HYDRO-ELECTRIC DEVELOPMENT

O N

D O G R I V E R

NEAR BEIRUT , LEBANON

B Y

FAWZI M. NAJM

MAY, 1951

H Y D R O - E L E C T R I C D E V E L O P M E N T

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N E A R B E I R U T , L E B A N O N

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A C K N O W L E D G E M E N T

The candidate wishes to acknowledge the valuable assistance rendered to him by Professor F. Antippa of the Physics Department in the A.U.B. during the preparation of this thesis. The candidate is also very thankful to Professors K. Yeramian and S. Macksoud for their help in some of the problems encountered.

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GENERAL INTRODUCTION

With the continuous ppogress of industry and power consuming machinery either in our homes, fields, factories, or elsewhere, we are coming more and more to realize that we do greatly need means to generate power to run such appliances and machinery.

It is not only that we need power, but we need it safe, continuous, easily manageable, convenient, and especially, economical. Instead of running our machines by steam energy or thermal energy of fuels, it is now becoming universally preferred to utilize electric energy for such a purpose.

Electric machines are replacing thermal ones in many of the new enterprises wherever electridity is available for that use. They are gaining preferance over the other machines because of the many advantages they possess. Some of these advantages may be the followings:

(1) They are simple in construction, durable, small, and light in weight.

(2) They are easily controlled in putting on or off.

(3) They are clean (free from the products of combustion such as smoke, ashes, and fumes) and not noisy.

(4) They have high efficiency.

(5) The are cheap in price.

(6) They require less maintenance and repairs.

(7) They have longer life of work -- about 20 years in contrast to that of thermal units which is 10 years only.

In Lebanon, the country at present is offering room for industrial and agricultural developments. And it is quite true that for the stimulation of such constructive developments cheap electric power has much to contribute.

One of the effective factors in such enterprises is the quality and the quantity of the power to be used. Very frequently we find the cases where industries are attracted to locations where cheap power is available. As pointed out above, electric energy is now universally preferred for the use in running industrial projects. But this energy need be generated. It can be generated by the falling waters. In places where water discharge and availabe head (the two requisites for water power) are potentially at hand, hydroelectric power plants can be developed for the production of electricity.

Eventhough for some cases the generation of electricity from water may be more costy than from the other sources, there are actually many other considerations which should offset this probability. In a country like ours, instead of importing the necessities for the other sources, why not to utilize the possibilities of making use of our natural resources in connection with this field of hydroelectric power plants?

There is no doubt that by making use of our national resources we shall be building a stronger economic standing and a better industry. Moreover, the supply of power will be more continuous, safer, and more economical. It will be more stable and not easily affected by the fluctuations in the outside wordly affairs as wars or other troubles which have a great bearing on the importation facilities, prices, and availability. Our oil presses, flour mills, saw mills, incubators, tanneries, pumps, lighting power houses, factories, industries and all the related equipment will be able to run for the production of our own supplies or even for exportation in any time of crisis in the national situations.

Guided by these considerations, the candidate has undertaken this study with the intention of acquainting himself with this field of wide applications and with the hope for the great benefits the country will have when all its potential power resources are harnessed into hydroelectric plants in conjunction with irrigation projects.

Part II

PRELIMINARY STUDY OF THE EXISTING CONDITIONS

To prepare for the planning of this project some information about the following subjects had to be obtained.

(1) The available gross head through which the stream flow may be utilized in the development of power.

(2) The available water discharge in the stream.

(3) The variations in the stream flow.

(4) The topography of the region where the plant is to be set.

On the 29th of October, 1950, a trip to the Dog River was made, accompanied by Professor Antippa from the A. U. B. with the intention of choosing the appropriate site for the location of the project and to obtain the necessary (I had better say possible) data and information for carrying on the design work.

It is well known that the city of Beirut gets its water supply from the Dog River. The headworks for that supply are at a point 3.5 km. above the highway bridge across the same river on the main Beirut-Tripoli road. The time of the visit was in the draught periods of the year. It was observed then that the water in the river channel below the Beirut Water Co. headworks was a trifling amount. Definitely it was out of question to choose a site for the project below the Beirut Water Company headworks.

Going higher along the river from the above mentioned headworks for a distance of about 500 meters, there is constructed the hydroelectric power plant which supplies the town of Jounieh with electricity. Going still higher than the headworks of the latter plant, it was found out that the river valley was getting narrower and narrower and thus making the possibility of having a plant site above those points quite impossible, without interfering with the Jounieh's Plant headworks. Moreover, there was the difficulty of reaching those high places as there was no regular or convenient road to lead to the place.

With those considerations in mind and the observation that the only amount of water which can be depended on for a new project is the water used by the Jounieh Plant and that which is lead into the Beirut Water Company headworks, it was found out that the only advisable site for a new project would be between the outlet from the Jounieh's Plant draft-canal and the headwork structures of the Beirut Water Company. This distance is approximately 350 meters long. In that area there is an existing bridge which permits easy crossing of the river. Also the convenience of utilizing the existing road along the river was another justification for that choice. Moreover, along one of the river banks there is flat land which provides a convenient palace for the construction of the Power House structure. By having the project built in that area, it was thought to use the availabe water discharged from the draft tube of the Jounieh's Plant and then discharge the same water from the new Project's draft tube into the river again before the Beirut Water Company headworks. Thus the water power can be utilized and then discharged into the river without interfering with any of the two existing developments in that vicinity.

The possible information which we could obtain from the place was (1) the availabe gross head or fall in elevation between the outlet of Jounieh's draft canal and a point above the Beirut Water Company headworks where it was observed to be a convenient place for discharge into the river, and (2) the available water flow in the Jounieh's Plant' supply canal.

The available gross head was measured by a transit and stadia. The water flow in the canal was obtained by finding the velocity of the water by the floats method and by measuring the cross section of the canal. This data and the calculations for the required information are shown on pages 57-59 in the appendix.

Unfortunately the necessary information related to the flow variations could not be obtained to help for a better study of this problem. And concerning the topography of the area, it was not possible to obtain a contour map which will help showing correctly the existing features of the land. According to the "Cadastral" Office in Beirut, there is not even a Cadastral plan for that region.

Part III

Discussion of the Project Elements and Method of Analysis Adopted in the Design.

This project will consist of the following elements which are necessary for its completion:

(1) The headworks

(2) The supply canal from headworks to the connection with the turbine in the powerhouse.

(3) The Intake and the Powerhouse--structural, hydraulic, and electric considerations.

(4) The apartment house to lodge one family for the operation of the plant.

(5) The draft tube and the tail race canal.

A discussion of each element will follow and the all integrated.

(1) The Headworks. The headworks (or diversion) will consist of (a) diversion structures across the river channel, (b) canal headgates or flow regulators at the head of the supply canal and (c) overflow spill way in the canal just below the head gates.

Refer to plate no. II for the general layout of these structures.

(a) For the diversion structure across the river, it was considered that a proper dam construction is unnecessary. To act as one, there has to be improvised on the site a dam made up of dumping some boulders in the river bed and interconnecting them with some other filling materials to block the flow and increase the water level to that needed on the canal headgates. When the flow in the river is more than what can be carried to the powerhouse, the excess water will overflow over the dam materials.

(b) To control and regulate the water supply admitted at the head of the canal system, headgates will be installed. These gates will be of the undershot type and built up of steel plates and steel framing with the necessary masonry structures as shown on plates No. II & III.

(c) On the canal just below the headgates, there will be built one spillway designed to carry away into the river channel the excess water which may enter the canal in the case of faulty operation of the headgates or fluctuations in the water level in the river. This spillway will be of the overflow fixed crest type.

(2) The Supply Canal from Headworks to Inlet to Turbine. Before proceeding on the canal design, it is necessary to decide on the shape of cross-section to be used. It is well known that the cross-section of the canal will vary with the material through which the canal will pass. In rock the section would be approximately rectangular, whereas in earth it would be trapezoidal with side slopes depending on the material. For this project, the land being made out of a soft rock region, the rectangular section will be adopted all through the work.

For best hydraulic section, whether rectangular or trapezoidal, the hydraulic radius is one half the water depth. In the case of rectangular section, this means that the width is twice the depth.

The area of cross-section and, hence, the velocity of flow for the given discharge depends on (1) the allowable loss of head or slope of water surface in the canal such that the annual cost plus power lost in friction head is a minimum, i.e., the best section of canal; or (2) some limitation in velocity necessary to avoid scour, or washing of banks, in the case of unlined canals in earth

(1) To determine the best section of canal, the cost per unit length of several different sections, varying in depth, is estimated and the annual cost of each section is computed-- based on a suitable percentage allowance covering fixed charges of interest, taxes, depreciation and maintenance.

The loss of head per unit length is estimated for the available discharge. Then the power lost is computed in horsepower, using the (assumed) combined efficiency of wheels and generators at the switchboard. The sale value of this power is estimated from existing plants in that region.

Thus the total annual cost for each assumed depth of canal will be the yearly cost of canal plus value of power lost.

By plotting a curve of unit annual costs as ordinates against depth of canal sections as abscissa, the minimum point on the curve or depth giving the least annual cost may be readily determined.

(2) Limitations in velocity are not taken into consideration here because of the canal being built of stones (lined or unlined) or of concrete where there is no fear of scour, silting or weed growth.

Items of Cost

The items of cost for a water power project are:

(1) fixed charges and

(2) operating costs

(1) The fixed charges will include: interest plus taxes and insurance, depreciation, and loss of energy due to grade.

(2) The operating costs will consist chiefly of wages and maintenance work on the plant.

Fixed Charges

(A) Interest plus taxes and insurance: Judging from current and local transactions, this item is assumed to amount to a total of 11% of the capital involved.

