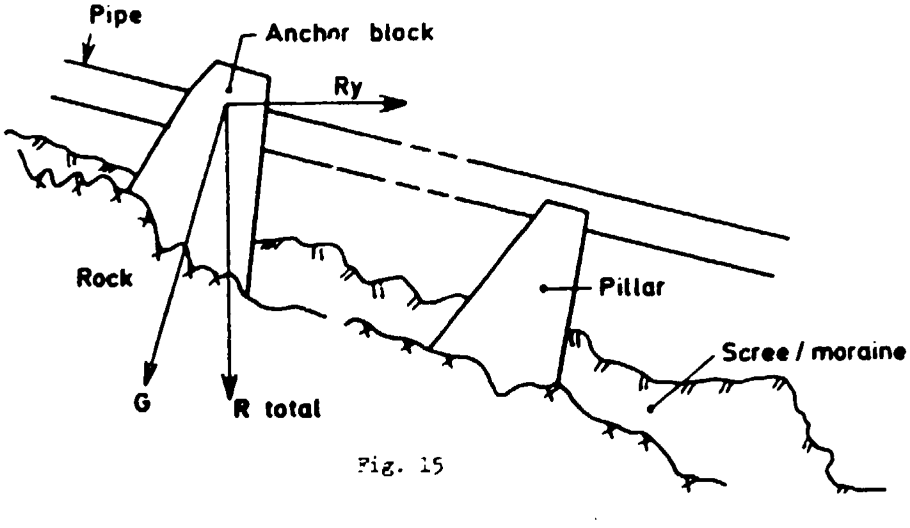


Fig. 15

The anchor blocks, erected at even intervals, have to hold water pressure from above in the direction of the pipe axis, water pressure from below in the same direction, the friction force from all the ground blocks, the axial component of the steel weight from above, and force from changes of the cross section.

P_1 = pf (f interior cross section of pipe)
P_2 = pf (p water pressure)
P_3 = f (Gs + Gv) cos α Gs = weight steel
Gv = weight water
P_4 = Gs sin
P_5 = $P_{1 \div 2}$ ($f_1 \div f_2$) changes in cross section
P_6 = friction caused by expansion

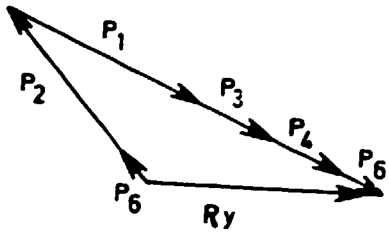


Fig. 16

Penstock

A penstock ought to have a minimum of positions of bend, because this enhance the price, and causes extra loss of head. If the penstock cannot be constructed as straight as possible, and by simple means in moraine grounds, this may cause considerable measurement problems regarding the stability of the penstock.

Enclosure 5 shows wood pipes on wooden trestles. This is a solution for flat terrain and low heads.

Types of pipe, advantages - disadvantages.

	Wood	Reinforced plastic	Steel	Ductile iron
Specific weight	1,6	1,5	7,9	-
E module kp/cm^2/$\cdot 10^3$	150	70	2000	-
Longitudinal expansion coeff. 10^6	4	20	12	-
Heat conductor number kcal/km °C	20	12	45	-
Max. diameter, meters	4	2,0	5-6	1,2
Max. pressure, "	65	160	1000	400
Friction ($h_f = f \frac{L}{D} \cdot \frac{v^2}{2g}$)	f = 0,015	f = 0,014	f = 0,020	f = 0,017
Durability against wear (gravel)	low	good	good	good
Durability against chemical substances	Acceptable	good	low	good
My be earth covered	partly	yes	partly	yes
Other points	Wood pipes may effectively be transported in bars. Possibilities for local production. Easy to lay. Need maintenance. Favourable regarding low heads and great quantities of water. Friction coeff. varies little over time.	Must be fabricated by special factories. Problems regarding joining. Sun influenced, may be earth covered Little overgrowth. Needs little maintenance. So far little used in powerplant constructions.	Is seldom earth covered. Rust-danger over time. Needs maintenance Friction increases with rust.	May be earth covered. Heavy transport. Does not rust.

Regulation installations

Generally

Figure 17 shows in principle the discharge for a river in Norway. Regulation installations can make interception of water possible, thereby increasing the production in periods when the load is high. For small power-plants this means, in most cases, that water is intercepted for use in periods when the flow normally is low. Regulation installations aim to balance the waterways's flow.

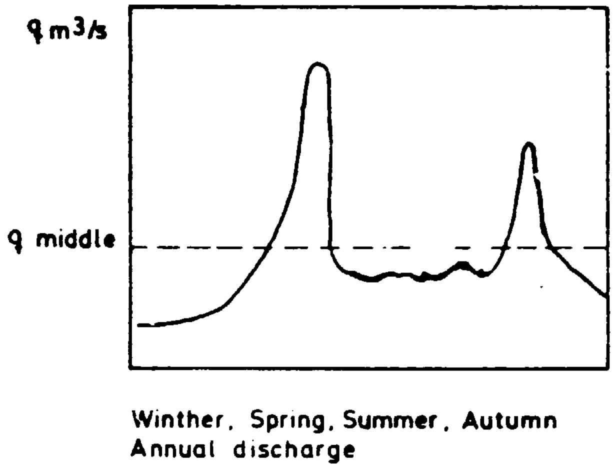


Fig. 17

In water conservation the best reservoir sites often are found in the upper part of the catchment area. This means that it is important to make the intake reservoir large enough for the daily, or preferably weekly, load variations. The draw off from the main reservoir may then be done at even intervals. Usually it is impossible to adjust the draw off from the main reservoir to daily consume variations. It is therefore of importance to enable the intake reservoir to take these variations.

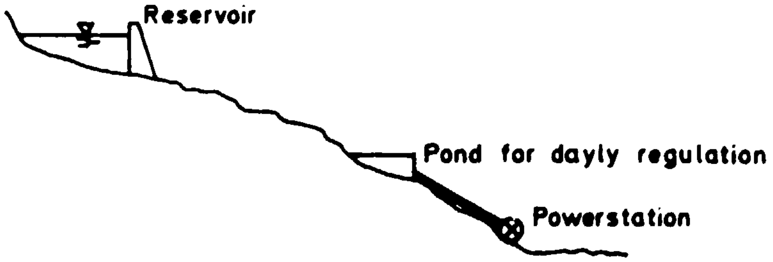


Fig. 18

Bigger plants will be aimed to erect sufficiently large reservoirs to intercept the water for use in high consume periods. If suitable lakes, which may be easily regulated, are not found in the area, big plants may stand the cost of artificially constructed reservoirs. The dams may become large and expensive, they will however, often be economically acceptable, because of the enourmous amount of energy, and the effect they represent for a larger plant.

Big dams are not of interest for small power-plants. The discharge is less, and/or the head of water is lower, or it may be possible to utilize only part of the waterway. Because of this, it is important to note that dams for small power-plants must be placed where the highest cubical contents per meter dam is to be found. For this reason, only big sills will be used for a necessary intake in river.

Topography, ground conditions and available recourses will determine the type of dam. The main types are:

GRAVITY DAM OF TRIANGULAR SECTION,
AMBURSEN DAM (FLAT SLAB DECK DAM),
FILLED DAM
ARCH DAM.

The local conditions will determine the solution for all these dams. In Norway, small dams will be standardized with special instructions etc. to prevent injudicous construction, and thereby accidents.

Gravity Dam of Triangular Section.

This dam is constructed of concrete, brick or stone-blocks. The dam resists the pressure of water mainly by its own weight. The basic form b : h, is constant. The main forces are water pressure (increase linearly with the depht), net weight, upward pressure of water which may be compressed in the base joint and ice pressure in areas exposed to frost in periods.

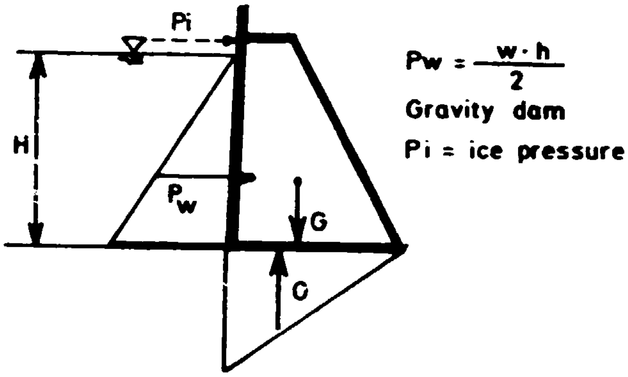
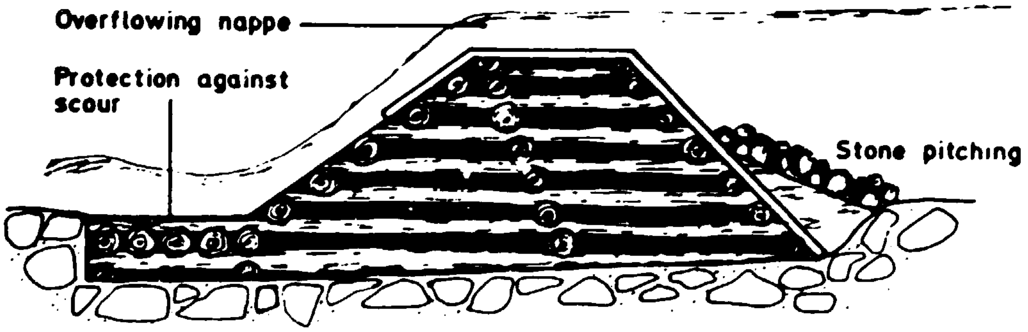


Fig. 19

Problems in the base joint may be reduced by injection of cement or by draining. The principle of a Gravity Dam of Triangular Section is shown in enclosure. This dam is of interest for small power-plants because of the simple construction, and the various building materials which may be used. Dam walled of stone-blocks must have a watertight slab upstream.

Rockfilled Timber Dam is constructed by the same principles as the Gravity Dam of Triangular Section, but is less expensive. Because of the settlement of the dam, the log walls should not be vertically erected, and a watertight slab must be placed upstream. In Norway, peat is usually prefered for waterproofing.



Rockfilled timber dam Fig. 20

Ambursen Dam (Flat Slab Deck Dam).