(B) Depreciation: This item depends on the cost of every element of the water plant and the life expectancy of the period of use of that element. The depreciation value can be obtained by two methods, vis, straight-line basis, and the sinking-fund method.

With the small difference between the results of the two methods, it was considered quite feasable to use the straight-line method in this case due to its simplicity for calculation of the different parts.

(C) Loss of energy due to grade: Due to the velocity of the running water in the canal, there will result a loss of head thru friction. Lost head means a loss of power which otherwide could have been developed and made use of. By calculating the head lost through this and by finding out the power which would have been developed from it and evaluating the price of that power annually, we can obtain the value of this item and include it in the fixed charges.

Operating Costs: This item is assumed to be 0.5% of the capital involved in the canal structure of stone-line surface and 1% of the capital involved in that of cement-rubble surface.

Appurtenances to Canal

(1) Spillways

(2) Escapes and wasteways

(1) A spillway structure will be used to prevent a rise in the

canal water level above the normal full supply water level.

The spillway to be used will be of the overflow fixed crest which consists of: (a) an overpour bank formed by a length of the canal's retaining wall, where the crown of overpour crest is made level with the normal water level in the canal; (b) a receiving basin in which the overpour water is collected; (c) a waste channel leading from the spillway receiving basin to a point of discharge in the river's channel.

The capacity of the spillway has to be enough to discharge the surplus water entering the canal, in excess of its normal or desired capacity.

The length of the spillway will be determined by using for the depth of overpour sheet the maximum increase in depth which can be safely allowed to continue down the canal beyond the down stream end of the spillway. This depth will be equal to the free board allowed along the canal.

(2) Escapes and Wasteways: The canal will be provided with an escape for emptying in case of an emergency such as a break or for the purpose of scouring out of silt deposited in the canal section above the escape.

This structure requires a gate and a waste channel from the canal to the point of discharge into the river's channel. The waste channel may have to run down a steep grade and will have to be either a canal with a series of drops to take up the excess fall or a chute. The capacity of the escape have to be designed to discharge the full canal flow.

(3) The Intake and the Powerhouse

(A) The intake structures will include (a) trash rack (b) check gate, hoist, and operating platform (c) flume for setting the turbine.

The Trash Rack: To intercept material carried by the water in the canal which may not be readily passed through the turbines, racks will be placed at the end of the canal just before the entrance flume leading into the turbine propeller. The racks are to be made of rectangular flat steel bars spaced about 3" apart in the clear. The rack bars are spaced and held in place by crossties and spools. The spools are placed near the back of the bars so as to allow the rack teeth to pass readily. To facilitate racking or cleaning the plane of the face of the racks will be inclined away from the vertical at an angle of about 15° with upper end farthest downstream.

The racks will be made in one section only since the required size is convenient for handling and will be supported at top and bottom and at such intermediate points as may be necessary by steel beams or channels set into the concrete flooring or side walls of the canal.

The total net rack area for the waterway is made large enough so that undue loss of head will not result through the racks.

The proper interval in the clear between the rack bars is quite an important detail because if too small, the racks will frequently clog with twigs, leaves and other bodies and require an excessive amount of cleaning. If too large, material will pass thru and may clog or injure the wheel runner. The maximum allowable size of opening depends somewhat on the size of wheel passages and the type of the wheel used.

The propeller type of wheel (as the one to be used for this project) permits a large rack-bar spacing for relatively large material will pass through this type of wheel without difficulty.

The design of the rack crossbeams and supports is made upon the basis of full hydraulic pressure occasioned by possible full clogging such that for a short time little or no water is passing through.

The top of the racks is placed a little above the high-water level in the canal. Provision has to be made at the river side for a pit in the side wall into which waste material may be dumped and from which it may be occasionally flushed into the river by means of a small gate opening into the head water near the racks.

Check Gate, Hoist, and Operating Platform:

The entire of this structure is located just outside the wall of the power house. There is provided a door from the inside of the engine room to the operating platform for regulating the gate opening or for cleaning the racks.

Flume for setting the Turbine:

The open-flume type of setting is chosen for this project. The details of this setting are shown on plate no. V . This is the usual wheel casing used for such a low head. The open-flume will consist of a simple rectangular pit in which the wheel is set. The supply canal will go through the wall of the power house to a pit just under the floor slab of the engine room which will act as the roof of the pit. The floor on which the wheel case rests will be made of reinforced concrete. Special care has to be taken to prevent or reduce settlement and vibration to a minimum in order to eliminate one of the very important causes of loss which is encountered in water power plants. Due to defects of this kind, the water power plant may give an efficiency at the turbine shaft of about fifty per cent only and evenless, where at least it should be about eighty per cent.

(B) Power House and its Equipment

The powerhouse is considered as a protective covering for the equipment to be housed. The equipment to be provided for in the lay out of the power house may be considere as follows:

(a) Turbine -- the prime mover

(b) Generator, governor and exciter

(c) Switch board and control

(d) Crane

(e) Workshop

(f) Lavatory

(g) Storage room

(h) Office

No transformers are considered to be necessary. As the plant is to supply a nearby factory, low voltage is generated directly.

(a) Turbine: The hydraulic turbine is the prime mover of the water power development and is the most important element which should receive careful consideration. The scope of this thesis can not include a part on the design of the turbine runners and the different accessories related to it. What could be treated here is the decision on the type of wheel to be used, as controlled by the availabe head and conditions, and the type of setting to be adopted to fit the existing features and characteristics of this small project.

However an approximate data could be obtained and that will serve as a tentative basis for conference with turbine and generator manufacturers who may, in the light of the information supplied, furnish dimension sheets of the appropriate dsign along with a cost estimate for the installation.

Wheel Type: The availabe head is the controlling factor for the choice of the wheel type and the setting of the wheel. For the availabe low-head a high-speed runner is best adopted. As the speed of a wheel varies as $\sqrt{h}$, the inherent tendency under a low head is toward a low actual r.p.m. Hence a type of wheel that will counteract this effect as far as practicable is desired to obtain as low cost as may be of wheels and generators. According to the present conditions then, and the limitations of the specific speed, it is found out that the propeller type of wheel is the one which is convenient for this development. This wheel is particularly adopted for low-head installation and is in wide use now for such plants.

Wheel Setting: The wheel may be set with its axis either horizontal or vertical. For the case in question the vertical shaft turbine will be adopted as this is the one recommended for such conditions.

(b) Generator: The generator, like the water wheel, will be of the vertical shaft type. Its characteristics will be given later in the design part.

(c) Switch Board: The connection between the generator and the switchboard is to be made by cables laid under the floor in the ducts so as to keep the overhead space free for the crane. The switchboard will have to contain the control, metering and the switching equipment of the station. The switchboard is usually supplied as a part of the generator equipement.

It will be fixed in a place in the power house where the operator can keep an eye on it when on another job in the engine room. It will be set about 150 cms. far from the wall and the space behind it will be enclosed by steel grilles with one access door to it. The height of the panels will be made high enough so that all instruments can be placed within easy reach to the operator.

(e) Crane: The crane to be provided for this power house will consist of a "block and tackle" system of pulleys mounted on a tripod which can be moved along the floor of the engine room from one place to another.

(f) Workshop: For carrying on any minor repair which may be needed for the powerhouse, there is a work bench placed in the turbine room. The operator can carry on such repairs and also keep a watch on the switch board which is at a near sight from the place of the work bench.

(g) Lavatory: One lavatory is provided which the operator and the office personnal can make use of.

(h) Storage: This room is provided for the use as a storage space. However, it may accommodate a small work shop if needed. This store has an entrance from the engine room and another from the outside to facilitate the transfer of the stored equipment without interfering with the engine room.

(i) Office: A small room is allotted for the office equipment which is assumed to include one desk, closet, and a telephone. As shown on plate no. IV, the office is provided with one door leading to the inside of the turbine room and with another leading to outside the powerhouse. The latter was thought essential for if persons coming for some business with the office, they carry on their work without interfering with the turbine room at all.

General Features of the Turbine Room: It is shown, from what has been said before, that special care was taken to have the t urbine room somehow secluded and free from the unnecessary circulation. The dimensions of the room were made large enough to equip the necessary machinery (turbine, generator and appurtenances, switchboard, and bench) and a free space for easy circulation inside the room. The clear height of the ceiling is made about 460 cms. to give a good clearence for the crane action.

The floor of the engine room will be covered with tile to have a smooth finish for a clean upkeep of the place.

The frame of the room will be made of stone bearing walls with a plaster finish in the inside and painted with a light colored tint for better lighting effect and to harmonize with the floor finish.

The windows which are an important detail in the structure constitute a large portion of the area of the main wall of the powerhouse. The sashes will be made of metal and the windows of glass panes and provided with iron railings.

The main door is set at one end of the room and made of sufficient size to permit easy transportation, in and out, of the powerhouse equipment and machinery. It will be made of rolling lift door which is well adapted for such large door. The roof will be a slab of reinforced concrete which can be used by the apartment house above it.

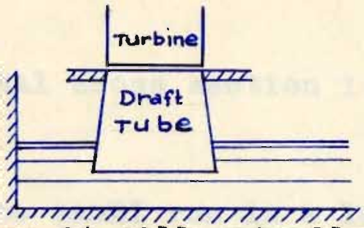
The powerhouse includes one generating unit only. No auxiliary one will be installed. As this project is hoped to serve for a private enterprise like a small chemical industry, saw mill or something along this line, it was thought inadvisable to go into the expense of installing an auxiliary unit. In case of breaks, there will not be much danger or public responsibility if the power is cut off for some time.

(4) The Apartment House. This apartment is built to lodge the plant's operator and this family. As shown on plate no. IV , it consists of one living and dining room combined, two bed rooms, one kitchen, and one bath room. With the intention of keeping the cost of the project as low as possible, the apartment was combined with the powerhouse structure and built as the first floor of the building. As the location of the plant is in the country, it was thought advisable to provide before the apartment a vast outdoor area which the family can make good use of in the summer. This porch area is provided by the roof of the turbine room. From the living and dining room there is a French window to lead to this porch. Building above the turbine room was avoided for the idea of keeping the living quarters somehow detached from the vibrating structures and also to do away with the making of beams in the roof slab which might have to be inconveniently placed.

(5) Draft Tube and the Tail-Race Canal: The draft tube is an extension of the turbine passages from the point of exit from turbine runner down to the tail race level. It is meant to serve two purposes. The primary one is to permit the placing of the turbine and connecting machinery at a level above that of the water in the tail race under high-water or flood conditions of the river. The secondary purpose is to reduce the velocity-head losses of water leaving the turbine.

The latter purpose is affected by the shape of the draft tube which is usually made flaring or increasing in diameter, as shown in the figure, so as to decrease the velocity from the exit of the tube.

The draft tube is usually made of steel and is furnished as part of the turbine equipment supplied by a manufacturing company. Hence the design details will not be attempted here;



As to the tail race, it will actually have to carry the same water as that of the supply canal and hence have the same capacity. However, the limitations due to its position and function may require alterations in its shape and size. To prevent high-water or flood water in the river from interfering with the wheel pit or the water flow in the tail race canal itself, it may have to be prolonged down along the river to a point where easy discharge into the river may be resolved to. These conditions will have to be finally and definitely decided on at the site.

PART IV

ECONOMIC STUDY OF THE SUPPLY CANAL

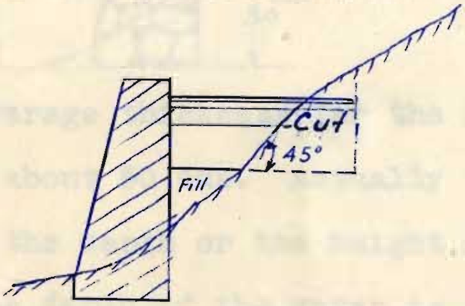
In this tudy the following points are taken into consideration:

(1) The cost of the canal cross section is calculated per unit length.

(2) Fifty per cent of the canal run in a loose gravel area.

(3) Fifty per cent of the canal run in a rocky region.

(4) The cross section of the canal is half in cut and half in fill as shown in the following sketch.



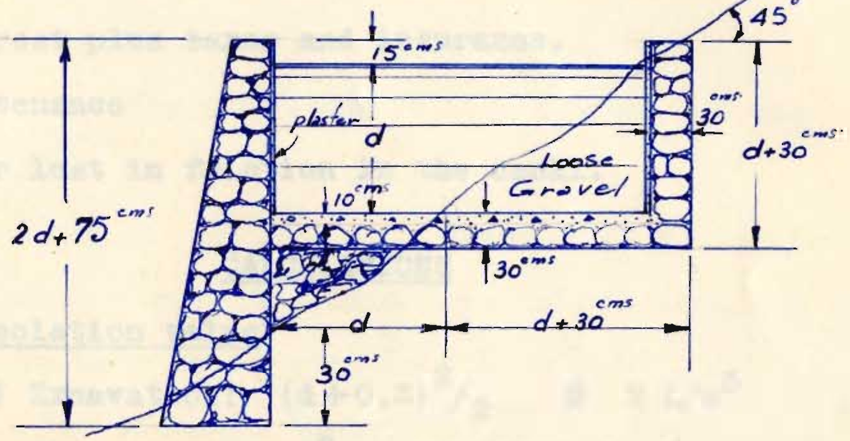
(5) All prices are shown on the price list page

(6) The canal construction is studied for the following conditions:
a. Stone-lined surface
b. Cement-rubble surface
c. Concrete walls surface

STONE - LINED SURFACE CANAL

(1) <u>In The Loose Gravel Area</u>

The following sketch shows a typical cross section



Average thickness for the high battered wall is assumed to be about 50 cms. Actually the average thickness varies with the depth or the height of the retaining wall but since the depth of the water is though to be somewhere near 1 meter, the average thickness of 50 cms. is taken for the whole range of d's considered in the investigation. The values for d around 1 meter will more or less be near to the actual price values.

<u>The Total Annual Cost Is Considered to Be Made up of The Following Items</u>:

A. Depreciation:--

(1) Excavation and fill where needed.

(2) Wall construction with stones and cement marter; The stones are expected to be obtained from excavation on the job.

(3) The floor blocage for the canal base.

(4) The floor concrete mat with expansion reinforcement cast on top of the floor blocage.

(5) Plaster above the stone wall in the case of the lined canal.

The sum of these 5 items constitutes the total money invested in the construction of the canal. This sum divided by the expected period of use of the canal gives the depreciation value on the straight-line basis.

B. Interest plus taxes and insurance.

C. Maintenance

D. Power lost in friction in the canal.

CALCULATIONS

A. <u>Depreciation value</u>

(1) Excavation: $(d+0.3)^2/_2$ @ $2\ L/m^3$

$= d^2+0.6d+0.09\ L$

Where d is the variable depth in meters.

(2) Walls:

$\left[(2d+0.75)0.5+(d+0.2)0.3\right]$ @ $23\ L/m^3$

$= (1.3d+0.44)23\ L$

(3) Floor Blocage:

$\left[(2d+0.3)0.2\right]$ @ $2\ L/m^3$

$= 0.8d+0.12\ L$

(4) Floor Concrete:

$\left[(2d+0.3+0.3)0.1\right]$ @ $50\ L/m^3$

$= 10d+3\ L$

(5) Plaster:

$\left[2(d+0.5)\right]$ @ $2\ L/m^2$

$= 4d+2\ L$

(for 2½ cms. average thickness)

B. Interest plus taxes and insurance

11% of the capital involved is considered

C. Maintenance

0.5% of the capital involved is considered

D. Power Lost in Friction

From Chezy's formula, $V = C\sqrt{mS}$, S can be expressed in terms of V, C, and m.

From the formula $S = \frac{h_f}{L}$ where S is the shape of the canal's bed, h_f the head lost in friction, L length of canal, we have for a unit length $S = h_f$.

In Manning's Formula, $C = \frac{1.49}{n} m^{1/6}$

taking n = 0.012

and m = d/2 since for best hydraulic section

m = d/2

we get $C = \frac{1.49}{0.012}\left(\frac{d}{2}\right)^{1/6}$

Since these calculations are being carried in the metric system it is necessary to change the value of C to the metric relations. This is done as follows:

$$C = \frac{1.49}{n} m^{1/6}$$

$$= \frac{1.49}{n}\left(\frac{L^2}{L}\right)^{1/6} \qquad \text{since } m = \frac{A}{P}$$

$$= \frac{1.49}{n} L^{1/6}$$

$$\frac{\text{K in meters}}{\text{K in feet}} = 1.49 \times 0.3048^{1/6}$$

$$= \log 1.49 + 1/6 \log 0.3048$$

$$= 0.17319 + 1/6\ (-1 + 0.48401)$$

$$= 0.17319 + (-0.08595)$$

$$= 0.08724$$

antilog $= 1.22$

Hence K (in meters) = 1.22 K (in feet)

and C in metric system

$$= \frac{1.49}{0.012}\left(\frac{d}{2}\right)^{1/6} \times 1.22$$

$$= 124 \times 1.22 \times \left(\frac{d}{2}\right)^{1/6}$$

$$= \frac{151}{2^{0.167}} d^{0.167} = \frac{151}{1.123} d^{0.167} = 134.4\ d^{0.167}$$

$$C^2 = 18{,}100\ d^{0.334}$$

From $\frac{Q}{A} = V$, we have $\frac{1.82}{2\ d^2} = C\sqrt{d/2\ S}$

$$V^2 = \frac{(1.82)^2}{4\ d^4} = C^2\ d/2\ S$$

Hence $S = \frac{2 \times (1.82)^2}{4d^4 \times C^2 \times d} = \frac{1.65}{C^2\ d^5} = \frac{1.65}{18100\ d^{5.334}}$

$$= \frac{1}{11000\ d^{5.334}} = h_f \quad \text{meters/meter length.}$$

Therefore money lost in friction is

$$h_f\ (1.82 \times 1000 \times \frac{1}{125} \times 3/4) \times 24 \times 360 \times 0.1$$

where $1.82 \times 1000 = Q$ in Kgs.

$\frac{1}{125}$ = Eff. ÷ 75 kgm. per hp = $\frac{60}{100 \times 75}$

3/4 = 1 HP = 750 watts = 3/4 K.W

24 = hrs. per day

360 = days per year

0.1 = L. price per K.W.H.