The Ambursen Dam has less weight, and because of this it has an inclined upstream face to get a vertical component of the water pressure. The slab is reinforced and stretched between wallshaped pillars, which is spaced 4 to 7 m. Forces and stability calculations are similar to the Gravity Dam, upward pressure excepted. This pressure is greatly reduced because of less contact surface in the base.

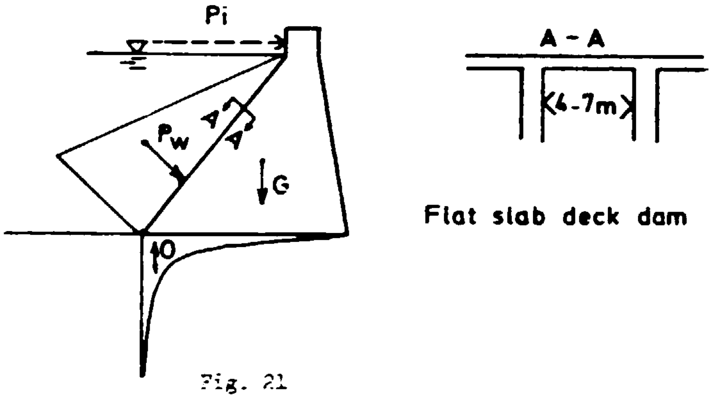


Fig. 21

The Ambursen Dam is not suitable for small power-plants, but where the dam site is short, and a high embankment is prefered, this dam may be of interest.

Filled Dams

Earth dam, stone/gravel dam and rockfill dam are the most common types. Where impermeable materials are inavailable, asphalt, peat etc. will be of interest as waterproofing materials.

For filled dams use of cheap masses is desired. In most cases the masses are not sufficiently compact, and a watertight core is required. This core is made of impermeable material or of a compact material (concrete, wood, asphalt).

Filled dams for small power-plants are suitable where the dam profile is long, and in combination with other types of dams to increase height of swell. It is necessary that all the possible filling masses are available in the vicinity of the dam site.

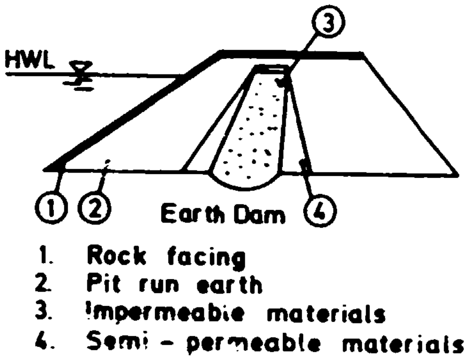


Fig. 22

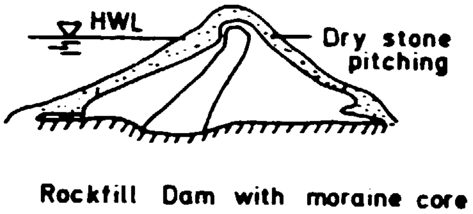


Fig. 23

Common denominators for the dams

Foundation on rock is unnecessary unless for Ambursen dams, however the ground should be cleared to hard ground for all dams (Filled dams, Gravity dams). Spillway is necessary, especially for filled dams because this type of dam has little resistance against overflow. For filled dams the spillway should be separately made, and to prevent overflow, freeboard should be placed an adequate distance above HWL (4 m).

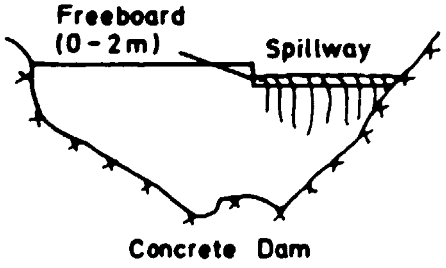


Fig. 24

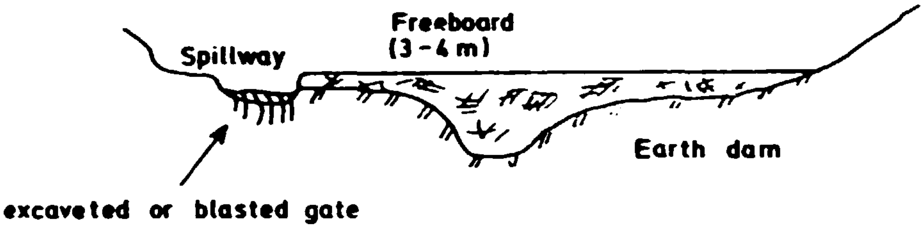


Fig. 25

To reduce overflow, flood-gates may be installed. This reduce the height of the freeboard, while simultaneously, less areas are overflowed during floods. In many cases, reduced freeboard may reduce the cost of the dam to such an extent that the gate is profitable for this reason only.

The following is a summary of the most important advantages and disadvantages for the various main types of dams. Enclosure 6 shows in principle the cost of the various dams. It must be noted that the topography, in most cases, determines the type of dam.

Enclosure 7, 8, shows in principle Rock-Filled Dam with moraine core, Gravity concrete dam, Ambursen dam.

Type of dam	Advantages	Disadvantages
Gravity dam of triangular section	Simple construction. Needs little skilled labour. May be founded on loose ground in some cases.	High upward pressure. Incalculable factual force conditions. Needs much concrete (low dams may be walled of stone in mortar).
Ambursen dam (flat slab deck dam) 5-15 m	Needs little concrete. Small upward pressure.	Reinforcing. Needs skilled labour. Should be founded on rock.
Rockfilled dam > 5 m	May be placed on thick layer of gravel. Cheap for big dams.	Needs material deposits in the vicinity of the dam. Separate spillway, must not be flooded.
Earth dam < 10 m	May be placed on loose ground. Reasonable cost of materials.	Crest level on 4 m above HRV. Needs stone cover on upstream face.
Wooden dam < 4 m	Cheap and simple construction. May be placed on ground of sand and stone.	Limited durability. Needs much maintenance

Gates

Stop logs give an inexpensive cut off of small apertures. The logs are pushed down in vertical folds, as shown by figure 26.

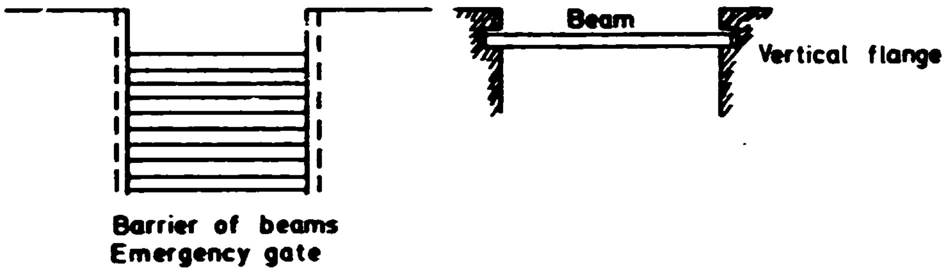


Fig. 26

Barriers of Vertical Beams are suitable for long and low apertures. The beams (wooden) are placed vertically in series.

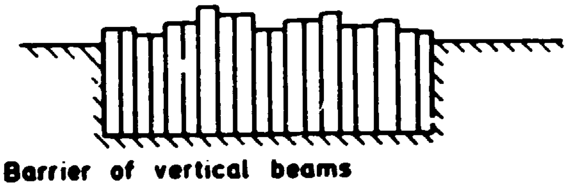


Fig. 27

Slidegates of wood or steel are easy to handle. These gates usually give a better protection against floods, because of their possibilities for greater dephts. Great lifting power is required, and this may entail expensive capstans.

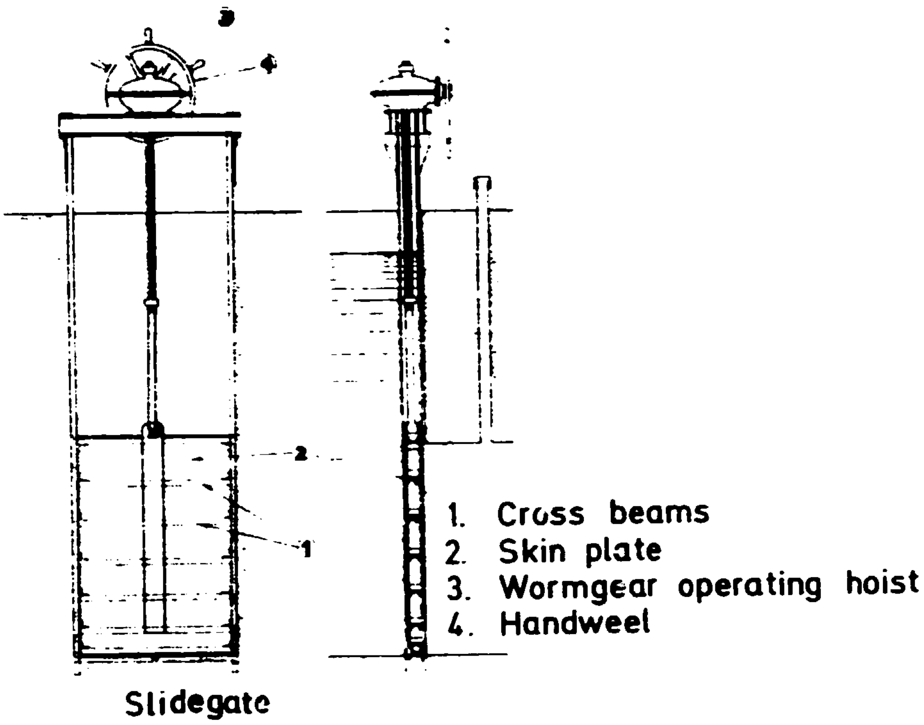


Fig. 28

To close greater apertures, Fixed Roller Gates usually replace Slidegates.

Trash rack

A trash rack is necessary to prevent trash etc. to destroy the turbines. It is often constructed of flat, galvanised steel bars spanning from top to bottom and inclines at 2:1. The inclination, and the narrow footpath not more than 0,5 m above the water at the top, have by experience been found to give the best performance with regard to cleaning off ice and trash (fig. 29). The water velocity through the rack should be less than 1 m/s. To prevent ice on the bars it should be dived in areas with frost, because ice on the bars increases the head loss.