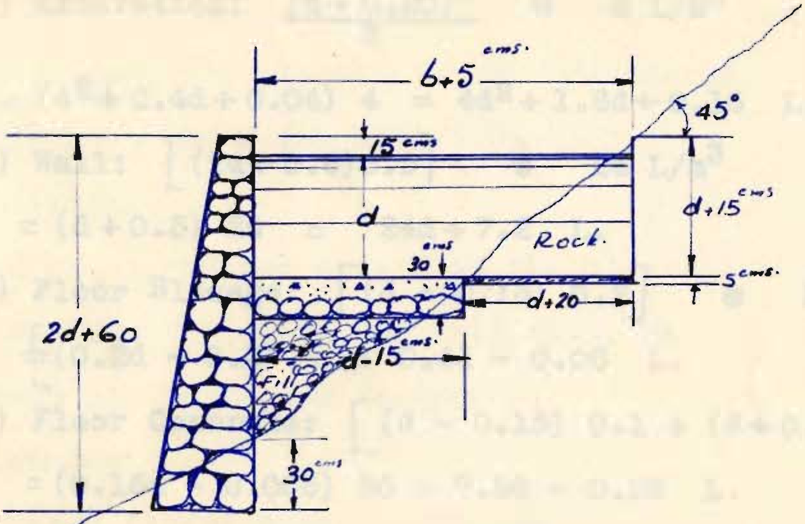
$$= h_f \times \frac{1820 \times 3 \times 360 \times 24 \times 0.1}{125 \times 4} = h_f \times 9450$$

$$= \frac{9450}{11000\ d^{5.334}} = \frac{1}{1.164\ d^{5.334}}$$

Values for different d's are calculated for items A, B, C, & D and are tabulated in table 3 page 53.

(2) In the Rocky Region

The following sketch shows a typical cross-section



The total annual cost is considered to be made up of the following items:

A. Depreciation

(1) Excavation and fill where needed

(2) Wall construction with stones and cement mortar-- on the downhill side only. The stones are expected to be obtained from excavation on the job.

(3) The floor blocage for the camal base over the filled area only as shown in the above sketch.

(4) The floor concrete mat with expansion reinforcement cast over the blocage and the rock base as shown in the above sketch.

(5) Plaster above the stone and the rock wall surfaces

The sum of items (1) to (5) divided by the expected period of use of the canal (30 years) gives the depreciation value.

B. Interest plus Taxes and Insurance

C. Maintenance

D. Power Lost in Friction in the Canal

CALCULATIONS

A. **Depreciation**

(1) Excavation: $\frac{(d+0.20)^2}{2}$ @ 8 L/m^3

$= (d^2+0.4d+0.04)\ 4 = 4d^2+1.6d+0.16$ L.

(2) Wall: $\left[(2d+0.6)0.5\right]$ @ 24 L/m^3

$= (d+0.3)\ 24 = 24d+7.2$ L.

(3) Floor Blocage: $\left[(d-0.15)\ 0.2\right]$ @ 2 L/m^3

$= (0.2d-0.3)\ 2 = 0.4d-0.06$ L.

(4) Floor Concrete: $\left[(d-0.15)\ 0.1+(d+0.20)\ 0.05\right]$ @ 50 L/m^3

$= (0.15d-0.005)\ 50 = 7.5d-0.25$ L.

(5) Plaster: (2.5 cm. thick)

$(2d+0.7)$ @ 2 L/m^2 $= 4d+1.4$ L.

B. **Interest plus Taxes and Insurance:**

11% of the capital involved.

C. **Maintenance:**

0.5% of the capital involved.

D. **Power Lost in Friction:**

$\frac{1}{1.164\ d^{5.334}}$ L. (Same as in D for case I above)

Values for different d's are calculated for items A, B, C, and D and are tabulated in table 4 , page 53 .

CEMENT - RUBBLE SURFACE CANAL

I. In the Loose Gravel Area

For typical cross section refer to figure on page 20. Here the plaster is not considered.

Terms Making up the Total Annual Cost:

A. Depreciation

Same as in "A" for case I in the Stone-Lined Surface, except for item (5) where for this case there is no plaster.

B. Interest plu Taxes and Insurance.

C. Maintenance

D. Power Lost in Friction in the Canal

CALCULATIONS

A. Depreciation Value

(1) Excavation

$(d+0.3)^2/_2$ @ 2 L/m^3 $d^2+0.6d+0.09$ L.

(2) Walls

$\left[(2d+0.75)\ 0.5+(d+0.15)\ 0.3\right]$ @ 26 L/m^3 **

$=(1.3d+0.42)\ 26 = 33.7d+11.1$ L.

(3) Floor Blocage

$\left[(2d+0.3)\ 0.2\right]$ @ 2 L/m^3 $= 0.8d+0.12$ L.

(4) Floor Concrete

$\left[(2d+0.3+0.3)\ 0.1\right]$ @ 50 L/m^3 $= 10d+3$ L

B. Interest plus Taxes and Insurance

11 % of the capital involved

C. Maintenance

1% of the capital involved

** Refer to price list page 56 .

D. Power Lost in Friction

$$C = \frac{1.49}{0.025}\left(\frac{d}{2}\right)^{1/6} \times 1.22 \; **$$

$$= 59.6 \times 1.22 \times \left(\frac{d}{2}\right)^{1/6} = \frac{72.7}{1.123}\, d^{0.167} = 64.7\, d^{0.167}$$

$$C^2 = 4200\, d^{0.334}$$

$$V = \frac{Q}{A} = C\sqrt{d/2\, S} = \frac{1.82}{2\, d^2}$$

$$V^2 = \frac{(1.82)^2}{4d^4} = C^2\, \frac{d}{2}\, S$$

$$S = \frac{2 \times (1.82)^2}{4\, d^4 \times C^2 \times d} = \frac{1.65}{C^2\, d^5} = \frac{1.65}{4200\, d^{5.334}}$$

$$\frac{1}{2550\, d^{5.334}} = h_f \quad \text{meters/meter length}$$

Money lost in friction is $h_f \times \frac{1820 \times 3 \times 24 \times 360 \times 0.1}{125 \times 4}$

$$= \frac{1 \times 9450}{2550\, d^{5.334}} = \frac{3.71}{d^{5.334}} \quad \text{LL.}$$

Values for different d's are calculated for items A, B, C, and D and are tabulated in Table 1, page 52.

II. <u>In the Rocky Region</u>

For typical cross section refer to figure on page 24. The items making up the total annual cost are the same as for case I above in this type of Canal Construction.

$n = 0.025$ in Manning's Formula is a fair value for cement rubble surface, obtained from Handbook of Hydraulics by King.
1.22 is the factor to change C from English to Metric system; refer to page for derivation.

CALCULATIONS

A. Depreciation Value

(1) Excavation: $\frac{(d+0.2)^2}{2}$ @ 8 L/m^3 = $4d^2 + 1.6d + 0.16$ L.

(2) Wall: $[(2d+0.6)0.5]$ @ 27 ** L/m^3 = $27d + 5.1$ L.

(3) Floor Blocage: $[(d-0.15)\ 0.2]$ @ 2 L/m^3 = $0.4d - 0.06$ L.

(4) Floor Concrete:

$$[(d-0.15)\ 0.1 + (d+0.20)\ 0.05] \text{ @ } 50\ L/m^3 = 7.5d - 0.25 \text{ L.}$$

B. Interest plus Taxes and Insurance

11% of the capital involved

C. Maintenance

1% of the capital involved

D. Power Lost in Friction

Same as in D for case I in this type of canal = $\frac{3.71}{d^{5.334}}$ L.

Values for different d's are calculated for items A, B, C, and D and are tabulated in Table 2, page 52.

Having 50% of the canal running in loose gravel and the other half in a rocky region, it is quite justifiable to add the total cost per meter per annum for each type of surface finish and divide the sum by two to obtain the average total cost per annum for the type of construction studied.

This is done in table 5, page 54, for the Stone - Lined Canal and in table 6, page 54, for the Cement - Rubble surface Canal.

In figure on page 55, there is plotted, first, a curve giving the average annual cost per meter length for the stone-lined canal; second, a curve giving the average

---

** Refer to Price List for 27 L/m^3 (p. 56) annual cost per meter length for the cement-rubble canal. Both curves are plotted in relation with the depth of the cross section considered.

It is quite apparent from those graphs that the stone-lined canal is cheaper than the cement-rubble one for corresponding values of the depth of the cross section. It is also seen in the above mentioned graphs that the stone-lined canal curve has a minimum around the depth of 90 cms.

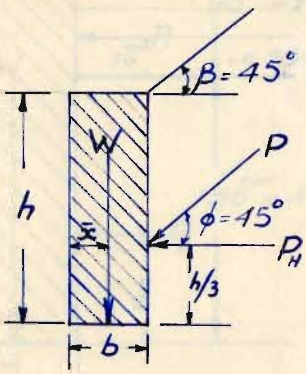
This cross section with the depth equal to 90 cms. and therefore the breadth of 180 cms. is considered to be the best economical section for the stone-lined surface as found out by the above analysis. This cross section is the one adopted for the supply canal not only because it does satisfy the efficiency and the economy problems but also because it meets the practical considerations which should be observed in such a choice. It is not deep to the extent of endangering a person if he falls in the canal. It is not wide to the extent of requiring a large land strip for its erection.

CONCRETE - WALLS CANAL

In regards to analysingthe cost of a canal cross section built from reinforced concrete with a depth of 90 cms. of water, it appears quite clearly, especially at the present trend of high prices of steel, that this section will be much more costy, than the two previously discussed sections. Since stones are abundant and cheap in that region, why to use concrete and steel where-ever this can be avoided?

DESIGN OF CANAL CROSS - SECTION

Up-hill side



B = 45°

ø = 45°

h = d + 20 cms = 110 cms = 3.61'

W. of earth = 110 #/ft³

W. of stones = 140 #/ft³

K = 0.26

$P = \frac{1}{2} W_e h^2 K = \frac{110}{2} \times \overline{3.61}^2 \times 0.26 = 187^{\#}$

$P_h = 187 \cos 45^\circ = 132^{\#}$

$W = 140 \times 3.61 \times b$

$\bar{x} = b/2$

$h/3 = 1.2'$

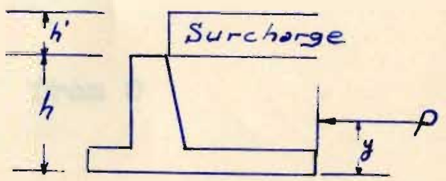
Overturning required F.S. = 2

$2 = \frac{140 \times 3.61 \times b \times b}{2 \times 132 \times 1.2}$; $b^2 = \frac{2 \times 2 \times 132 \times 1.2}{140 \times 3.61} = 1.24$

$b = \sqrt{1.24} = 1.11' = 34$ cms.

Down-hill side

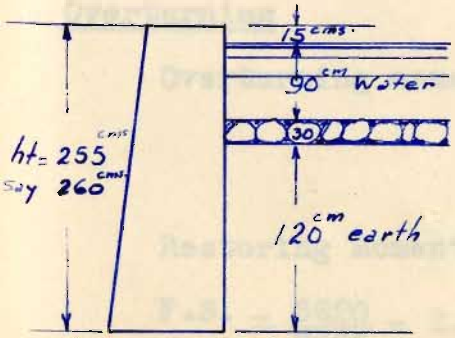
for d = 90 cms.



**

$P = \frac{1}{2} wh(h + 2h') \frac{1 - \sin \phi}{1 + \sin \phi}$

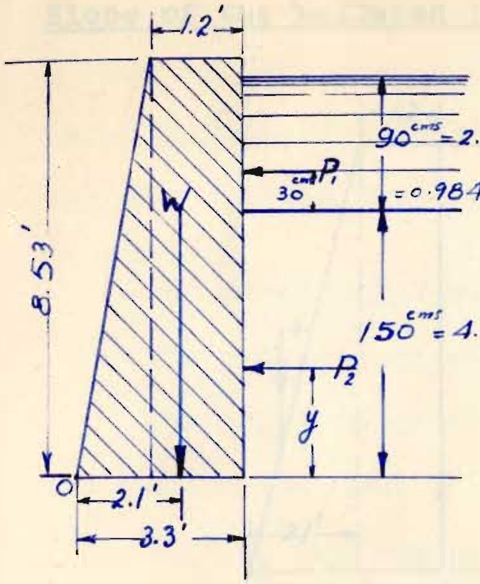
$Y = \frac{h^2 + 3h h'}{3(h + 2h')}$



ht = 260 cms = 8.53'

W. of water = 62.5 #/ft³

** Taken from concrete book, "Design of Concrete Structures" By L.C. Urquhart and C.E. O'rourke, Fig. 144. p.396.



$$P_1 = W_\omega \frac{h^2}{2} = \frac{62.5 \times 2.95^2}{2} = 272\ \#$$

acting at 0.98
4.92
5.90' above base

<u>Surcharge on lower part</u>

$$\frac{62.3}{110} = 0.57'$$

$$0.57 \times 2.95 = 1.68' = h'$$

$$P_2 = \tfrac{1}{2}\, 110 \times 4.92(4.92 + 2 \times 1.68) \frac{1 - 0.707}{1 + 0.707} = 385\ \#$$

$$Y = \frac{4.92^2 + 3 \times 4.92 \times 1.68}{3(4.92 + 2 \times 1.68)} = 1.97'$$

Trapezodial Section:

$$\Sigma M_o : \quad 1.2 \times 8.53 \times (2.1 + 0.6) = 27.6$$

$$2.1 \times \frac{8.53}{2} \times \frac{2.1 \times 2}{3} = 12.5$$

$$27.6 + 12.5 = \underline{\underline{40.1}}$$

$$\Sigma A : \quad \frac{3.3 + 1.2}{2} \times 8.53 = 19.2^{\square'}$$

$$x = \frac{\Sigma M}{\Sigma A} = \frac{40.1}{19.2} = 2.1' \text{ from } 0$$

<u>Overturning</u>

Overturning moment: $272 \times 5.90 = 1600\ '\#$

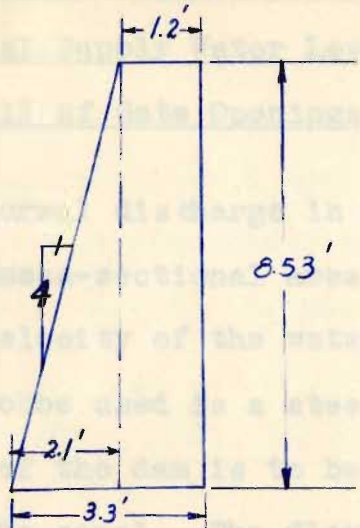
$+ \ 385 \times 1.97 = \underline{760}\ '\#$

$2360\ '\#$

Restoring moment: $19.2 \times 1 \times 140 \times 2.1 = 5620\ '\#$

$$F.S. = \frac{5620}{2360} = 2.38 \quad \text{OK.}$$

Slope of the battered face of the down-hill wall



H : 2.1'

V : 8.53'

$$\frac{H}{V} = \frac{2.1}{8.53} = \frac{1}{4.06}$$

A slope of $\frac{H}{V} = \frac{1}{4}$ is to be used for the other section along the length of the canal.

This wall is to be 1.2' wide at the top throughout the whole length of the canal.

HEADWORKS

Design of Head Gate and Appurtenances, Relative Elevations of Canal Normal Supply Water Level, Dam Crest, Bed of Canal, and Top and Sill of Gate Openings.

The normal discharge in the canal is 1.82 $m^3/sec = 64.3$

The cross-sectional area of the canl is 1.62 $m^2 = 17.4\ ft^2$

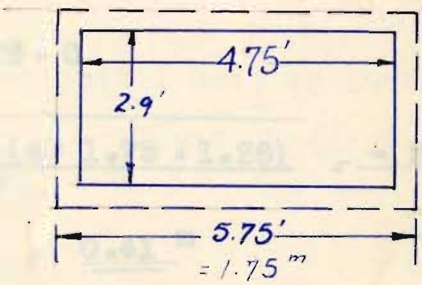
The velocity of the water in the canal is 1.12 m/sec = 3.67 ft/sec.

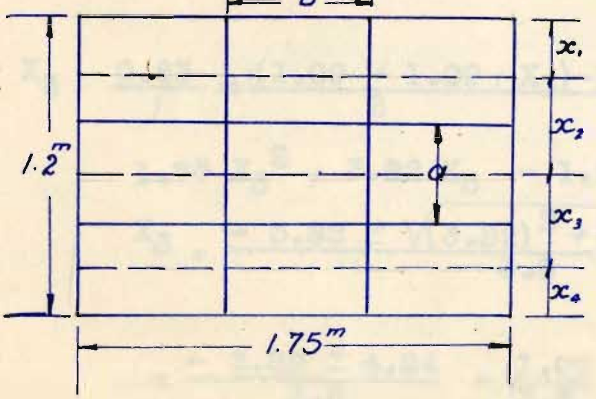
The gate tobbe used is a steel gate of the undershot type. The crest of the dam is to be 0.7' above the full supply water level in the canal. The flow thru the gate opening is submerged. The coefficient of discharge is taken as 0.7. Hence for a head of 0.7', the discharge per square foot of gate opening is

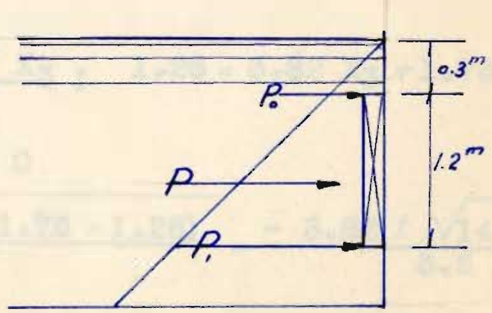
$$Q = C A \sqrt{2 g h} = 0.7 \times 1 \sqrt{64.4 \times 0.7} = 4.7 \text{ cusec per sq. ft.}$$

Then, the required area of gate opening is $\frac{64.3}{4.7} = 13.7\ ft^2$

Let opening be 2.9' X 4.75'
Using 6" overlap of gate on each side, the gate outside dimensions are 3.9' X 5.75'







$P_o = w\ h = 1 \times 0.3 = 0.3$ tons/m^2

$P_1 =$ 1.5 tons/m^2

$$P = \frac{1.5 + 0.3}{2} \times 1.2 \times 1.75 = 1.9 \text{ tons on gate}$$

The gate is to be composed of a steel sheet of uniform thickness, stiffened with ribs so spaced that they will receive equal pressure, and therefore be of equal dimensions.

Suppose that 2 horizontal ribs are placed as above, thus dividing the gate into 3 areas. Each area carries $\frac{1.9}{3} = 0.63$ tons.