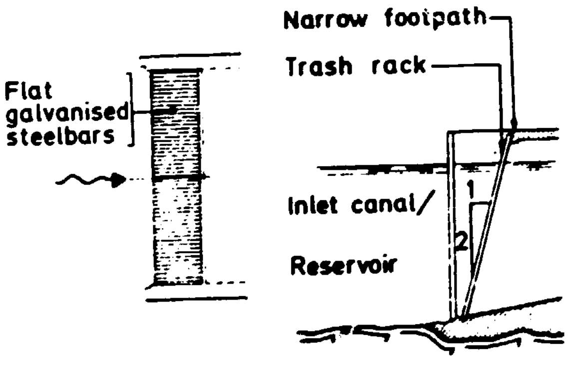


Fig. 29

General layout

The power plant's layout depends on its size and the location of turbine, generator and transformer.

The building has to have ventilation, light and, in some cases, lifts and cranes.

Figure 29 shows the constructional principle of a small power plant. The foundation is made of concrete, and is securely fastened to the ground. Walls and roof may be built of localy available materials (i.e. wood, stone etc.), but the wall where the switch gear is erected, has to be built in some incombustible material, as for example brick.

In industrialized areas it may be convinient to use concrete-elements or metall-plates (aluminium, iron). In Norway, where extensive use of small power-plants is practicable, the possibility of producing standardized buildings is beeing considered.

When constructing small power-plants use of mobile cranes should be prefered.

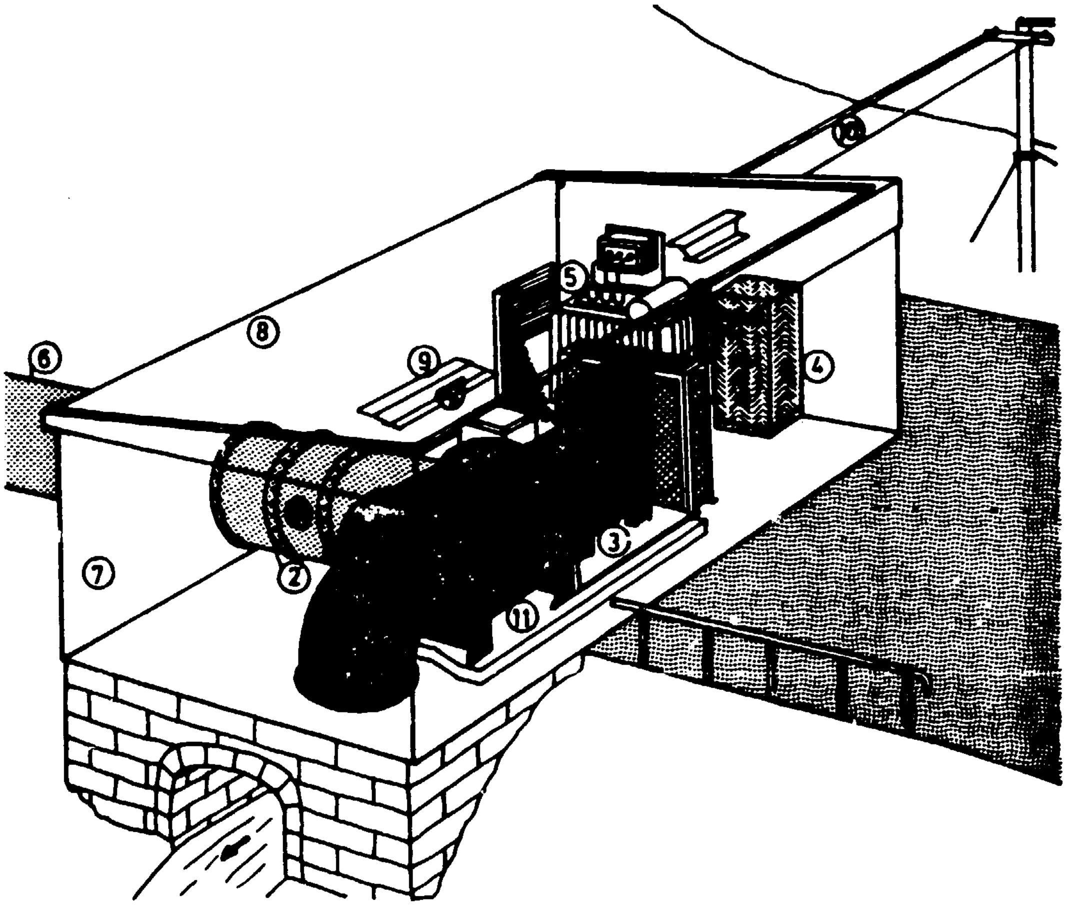
The building ought to be made as small as possible. This can be achieved by placing part of the equipment, as transformer and ventilator, in the open.

To make control and replacement of defective parts easier, the roof or one of the walls should be easily moveable. This permits easy access for the trucks to the stationary equipment.

Where it is possible, turbine and generator ought to be placed on a frame, which should be secured to the foundation. Repair is simplified when removal of the whole frame is possible. With such timesaving devices it is also possible to reduce the loss of energy.

Enclosure 6 shows the total costs of a power-plant with building, turbine, generator etc.

Note: Several photographs have been omitted due to the fact that only a poor copy was produced.

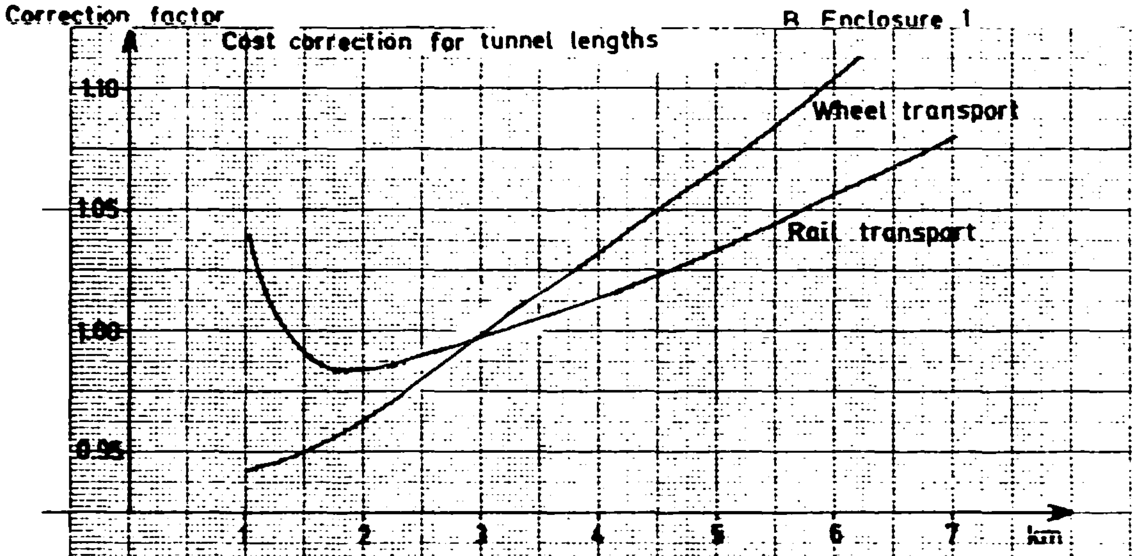


Constructional arrangment of a power plant

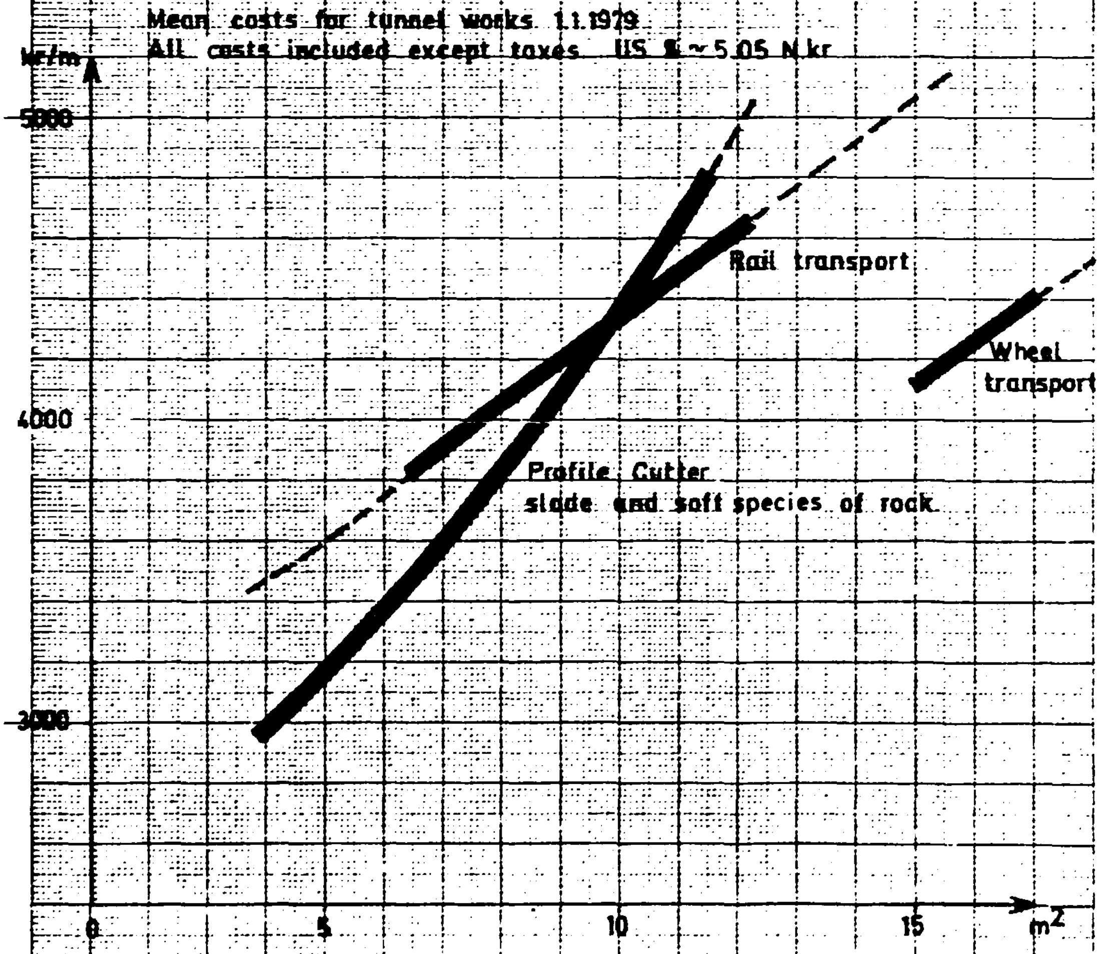
1. Francis turbine
2. Valve (Butterfly valve)
3. Generator
4. Switchgear
5. Transformer (If possible it should stay in the open)
6. Pipe
7. Walls of sheap materials (wood, brick)
8. Roof, easy movable
9. Crane (not necessary)
10. Grid
11. Frame (metal)

Fig. 29

B Enclosure 1



Cost correction for tunnel lengths



Mean costs for tunnel works 1.1.1979
All costs included except taxes US $ ~ 5.05 N.kr

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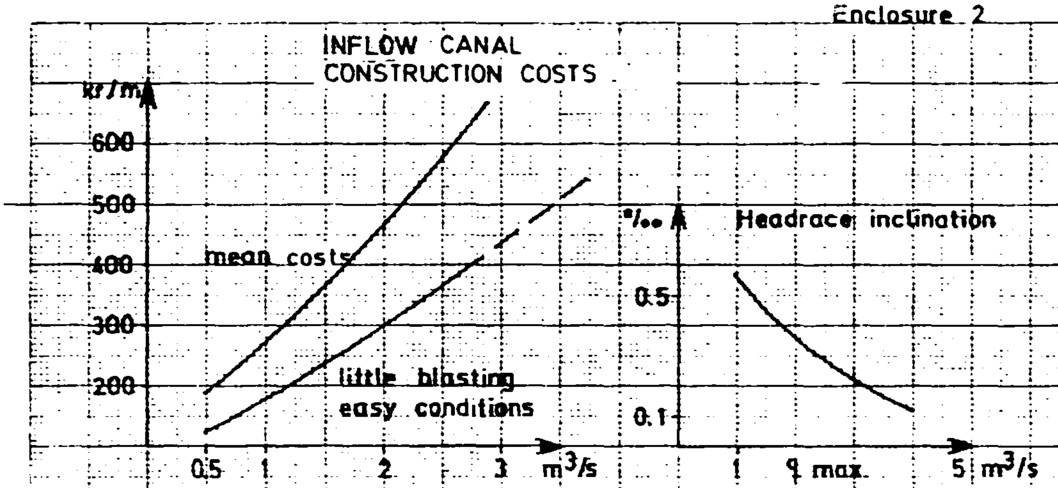
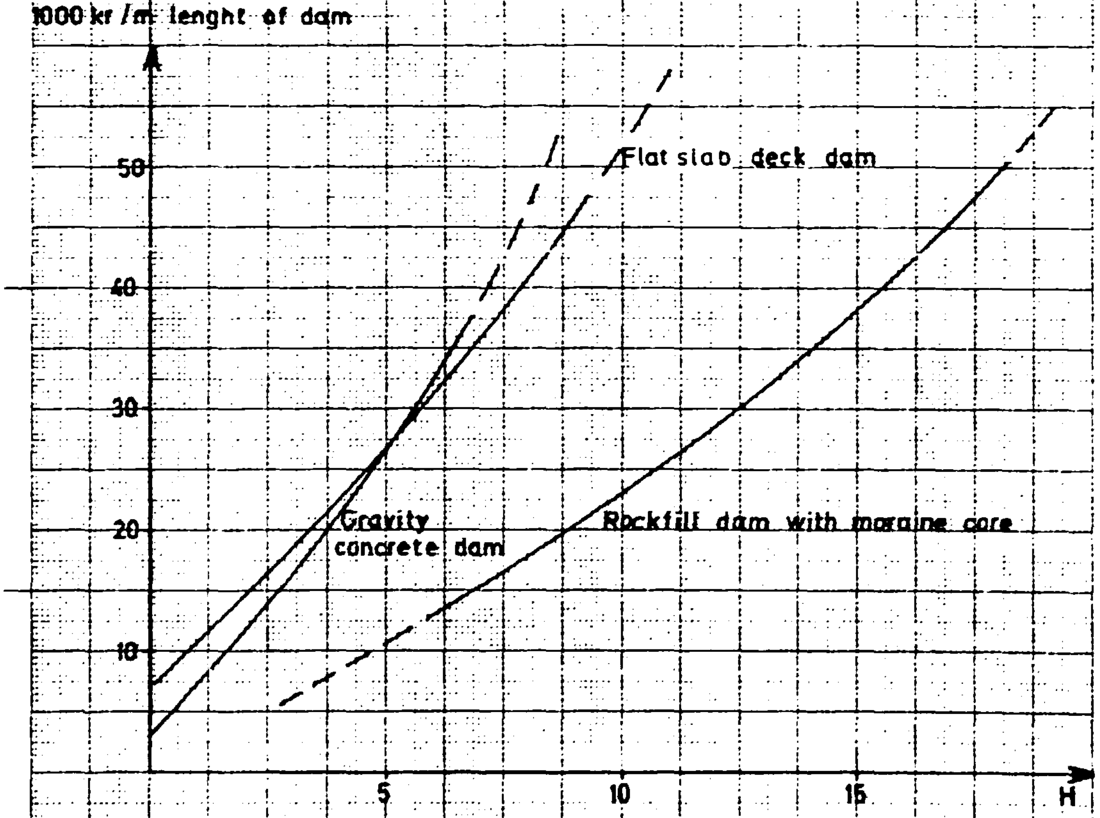
Enclosure 2



MEAN COSTS FOR DAMS. ALL COSTS INCLUDED
EXCEPT TAXES. 1.1.1979 US $ ~ 5.05 N.kr



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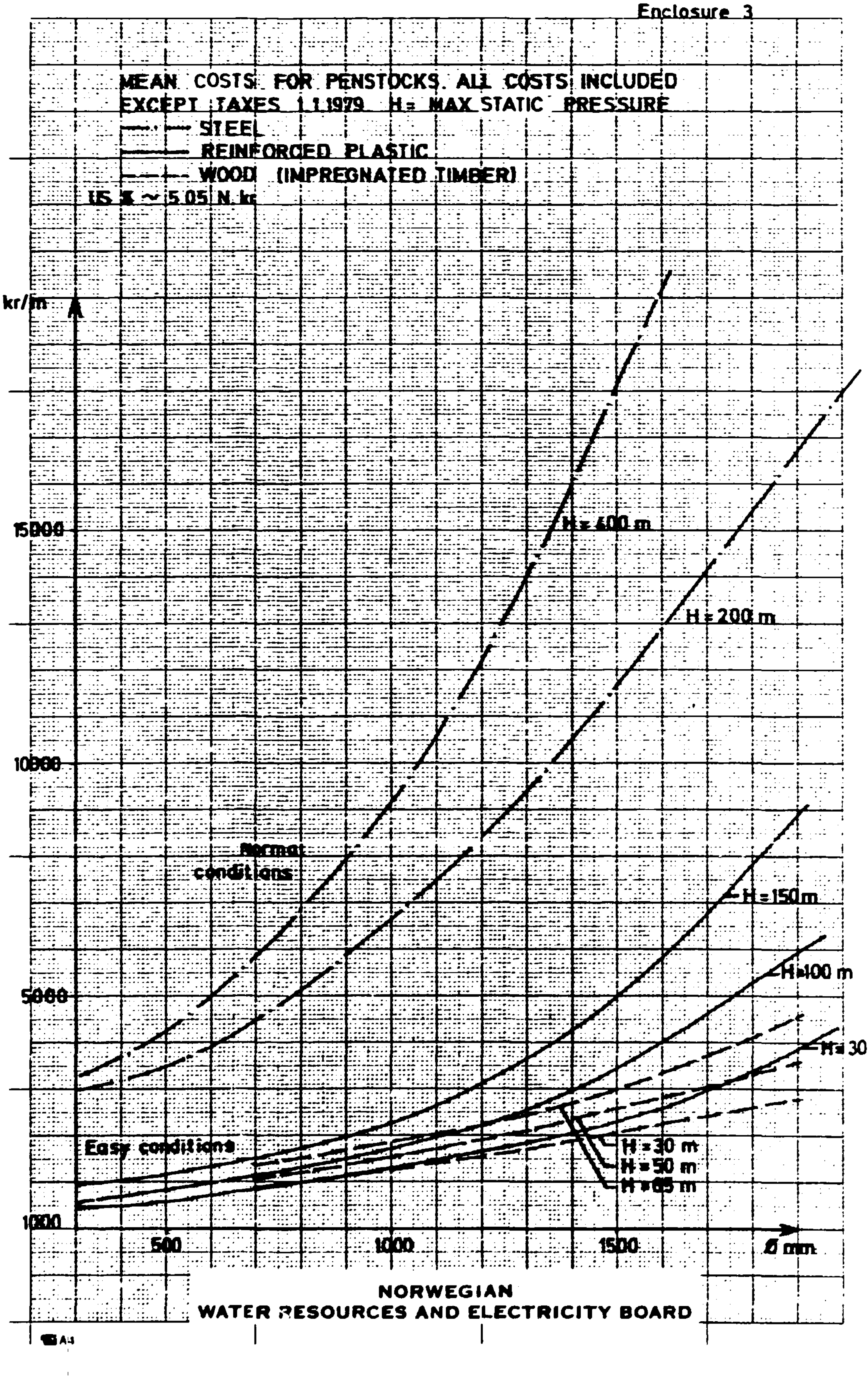
Enclosure 3