The slope of the pressure diagram is $1.5/1.5 = 1.0$

The distances X_1, X_2, X_3 and X_4 shown above are calculated as follows:

For X_1 : $\frac{0.32}{1} = \frac{(0.3 + 0.3 + X_1)\ 1.75\ X_1}{2}$; $0.64 = 1.05X_1 + 1.75\ X_1^2$

$$1.75\ X_1^2 + 1.05 - 0.64 = 0$$

$$X_1 = \frac{-1.05 \pm \sqrt{(1.05)^2 + (4 \times 1.75 \times 0.64)}}{2 \times 1.75} = \frac{-1.05 \pm \sqrt{1.1 + 4.5}}{3.5}$$

$$= \frac{-1.05 \pm 2.37}{3.5} = \frac{1.32}{3.5} = 0.38^m$$

For X_2 : $\frac{0.63}{1} = \frac{(0.68 + 0.68 + X_2)\ 1.75\ X_2}{2}$; $1.26 = 2.38\ X_2 + 1.75\ X_2^2$

$$1.75\ X_2^2 + 2.38\ X_2 - 1.26 = 0$$

$$X_2 = \frac{-2.38 \pm \sqrt{(2.38)^2 + (4 \times 1.75 \times 1.26)}}{2 \times 1.75} = \frac{-2.38 \pm \sqrt{5.65 + 8.8}}{3.5}$$

$$= \frac{-2.38 \pm 3.81}{3.5} = \frac{1.43}{3.5} = 0.41^m$$

For X_3 : $\frac{0.63}{1} = \frac{(1.09 + 1.09 + X_3)\ 1.75\ X_3}{2}$; $1.26 = 3.82\ X_3 + 1.75\ X_3^2$

$$1.75\ X_3^2 + 3.82\ X_3 - 1.26 = 0$$

$$X_3 = \frac{-3.82 \pm \sqrt{(3.82)^2 + (4 \times 1.75 \times 1.26)}}{3.5} = \frac{-3.82 \pm \sqrt{14.5 + 8.8}}{3.5}$$

$$= \frac{-3.82 \pm 4.84}{3.5} = \frac{1.02}{3.5} = 0.29^m$$

For X_4 : $\frac{0.32}{1} = \frac{(1.38 + 1.38 + X_4)\ 1.75\ X_4}{2} = \frac{4.82\ X_4 + 1.75\ X_4^2}{2}$

$$0.64 = 4.82\ X_4 + 1.75\ X_4^2$$

$$X_4 = \frac{-4.82 \pm \sqrt{(4.82)^2 + (4 \times 1.75 \times 0.64)}}{3.5} = \frac{-4.82 \pm \sqrt{23.2 + 4.5}}{3.5}$$

$$= \frac{-4.82 \pm 5.27}{3.5} = \underline{0.13^m}$$

__Check:__ $X_1 + X_2 + X_3 + X_4 = 0.38 + 0.41 + 0.29 + 0.13 = \underline{1.21\ ^m}$

__The Thickness of the steel plate__ is calculated by the following formula:-- $t = a\ b \sqrt{\frac{C\ P}{2\ S\ (a^2 + b^2)}}$

Where C is a constant = 0.8 if sheet is fixed to intermediate ribs.

P = max. water pressure in kgs/cm^2 on the section considered.

S = allowable stress in kgs/cm^2, which is 1200 for steel.

a = vertical distance between horizontal ribs. cms.

b = horizontal distance between vertical ribs. cms.

t = thickness of plate in cms.

Using 2 vertical ribs and 2 horizontal ones as shown above,

a = 35 cms , b = 57 cms , $P = \frac{630}{35 \times 57} = 0.316$ kgs/cm^2

Then $t = 35 \times 57 \sqrt{\frac{0.8 \times 0.316}{2 \times 1200\ (1220 + 3240)}}$

$$2000 \sqrt{\frac{0.253}{2400 \times 4460}} = 2000 \sqrt{0.000,000,0237}$$

$$2000\ (0.000154) = 0.308 \text{ cms.}$$

Add 50% for rust and other factors = 0.15 cms.

Total thickness = 0.308 + 0.15 = __0.46 cms.__

The minimum allowable thickness for a gate steel plate is 6 m/m. __Hence use here a 6 m/m plate.__

__Design of the ribs:__ The horizontal ribs are considered to be carrying the load. The load on each rib is 630 kgs as found before.

The bending moment,

$M = 1/8\ W\ L = 1/8 \times 630 \times 1.71 = 135$ kgm.

$= 135 \times 2.2 \times 3.28 \times 12 = 11700$ in-lb.

@ 1800 psi, $\frac{I}{C} = \frac{11700}{18000} = 0.65$ in^3

Use 1 [@ 4.1#/' 3" 1½" ($\frac{I}{C}$ 1.1)

For vertical ribs use /Ls 2½"×2½"×¼" @ 4.1 #/'

Design of the Lifting Device

The total horizontal farce acting on the gabe is 1.9 tons. Assumed that the coefficient of static friction is 0.40 The vertical force necessary to overcome this friction is $V = 1900 \times 0.4 = 760$ kgs. The lift has to account for this V and the weight of the moving parts of the gate. They include :

Steel sheet: $1.75^m \times 1.2^m \times 0.006^m \times 7850$	=	99 kgs.
4 ribs [s : $4 \times 1.75 \times 4.1 \times \frac{3.28}{2.2}$	=	43
4 ribs Ls $4 \times 1.2 \times 4.1 \times \frac{3.28}{2.2}$	=	30
Strips at two edges for water proofing	=	40
Add about 20% for details	=	50
		262 kgs.

Total to be lifted 760
262
1022 kgs.

Use a hoist with a capacity of 1½ tons.

Summary:

1) The difference of elevation between the crest of the dam and the full supply water level in the canal is 0.7'.

2) The gate opening is 2.9' × 4.75'

3) The gate dimensions are 3.9' × 5.75'

4) The gate opening is below the panel wall which is to be extended up to the operating platform above high water level in the river.

5) The top of the gate opening, formed by the lower edge of the panel wall, is at the same level of the full supply water level in the canal.

6) The position of the bed of the canal is 2.96' (90 cms) below the top of the gate opening.

SPILLWAYS

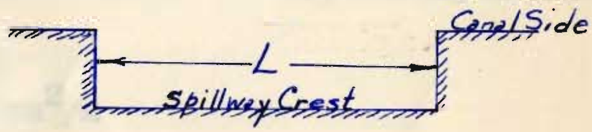
(1) Spillway just below the head gates. The normal capacity of the canal is 1.82 m^3/sec = 64.3 cusec. The excess capacity which may enter the canal due to faulty gates, assumed to be 33% of the normal capacity = 21 cusec. The spillway is to discharge this excess of 21 cusec. Assumed that the overpour depth is 6" which is the allowed free board.

Using Francis' formula for flowover a sharp crested weir, $Q = 3.33\ L\ H^{3/2}$, the required length of spillway crest, L, is:

$21 = 3.33\ L\ 0.5^{3/2}$

$= 3.33\ L \times 0.354$

$L = \dfrac{21}{3.33 \times 0.354} = 18'$



(2) Spillway just above the racks at the intakes to the powerhouse.

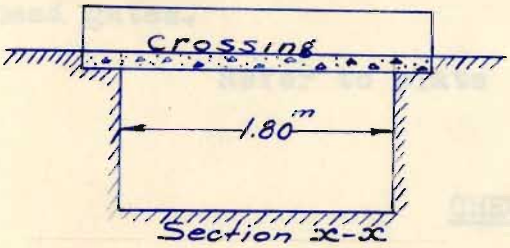
This spillway is assumed to carry away an excess quantity of water over the normal capacity of 25% which may be due to surface run-off or drainage water from higher lands collecting into the canal system.

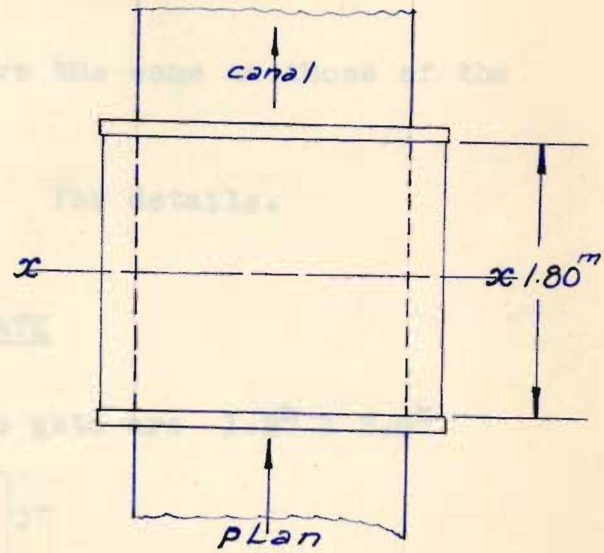
$Q = 0.25 \times 64.3 = 16$ cusec.

Using $H = 6" = 0.5'$ $\quad L = \dfrac{16}{3.33 \times 0.354} = 13.6'$

CROSSING OVER THE CANAL

This crossing is designed as a slab supported on two sides only.





Design of Slab

L.L. = 300 kgs/m^2

D.L. = 350 kgs/m^2 Assuming a 14 cms slab

Total = 650 kgs/m^2

Considering the slab to be simply supported, and the distance is 2 m from c. to c. of supports.

$M = 1/8 \times 650 \times 2^2 = 325$ kgm. = 32500 kgcm.

Using $d = 0.0335\sqrt{M}$ * Where d = effective depth of tension steel in cms. & M = Bending moment in kg cm

$= 0.0335\sqrt{32500} = 6.05$ cms.

Then $As = 0.833\,d$ **

$= 0.833 \times 6.05 \times 5.05\ cm^2/m$

Use 6 - 12 m/m ø bars ($As = 6.78\ cm^2/m$) and total height of slab equal to 14 cms.

Design of Railing

The railing is to be made of iron pipes embedded in a concrete border edge. Diam = $1\frac{1}{2}$"

Refer to plate II for details.

---

* From Béton Armé by Dunod.
** From Béton Armé by Dunod.

ESCAPE GATE or WASTEWAYS

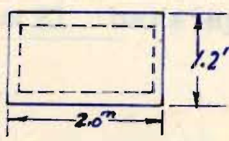
The capacity of this gate is to be equal to that of the canal, namely 64.3 cusec.

The dimensions to be used are the same as those of the head gates.

Refer to plate III for details.

CHECK GATE

The dimensions used for this gate are $1.2^{m} \times 2.0^{m}$



The remaining design parts are the same as those of the headgate.