MEAN COSTS FOR PENSTOCKS. ALL COSTS INCLUDED EXCEPT TAXES 1.1.1979 H= MAX STATIC PRESSURE

NORWEGIAN
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Enclosure 4

NORWEGIAN
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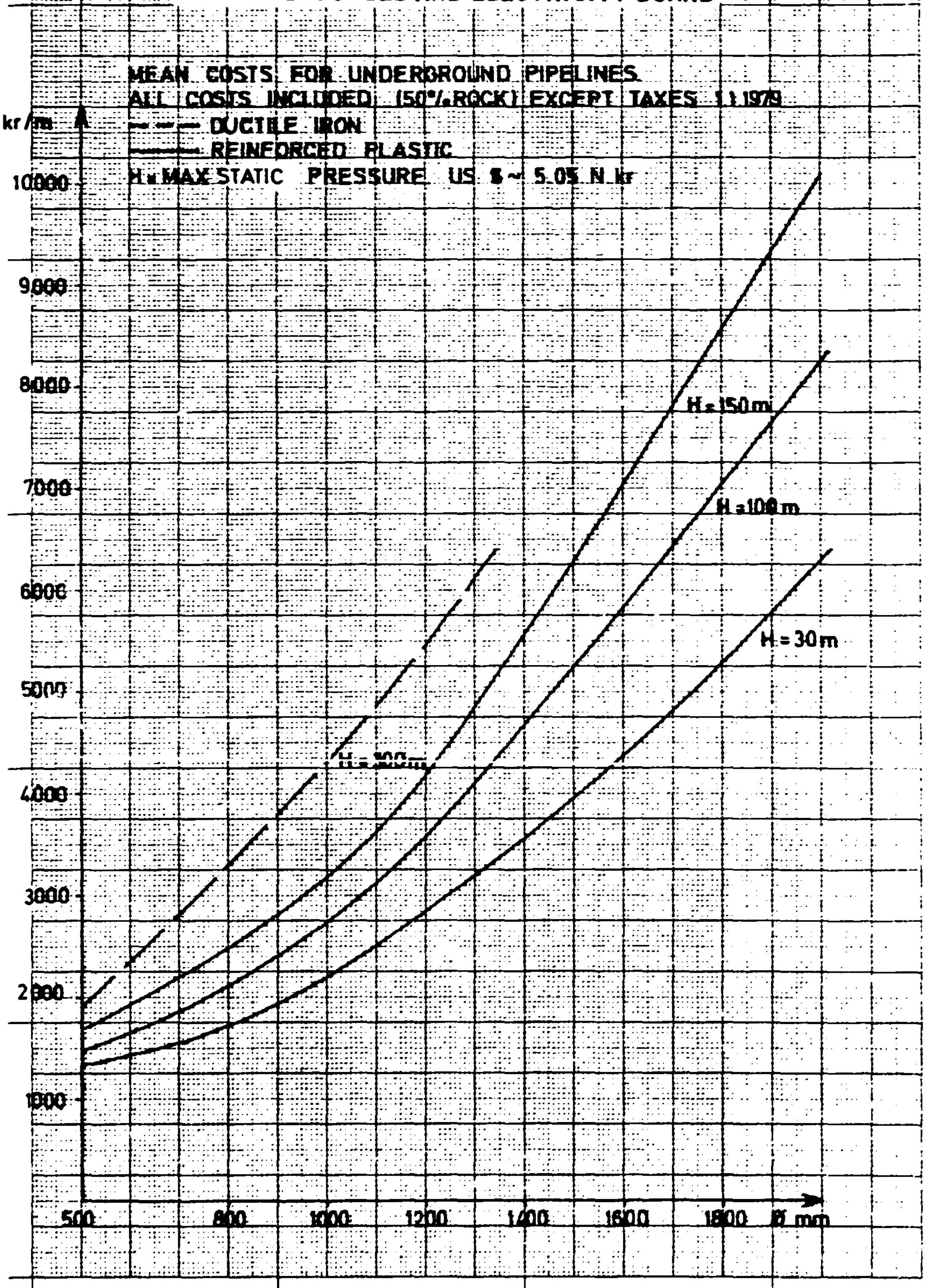
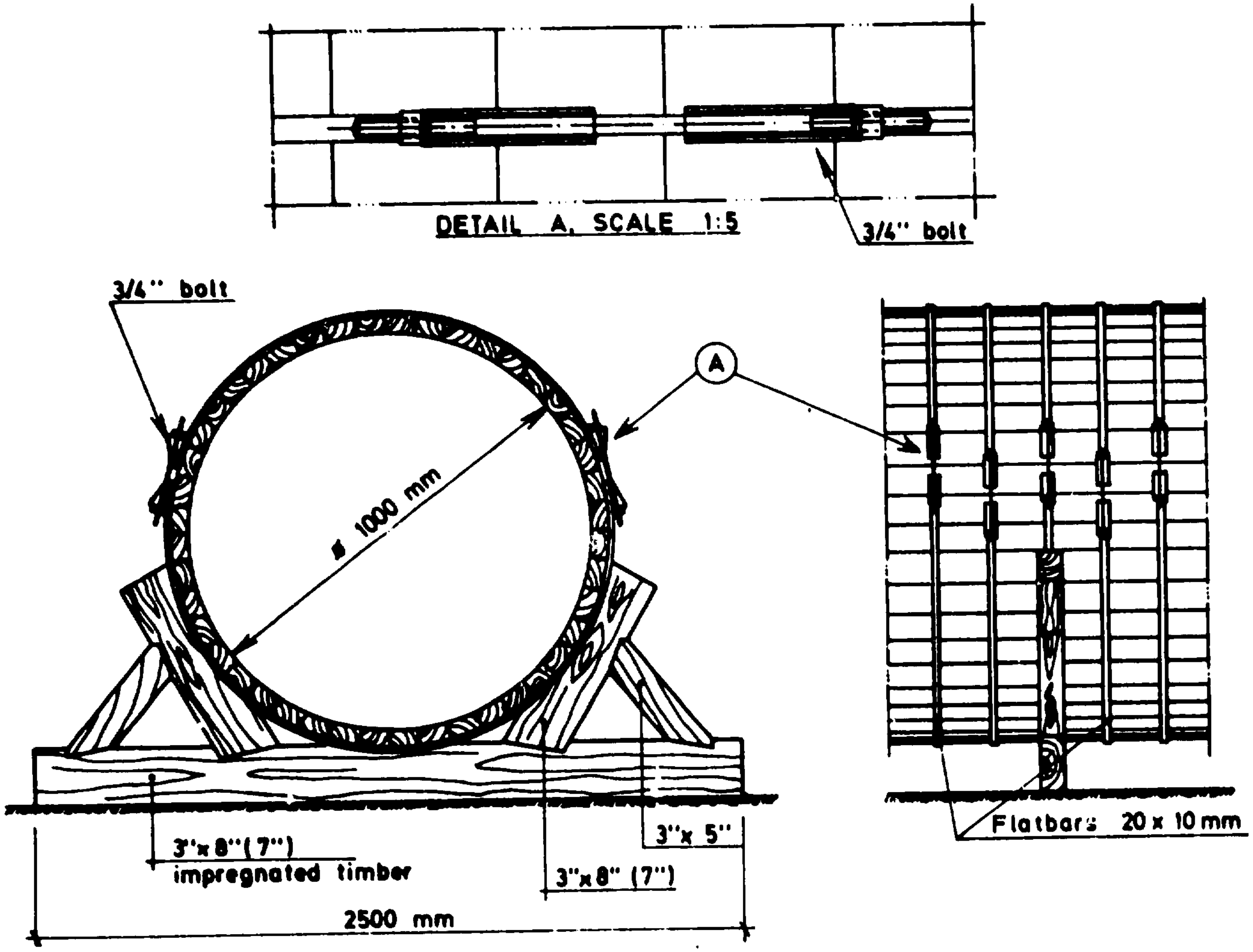


MEAN COSTS FOR UNDERGROUND PIPELINES
ALL COSTS INCLUDED (50%ROCK) EXCEPT TAXES 1.1.1979
— — — DUCTILE IRON
——— REINFORCED PLASTIC
H = MAX STATIC PRESSURE US $ ~ 5.05 N.kr