SWITCH BOARD FRAMEWORK

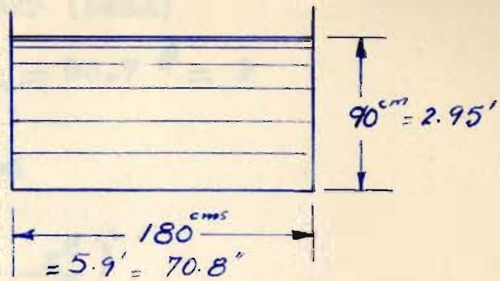
The framework consists of a sill, uprights, and braces.

Sill: 6 in steel channel bolted and grouted to the floor.

Uprights: 1$\frac{1}{4}$" standard black iron pipes or angle irons, braced to the wall by similar pipes or angles.

Panel: This will be supplied with the generator unit.

Design of the Racks



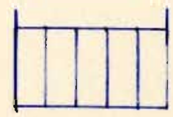
Let the rack bars be $\frac{1}{4}$" thick

and 3" clear distance apart.

Let n = number of bars needed.

then: $n \times \frac{1}{4}" + \left[(n+1) \times 3 \right] = 70.8"$

$$\frac{n}{4} + 3n + 3 = 70.8"$$



$$\frac{n + 12n + 12}{4} = 70.8"$$

$$13n = 4 \times 70.8 - 12 = 271.2$$

$n = 271.2/13 = 21$ bars approx.

for n = 21 bars exactly

$$21 \times \frac{1}{4} + 22x = 70.8"$$

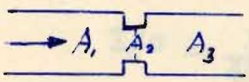
$x = 2.98"$ as exact spacing clear between bars.

$$2.95' \times 5.9' = 17.4$$

$$\frac{17.4}{\cos 15^{\circ}} = \frac{17.4}{0.966} = 18^{\square'} \text{ gross area}$$

$$21 \times \frac{1}{4 \times 12} \times 2.95 = 1.29^{\square'}$$

$$\frac{1.29}{\cos 15^{\circ}} = \frac{1.29}{0.966} = 1.335^{\square'} \text{ bars area}$$

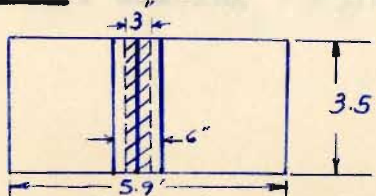


$$A_1 = 18^{\square'}$$

$$A_2 = 18 - 1.33 = 16.67^{\square'}$$

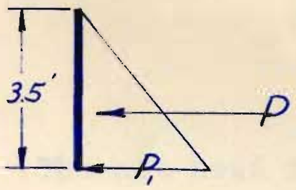
$$A_3 = 18^{\square'}$$

Rack Bars



3.5' = (d + over board)

No intermediate horizontal cross beams are considered necessary.

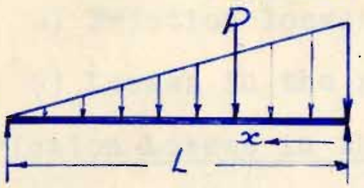


$P_1 = wh = 62.5 \times 3.5 = 219$ #/ft^2

Total load on bar (beam)

$$219 \times \frac{3}{12} \times \frac{3.5}{2} = 95.7\ \# = P$$

Considering the beam to be simply supported



$$M_x = \frac{P}{3} x \left(1 - \frac{x^2}{L^2}\right)$$

Mmax occurs when $x = 0.5774\ L$

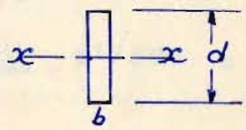
$\therefore$ Mmax = $0.128\ PL = 0.128 \times 95.7 \times 3.5 = 43$ ' #

= 516" #

@ 1800 psi stress

$$I/c = \frac{516}{18000} = 0.0287 \text{ in}^3 \text{ needed.}$$

Having considered the bars to be ¼" thick, we have for a 2" depth, $I/c = \frac{b\,d^3}{12}$



$$I = \frac{b\,d^3}{12} = \frac{1}{4} \times \frac{8}{12} = 0.167 \text{ in}^4$$

$$\frac{I}{c} = \frac{0.167}{1} = 0.167 \text{ in}^3$$

for a 1.5" depth

$$I = \frac{1}{4} \times \frac{1.5^3}{12} = 3.375 \text{ in}^4 = 0.0703$$

$$I/c = \frac{3.375}{48 \times 0.75} = \frac{3.375}{33.8} = 0.1 \text{ in}^3$$

Hence a bar 1.5" × ¼" is enough.

The bars will be cross tied by steel rods as will be shown on the detail drawing on plate III.

CALCULATION FOR THE HEAD UNDER WHICH THE TURBINE OPERATES

The net head is the gross available head minus the losses before the turbine. The losses are :

a) Friction losses in the canal (slope of the canal).

b) Losses in the racks and bends.

a) Friction Losses in the Canal (Slope)

For the canal used, it was found out that the slope is

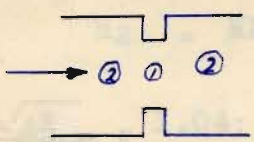
$$S = \frac{1}{11000\ d^{5.334}} = \frac{1}{11000 \times 0.57} = \frac{1}{6270}$$

$$= 0.00016$$

Since $hf = SL$ and $L \approx 260$ meters

$$hf = 0.00016 \times 260 = 4.2 \text{ cms.}$$

b) Loss in the Racks



$$V_2 = \frac{Q}{A_2} = \frac{1.82 \times 35.31}{2.95 \times 5.9} = 3.7'/\text{sec} = 1.12 \text{ m/sec.}$$

$$V_1 = \frac{Q}{A_1} = \frac{1.82 \times 35.31}{16.1} = 4'/\text{sec} = 1.22 \text{ m/sec.}$$

The loss in the racks is actually due to sudden contraction, friction, and sudden enlargement. The first and the last only are considered. The friction is neglected.

(1) Loss Due to Sudden Contraction

In the Handbook of Hydraulics by King (page 167, formula 32) the following is given for loss of head due to sudden contraction in pipes:

$$H_3 = K_3 \frac{V^2}{2g}$$ Where H_3 is the head lost in ft.

K_3 is a constant

V is the velocity in the smaller pipe.

There, values of H_3 are tabulated for $\frac{d2}{d1}$, ratio of diameter of larger pipe to diameter of smaller.

Since $\frac{\pi/4\ d_2^2}{\pi/4\ d_1^2} = \frac{A2}{A_1} = \frac{d_2^2}{d_1^2}$

$\frac{d2}{D1} = \frac{\sqrt{A2}}{\sqrt{A1}}$ Hence the ratio of the square root of the areas of the canal section is taken in place of the ratio of the diameters of the pipes as in the tables mentioned above.

$\frac{\sqrt{A2}}{\sqrt{A_1}} = \frac{\sqrt{17.4}}{\sqrt{16.1}} = 1.04$; using a value of 1.1,

this gives H_3 (with a $V = 4'/\text{sec}$) equal to 0.01 ft. = 0.3 cms.

(2) Loss Due to Sudden Enlargment

In the above mentioned Handbook, the following formula is given for this loss in pipes.

$$H_2 = K2 \frac{V^2}{2\ g}$$ where H, K and V are as in (1) above.

$\frac{\sqrt{A2}}{\sqrt{A1}} = 1.04$; using 1.2, H_2 (with $V = 4'/\text{sec}$) is equal to 0.02' equal to 0.6 cms. (1) plus (2) = 0.3 + 0.5 = 0.9 say 1 cm.

b') Loss of Head Due to Bends 1)

$H = C\ V^{2.25}$ Where H is the lost head in ft. for 90° bend
V is the velocity in ft. sec.
C is the coefficient varying with the radius of the centre line of the bend.

With $V = 4'/\text{sec}$, $R = 15'$, bend = 90°

$H = 0.11$ ft.

For a 45° bend : $0.11 \times \frac{3}{4} = 0.0825'$

For a canal : $0.0825 \times \frac{1}{2} = 0.041'$ = 1.25 cms.

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1) From Handbook of Hydraulics " by King, Page 168.

With $V = 4'/\text{sec}$, $R = 40'$, bend = 90°

$H = 0.17$

For a 45° bend : 0.17 x 3/4 = 0.127'

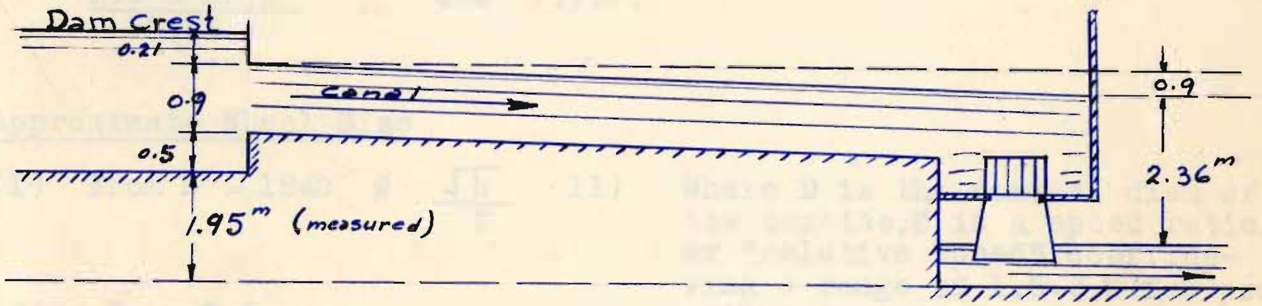
For a canal : 0.127 x 1/2 = 0.064' = 1.92 cms.

3.17 cms.

The Total Head Lost

4.2 + 1 + 3.2 = 8.4 say 9 cms.