Enclosure 5

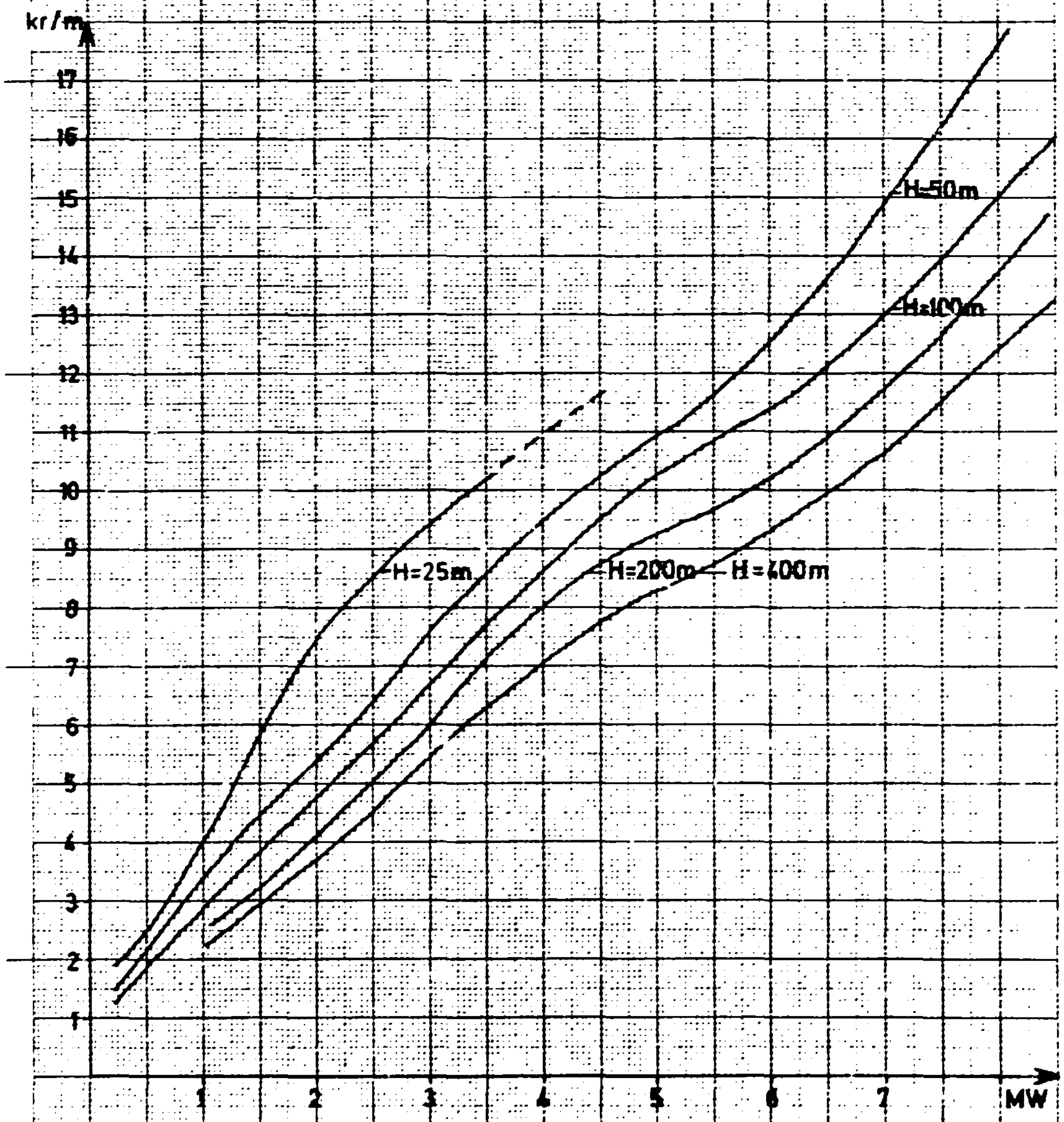


NORWEGIAN WATER RESOURCES AND ELECTRICITY BOARD

Enclosure 6

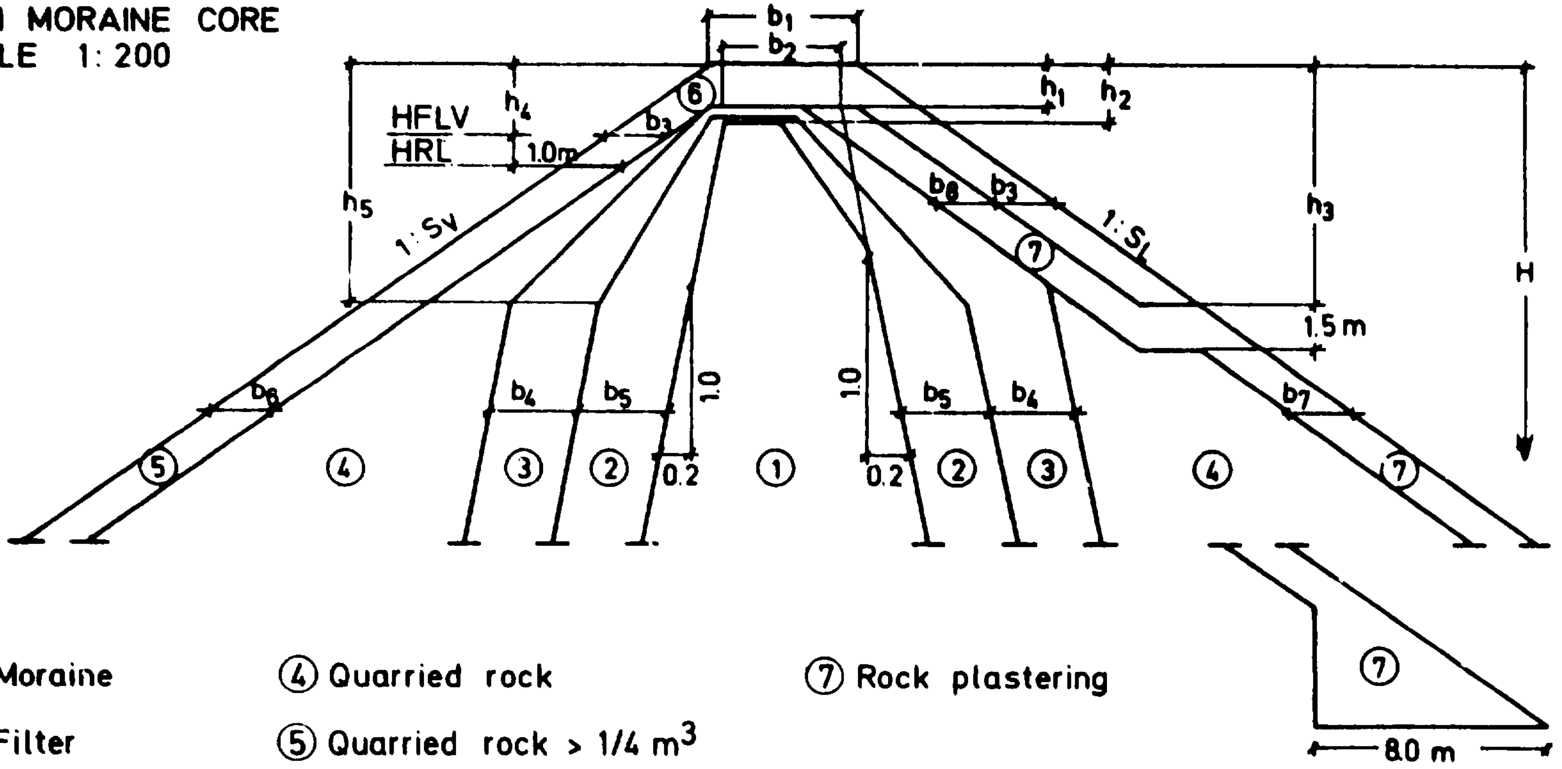
MEAN COSTS FOR POWER-PLANTS, EQUIPMENT INCLUDED (TURBINE, GENERATOR, ETC.) ALL COST INCLUDED EXCEPT TAXES 1.1.1979

H = MAX STATIC PRESSURE   US $ ~ 5.05 N kr



NORWEGIAN
WATER RESOURCES AND ELECTRICITY BOARD

ROCKFILL DAM
WITH MORAINE CORE
SCALE 1: 200



① Moraine

② Filter

③ Transition

④ Quarried rock

⑤ Quarried rock > 1/4 m^3

⑥ Quarried rock, 50% >1/2 m^3

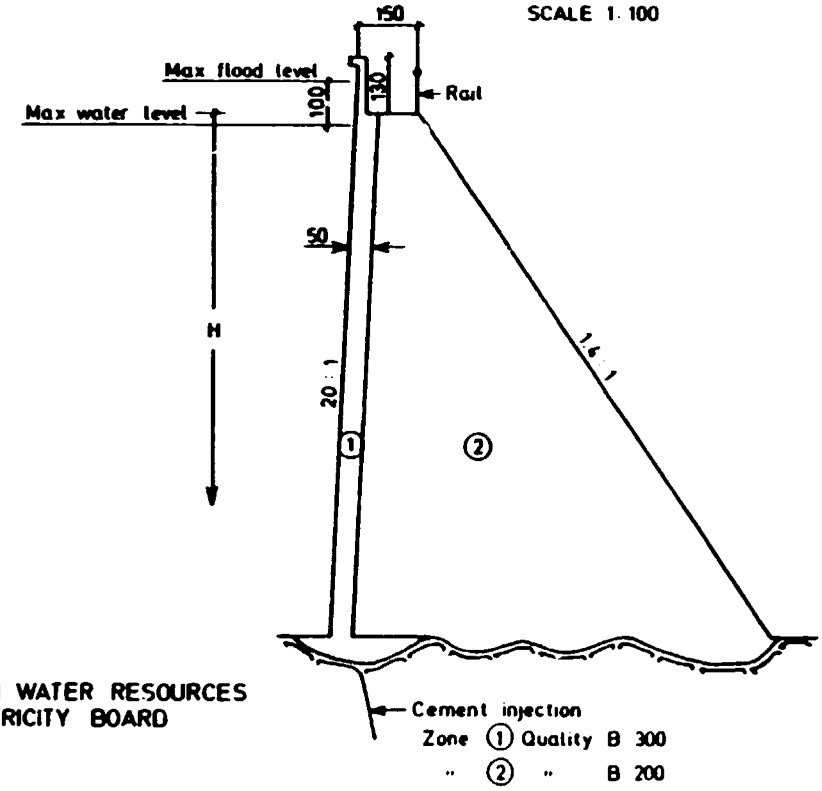
⑦ Rock plastering

NORWEGIAN WATER RESOURCES AND ELECTRICITY BOARD

Enclosure 7

Enclosure 8

GRAVITY CONCRETE DAM
SCALE 1:100



NORWEGIAN WATER RESOURCES
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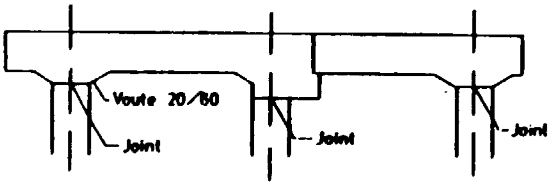
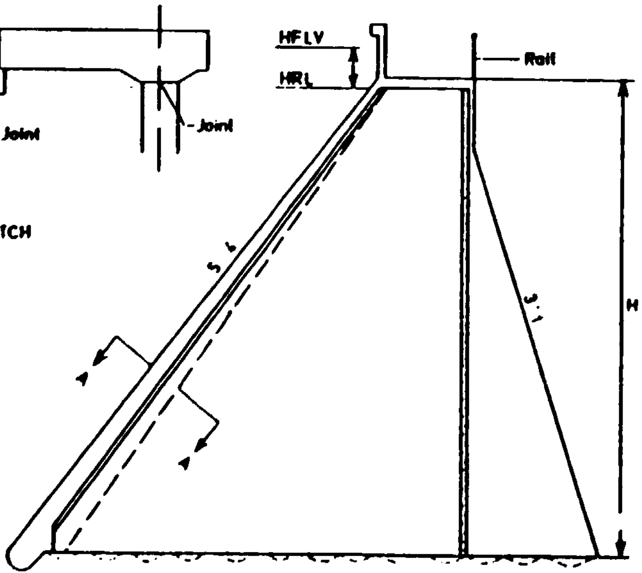


A - A
HORIZONTAL SKETCH



NORWEGIAN WATER RESOURCES
AND ELECRICITY BOARD

FLAT SLAB REINFORCED - CONCRETE STRUKTURE
SCALE 1:100

HYDROLOGY OF SMALL CATCHMENTS

by D. Lundquist, Hydrologist, The Hydrological Department, NVE

Traditional hydrology

Hydrological data used for planning and operating hydro power-plants is based on observed runoff series. If available, the hydro power planning is based on runoff series from the river system concerned, or if these are not available, series from nearby rivers. For quantitative estimates precipitation observations are also regularly considered.
When planning projects with large catchment areas, the hydrological data are usually represented by monthly or weekly mean discharges. However, for projects in small catchment areas where the possibility of storage resevoirs is limited, the short time variation of the runoff will play an important part for planning and operation. Here it will be a necessity to make use of daily mean discharge series.

Today, computer simulation programmes play an important part in the planning of hydro power projects. Runoff series, preferably of 30 years length, which represents the catchment area for the project are used as input in the simulation programmes for computing the annual power production (kWh).

Other input parameters are reservoir volume, turbine capasity and waterway dimensions. Computation with a set of different parameters which gives a set of different output results is used to decide the project's design.

For simplified analysis it is usual to construct duration curves for the runoff. Construction of summation curves for deciding optimal reservoir volume and annual power production has been a commonly used technique in the past, but today simulations by computer has outdated the summation curves.

For larger dams there are several regulations and restrictions regarding design and spillway construction, which require flood statistics and analysis based on runoff series. To decide flood frequency, empirical equations are also in use.

The operation strategy of small scale power projects is usually based on experience, sometimes supplied with snow surveys in the catchment area.

As small power-plants often have limited reservoir capasities, it is only possible to plan the operation strategy for short periods ahead. For this purpose hydrological analysis is not generally used.

Utilizing hydrological models

A brief outline of the traditional use of hydrological data for planning and operating hydro power stations has been given in the previous chapter. During the last years, however, the use of mathematical hydrological models as a supplement to the traditional hydrology, has been introduced.

Frequently representative hydrological series are not available for power plants in small catchments. Observed series often represent much larger areas than the small catchments concerned, and may, even be measured in another river system. In some projects, however, there has been installed a temporary discharge station representing the small catchment, but only a shortterm serie is available, perhaps only one or two years of record. In this latter case representative data excist, but the observation period is too short.

Both of these hydrological data problems can be handled with the help of a hydrological model which simulates runoff series for the catchment. Where representative observations are completely missing, the model must be calibrated by other available data. The conditions in the model are then changed in accordance with the differences between the calibration catchment and the catchment to be developed. When short term observations excists, the model is calibrated to extend these data to a longer serie.

A common type of such hydrological models are precipitation-runoff-models where a simplified catchment is described by mathematical expressions. This type of model is able to transform observed precipitations data into a simulated runoff serie. As an example, the Norwegian SNSF-model and a practical application will be briefly described.

In the SNSF-model the catchment area is devided into subbasins of different character, (fig. 1), and the water transfer through each subbasin is simulated by a system of tanks. Consequently one set of parameters describes the main structure of the catchment, and a second set of parameters describes the individual properties of the subbasins. The catchment area is also devided into different altitude zones for computation of areal precipitation and snowmelt, which results in a third set of parameters describing the topography and climate of the catchment. These three sets of parameters make it possible to define a fairly representative model of a Norwegian catchment.

When planning four small hydro power plants in a river nearby Oslo with a catchment area of 465 square km, a practical application of the SNSF-model was done (fig. 2). Since there were no available runoff data for the river, the model was calibrated with data from a nearby river system (A) and then transformed to the river concerned (B) by using information about topography, climate and use of land. The calibration was carried out with precipitation data from ganging station no. 1 and no. 2. When simulating the runoff for river B, precipitation data from stations no. 2 and no. 3 were used. By this method an artificial runoff series of 20 years length was simulated for river B. This series was then used during the planning of the four power-plants.

During operation of hydro power systems, hydrological models can also be used to give valuable runoff prognoses. With an updated model the hydrological conditions in the catchment are known, and expected input to reservoirs and plants can be simulated with the help of quantitative weather forecasts. This method has so far not been applied to the operation of power - plants in small catchments.

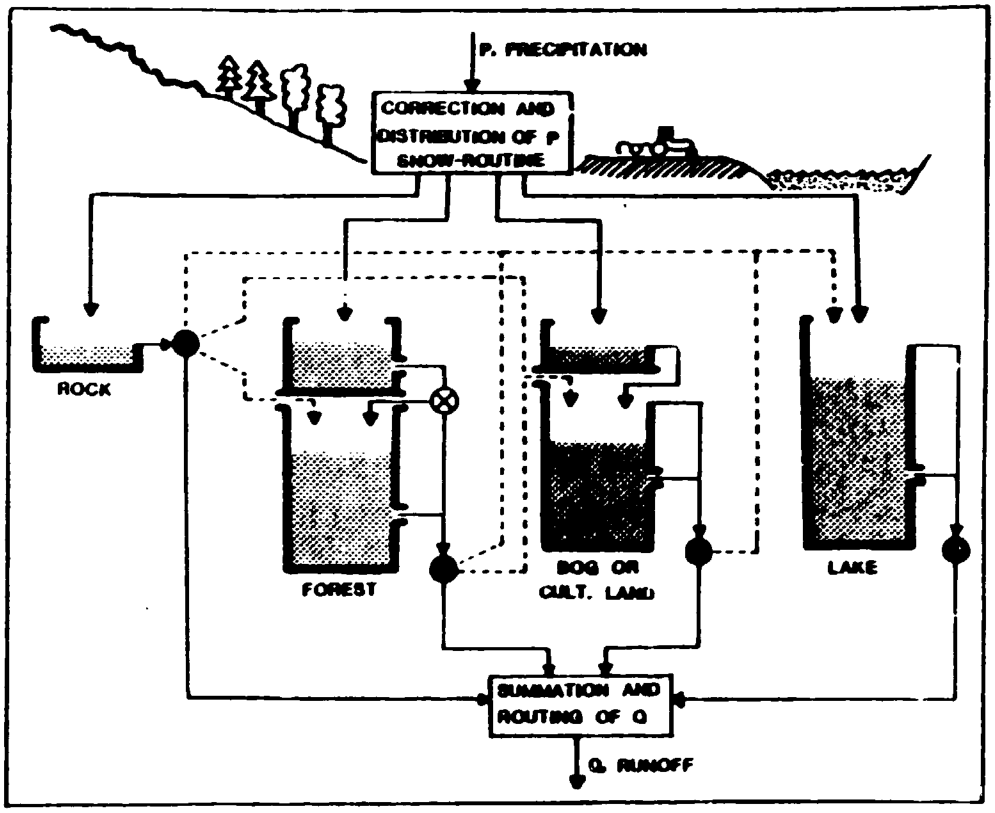


Fig. 1 The SNSF-model.

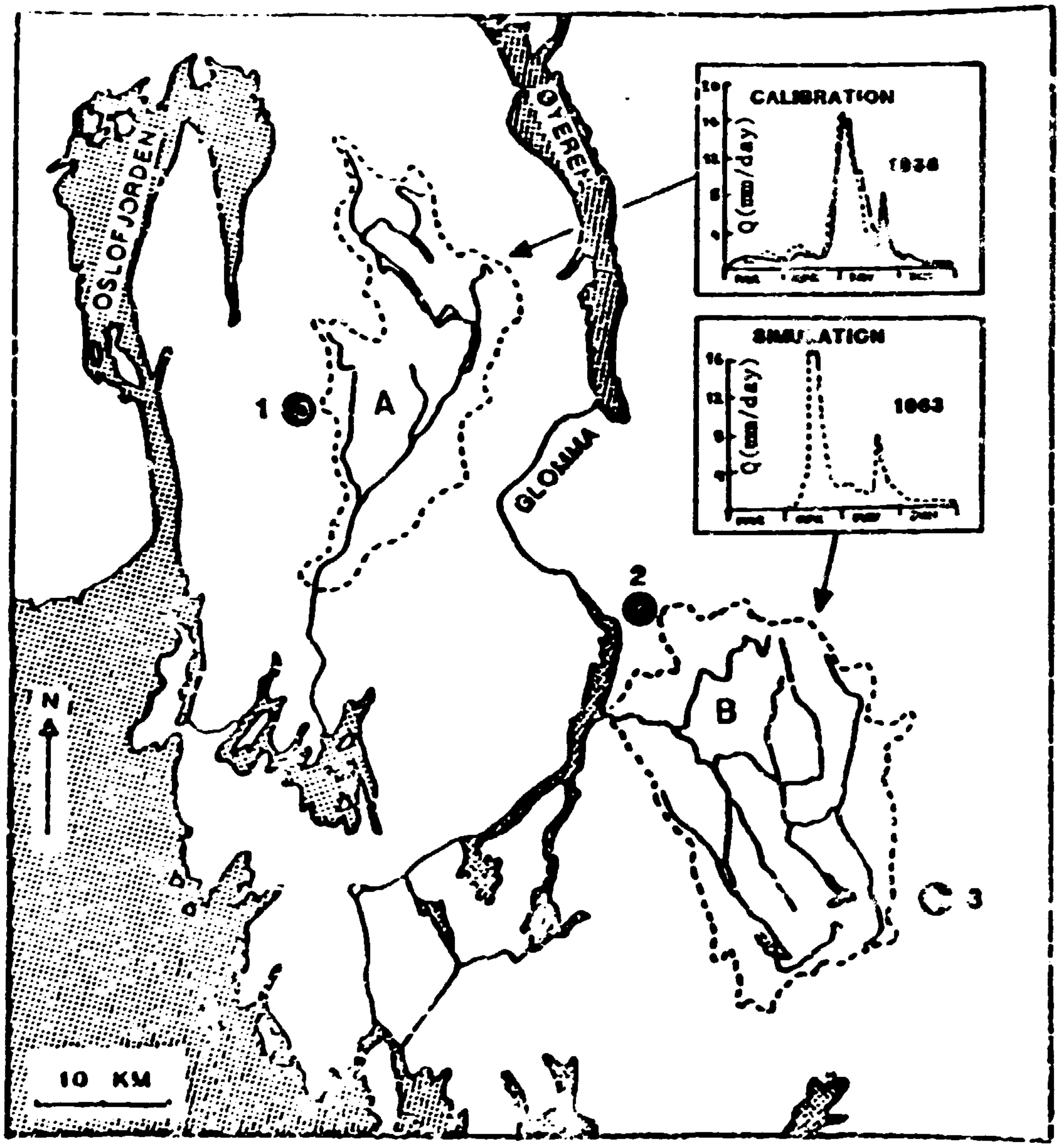


Fig. 2 shows use of the SNSF-model for simulation of a runoff series when planning small power-plants in a waterway.

WATER SUPPLY AND ENERGYPRODUCTION

by T. Jensen

In mountanious countries like Norway, water supply often is based on water with high static pressure. This frequently has a head which make use of pressure reduction valves necessary. The valves will prevent use of expensive pipe materials in the distribution network. In Norway, maximum hydrostatic pressure is not allowed to extend 70 m.

The energy will be killed in the pressure reduction valves. To prevent this one should aim to use turbines and thereby reduce the pressure and produce energy. In addition to the powerplant with stationary equipment, it is the reinforcement of the penstock to adapt it to the static pressure and occasional on/off switches, which makes the additional costs.

To lower the cost one should use mechanical and electrical equipment manufactured in great series. The turbines can be altered pumps, which will have approx. 30 % of the usual turbine cost, but with an unfavourable efficiency curve (see fig. 1).

However, the pointed curve is no hindrance, because the flow through the pipe often remain constant. The distribution reservoir takes the 24 hourly variations.

When it comes to service and maintenance, the pump is favourable. It also has a relatively high r.p.m. which does not require a gear to raise the r.p.m. to suit the generator. When looking at the efficiency curve it is obvious that the pump must operate on constant flow. Load variations must therefore be arranged by load-divertion by simple adjustable water resistances.

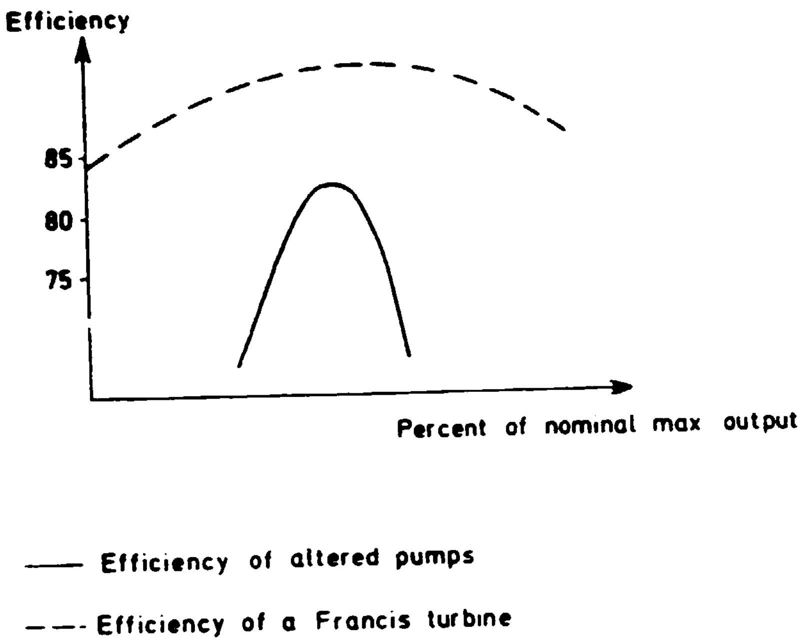


Fig. 1

An example showing the combination of water supply and small power plants.

Figure 2 shows an existing water supply plant where the inlet is placed at c.l. 800 (800 m above sea-level) and the distribution reservoir at c.l. 230. Four reduction valves are installed from c.l. 800 to c.l. 230. An examination has proved it possible to replace these with two turbines. One of these is supposed to be altered pump. The annual energyproduction are expected to be 1,8 GWh and the total additional costs are estimated to 1,70 mill.kr 1.1.79 (US $ 1 = 5,05 Nkr), this means 0,94 Nkr/kWh. The cost does not include taxes.

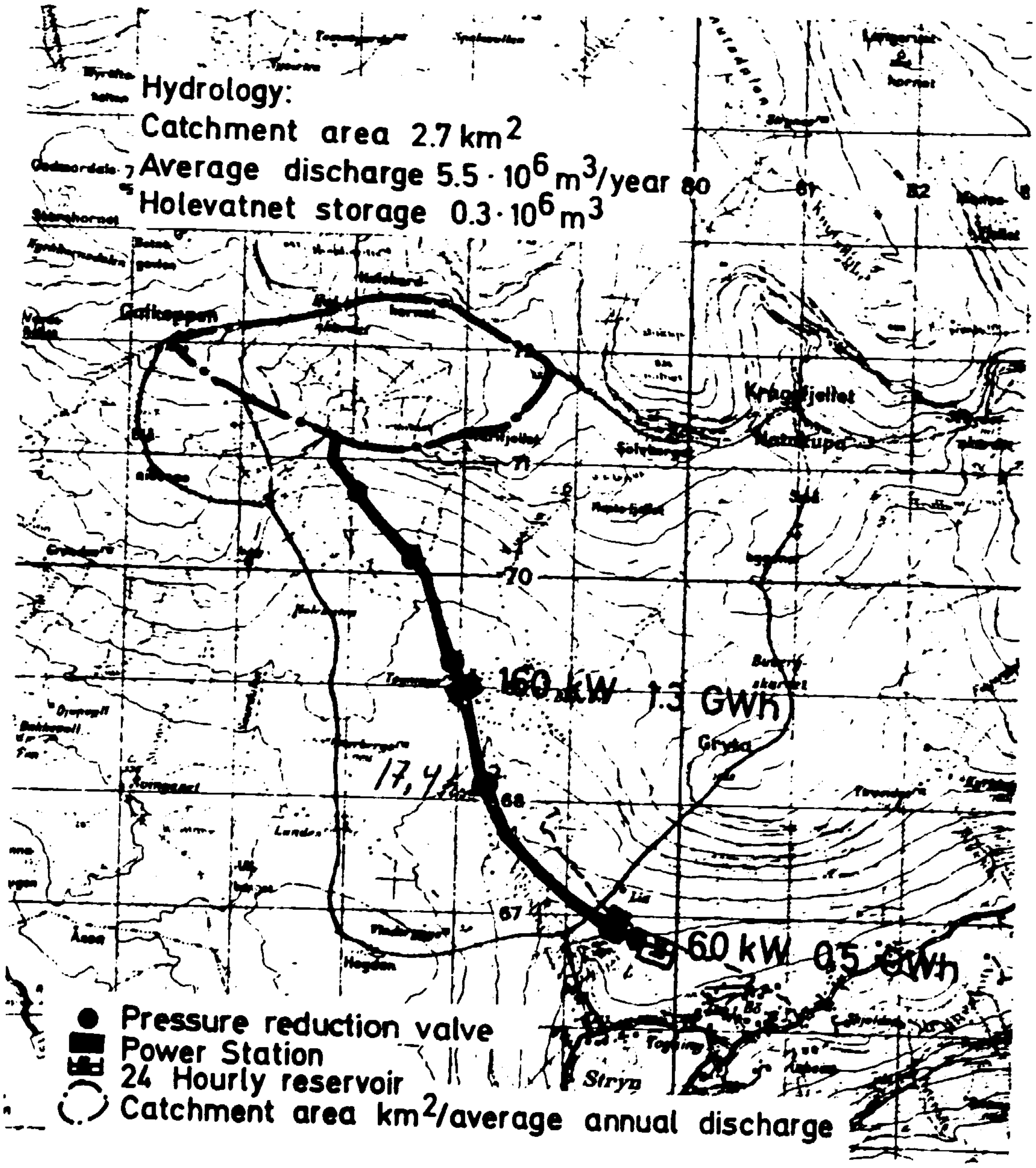

Hydrology:
Catchment area 2.7 km²
Average discharge 5.5 · 10⁶ m³/year
Holevatnet storage 0.3 · 10⁶ m³
Galkoppen
Kråkfjellet
160 kW 1.3 GWh
60 kW 0.5 GWh
17,4
70
68
67
Stryn
● Pressure reduction valve
■ Power Station
24 Hourly reservoir
Catchment area km²/average annual discharge

Fig. 2

In this case it was necessary to use the existing ductile iron pipe with diameter 200 mm. An average flow of 0,08 m^3/s will give the best result compared to head loss and energyproduction, but this flow is only 45 % of average discharge. The annual production could be 5,6 GWh if the energyprouction had been taken into consideration when the water supply plant was constructed. The pipe would be changed from Ømm 200 to Ømm 400, and the total additional cost would be 3,83 mill.kr. (See III in table 1.)

III The scheme planned for energyproduction:

I-II The two possible powerstations:

	I	II	III
Average flow m^3/s	0,08	0,05	0,20
Head hydrostatic pressure m	356	214	514
Max. output kW	163	63	820
Annual production GWh	1,30	0,50	5,6
Types of turbines	Pelton	Altered pump	Pelton
Average efficiency %	0,56	0,69	0,86
The cost of mechanical and electrical equipment mill. kr 1.1.79	0,72	0,40	2,40
Total cost mill. kr 1.1.79	1,03	0,67	3,83
The cost per kW kr/kW	6.320	10.630	4.670
Annual costs+ (1 Nkr=100 øre) øre/kWh	6,7	11,2	5,7

+40 years depreciation time, a 7 % interest rate and 1 % annual maintenance. (US $ 1 = Nkr 5,05)

These examples shows that it is economic favourable with a similar utilization of the energy instead of using pressure reduction valves in water supply plants.

PROCEEDINGS REGARDING PLANNING, OFFICIAL TREATMENT AND IMPLEMENTATION.

by O. Gunnes

Because of the large number of schemes, a pre-feasibility study, comprising plants up to 10,000 kW, will be carried out for the whole country. This study is undertaken by the Norwegian Water Resources and Electricity Board (NVE) which is the official body for water resources and electricity matters in Norway. The study starts with a topographical and hydrological investigation based on available hydrological data and maps in scale 1:50,000. The office work is combined with a field visit and discussions with the local staff, in order to get a more realistic impression of the projects than map studies can give. The pre-feasibility study gives a brief assessment for each project regarding hydrological data, reservoir data, waterways (pipes, shafts, tunnels etc.), head, installed capacity, energy output and cost estimate.

This registration makes it possible for each county to make a schedule for wanted development of hydro-power.

With basis in such a schedule, the local electricity bodies may apply to the NVE for official financial support for further planning. Such support may be given on special conditions.

Whetherfinancial planning support is given or not, the next step is to develop a more comprehensive feasibility study. This study has to include a far more comprehensive technical investigation, beside reports considering juridical matters (water rights), ecological and environmental consequences etc.

This feasibility study is the basis for an application to the NVE, and further to the Ministry of Oil and Energy, to get approval for implementation of the planned scheme.

In most cases, except pure reconstruction of old plants in their old shape, applications according t the water-right laws have to be produced. Similar applications according to the electricity law are required if the voltage is higher than 1,000 V.

Approvals regarding the water-rights are finally given by the Ministry of Oil and Energy, or by the Parliament (larger plants), while the electricity approval is given by the NVE.

The detailed studies and design, together with preparation of the financial arrangements, normally proceed parallel with the formal application treatment.

The feasibility study, as well as the detail studies and the design, are carried out by Norwegian consultants, or in some cases by the electricity bodies themselves. (Some of the bigger organisations have established their own design and construction offices.)

The financing of hydro-power is normally arranged by loan.

No construction may begin until the formal approvals are given. A number of Norwegian contractors have an outstanding experience regarding water-power construction, and most of the work is undertaken by these contractors.

The manufacturing of hydraulic-mechanical and electrical equipment is also dominated by Norwegian companies, although the international competition is far harder here than for the civil works.

Both for the civil works (contractors) and for the mechanical/electrical equipment, a tender procedure is usual.

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