The Net Head under which the Turbine Operates



1.95 + 0.50 + 0.90 = 3.35

3.35 - (0.90 + 0.09) = 2.36 meters

The Power Delivered to the Turbine

$$P = WH = \frac{1.82 \times 1000 \times 2.36}{75} = 57.2 \text{ hp.}$$

The Power Delivered by the Turbine

H P out put = H.P input x Efficiency

= 57.2 x 0.8 = 45.76 hp.

= 34.1 K.W.

Tentative Selection of Turbine and Generator

The Net head, $h = 2.36$ m. = 8'

From Figure 85, page 245 in Water Power Engineering by Barrows, for a head of 8', " A European Kaplan and Propeller Type-Karpov" Turbine is suggested with an N_s of 190 r.p.m.

From $N_S = \frac{Ne \sqrt{b\ hp}}{h^{5/4}}$ 1) Where N_s is specific speed and Ne is the value of r.p.m. at which the max. efficiency under the given head is attained.

$$Ne = \frac{Ns\ h^{5/4}}{\sqrt{b\ h\ p}} = \frac{190 \times 8^{1.25}}{57.2}$$

$$\frac{190 \times 13.5}{7.56} = 360 \text{ r.p.m.}$$

Approximate Wheel Size

(1) From $N = 1840\ \phi \frac{\sqrt{h}}{D}$ 11) Where D is the nominal diam of the turbine. ϕ is a speed ratio, or "relative speed" coeff. having a range of 1.5-3.0 for propeller type turbines.

using $\phi = 2.5$

and N = Ne = 360 r.p.m.

we get $D = \frac{1840 \times 2.5 \sqrt{8.00}}{360} = 36"$ nominal

(2) From $h\ p = Pu\ D^2\ h^{3/2}$ 111) Where Pu = unit power constant or power of the wheel under 1-ft. head, (range for propeller types = 0.0015 - 0.0025)

Pu = 0.0023 as obtained from fig. 76, page 233 in

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1) From Hydraulics by R.L. Daugherty page 404

11) From Water Power Engineering by Barrows, equation 13, page 229

111) From Water Power Engineering by Barrows, equation 15, page 229

" Water Engineering" by Barrows which is based on outlet diameters.

$$D^2 = \frac{h\,p}{Pu\ h^{3/2}} = \frac{45.76}{0.0023\ (8.0)^{1.5}}$$

D = 30" outlet

Generator

Assumed efficiency = 0.9

Power delivered by turbine = 34.1 K. W.

Output from generator = 34.1 x 0.9 = 30.69 K.W.

Summary

One Turbine

Vertical shaft

Propeller type

Ns = 190 r. p. m.

Ne = 360 r. p. m.

D = 35" Nominal

b h p = 45.76 hp (with 0.8 efficiency)

One Generator

Vertical shaft

110/190 volts

3 phase, star connected

50 cycles per second

Capacity of 40 Kv.A (at 0.8 P.F. = 32 K.W.)

N = 360 r. p. m.

V

COST ESTIMATE OF THE PROJECT

The items of coast for a waterpower are (1) fixed charges and (2) operating costs.

(1) The fixed charges include

a) Interest b) Insurance c) Taxes and

d) depreciation

(2) The operating costs include wages and maintenance.

The cost is made up as follows :

Headworks :

	Quantity	Unit price L.L.	Total Price L.L.
Rubble masonry	12 m3	25	300
Ashlar masonry	3	30	90
Dam masonry structure	40	20	800
Cyclopean concrete	8	45	360
Plain concrete	30	55	1650
Reinforced concrete	0.82	95	90
			3290
	+ 5% accidentals :		170
			3460

Interest, insurance, and taxes : 11%		=	380
Depreciation, 40 years	:	=	865
Maintenance , 2%		=	69

Total per year : 1314

Steel Gates

B/F 1314

	Quantity	Unit Price L.L.	Total Price L.L.	
Steel (in place)	400 kgs	1.5	600	
Hoist			200	
			800	
		x 3	2400	
Interest, insurance, and taxes, 11%			= 264	
Depreciation, 25 years			= 96	
Maintenance , 2%			= 48	
Total per year				= 408

Trash Racks

	Quantity	Unit Price	Total Price	
Steel in place	120 kgs.	1.5	180	
Painting of racks	2.88 m2	2.5	7.2	
Pipes 1 1/2" Ø	21 M.R.	2	42	
			229,2	
Interest, insurance, and taxes , 11%			25,2	
Depreciation ,20 years			11,5	
Maintenance 0,5 %			1,1	
Total per year				= 38

Spillways (2)

	Quantity	Unit Price	Total Price
Catch basins	10 M.R.	10	100
Channels to river	38 M.R.	4	152

Crossings (2)

	Quantity	Unit Price	Total Price
Reinforced concrete	1.2 m3	95	114
			366

c/F 1756

B/F 1756

	Quantity	Unit Price L.L.	Total Price L.L.	
Interest, insurance, and taxes, 11%			40,2	
Depreciation, 25 years			14,6	
Maintenance, 1%			3,7	
Total per year				59
<u>Canal (including tail race)</u>				
	300 M.R.	10	3000	
Interest, insurance, and taxes, 11%			330	
Depreciation, 30 years			100	
Maintenance, 1%			30	
Total per year				460
<u>Power House</u>				
Building Foundations			3000	
Building Superstructure				
Turbine Room	80 M2	75	6000	
Westwing ground floor	77 m2	70	5400	
Westwing 1st floor	92 m2	70	6400	
			20,800	
Interest, insurance, and taxes, 11%			2300	
Depreciation, 50 years			415	
Government tax on building			60	
Maintenance, 1%			208	
Total per year				2283

C/F 5258

B/F 5258

	Quantity	Unit Price L.L.	Total Price L.L.	
Turbine, Generator, Control Board & Other Equipment				
			25000	
Interest, insurance, and taxes, 11%			2750	
Depreciation, 25 years			1000	
Maintenance, 2 %			500	
Total per year				4250
Land				
About	6000 m2	0.4	2400	
Interest, 6%			124	
				124
Operation				
Day operators	1 at	200/month	2400	
	1 at	90/month	1080	
Night operator	1 at	150/month	1440	
Reserve to indemnify operators			440	
Total per year				5360
Grand Total per year ........L.L.				14,992

Available Power from Generator is 30 K.W;

Available Energy per year is

$$300 \times 24 \times 30 = 216000 \text{ K W H./Year}$$

$$\text{Cost per K.W.H.} = \frac{\text{Annual cost}}{\text{K.W.H. per year}}$$

$$= \frac{1500000}{216000} = 6.95 \text{ Lebanese Piasters}$$

C O N C L U S I O N

As shown above, the cost per K.W.H. of electricity, generated in this plant is about 7 Lebanese Piasters. By comparing this figure with the current prices of electricity in the present market, it is found out that even with such a small project with its low head, a good, reliable, and cheap source of electric power is made available in that limited area where the plant is set.

On the other hand, if this figure is compared with those of the cost prices of large hydroelectric power plants, it would seem that this project is quite expensive and a cheap source is not the result. Actually it may be so. But I may point out here that the larger the power developed the smaller the cost of development per unit capacity. Moreover, the cost of the development varies inversely as the available head utilized by the plant.

VII

APPENDIX A

CEMENT - RUBBLE CANAL in LOOSE GRAVEL

Table 1.

Depth	Excavation	Walls	Floor Blocage	Floor concrete	Total Money Invested	Interest Taxes Insurance	Depreciation	Maintenance	Friction Losses	Total Cost per annum per unit Length.
meters	$d^2+0.6d+0.09$ £.L.	$33.7d+11.1$ £.L.	$0.8d+0.12$ £.L.	$10d+3$ £.L.	£.L.	11 % of C £.L.	C/30 £.L.	0.01 C £.L.	$3.71/d^{5.334}$ £.L.	£.L.
1.50	3.24	61.65	1.32	18	84.21	9.26	2.81	0.842	0.426	13.338
1.40	2.89	58.28	1.24	17	79.41	8.74	2.65	0.794	0.614	12.798
1.30	2;56	54.91	1.16	16	74.63	8.21	2.49	0.746	0.914	12.360
1.20	2.24	51.54	1.08	15	69.86	7.68	2.33	0.699	1.400	12.109
1.10	1.96	48.17	1.00	14	65.13	7.17	2.17	0.651	2.180	12.171
1.00	1.70	44.80	0.92	13	60.42	6.65	2.01	0.604	3.710	12.974
0.90	1.44	41.43	0.84	12	55.71	6.14	1.86	0.557	6.550	15.107
0.80	1.11	38.06	0.76	11	50.93	5.60	1.70	0.509	12.370	20.179
0.70	1.00	34.69	0.68	10	46.37	5.11	1.54	0.464	24.740	31.854
0.60	0.81	31.32	0.60	9	41.73	4.59	1.39	0.417	55.400	61.797

CEMENT - RUBBLE CANAL in ROCK

Table 2.

Depth	Excavation	Walls	Floor Blocage	Floor concrete	Total Money Invested	Interest Taxes Insurance	Depreciation	Maintenance	Friction Losses	Total Cost per annum per unit Length.
"	$4d^2+1.6d+0.16$	$27d+5.1$	$0.4d-0.06$	$7.5d-0.25$	"	"	"	"	"	"
1.50	11.56	45.60	0.54	11.00	68.70	7.56	2.29	0.687	0.426	10.963
1.40	10.24	42.90	0.50	10.25	63.89	7.03	2.13	0.639	0.614	10.413
1.30	9.00	40.20	0.46	9.50	59.16	6.51	1.97	0.592	0.914	9.986
1.20	7.84	37.5	0.42	8.75	54.51	6.00	1.82	0.545	1.400	9.765
1.10	6.76	34.8	0.38	8.00	49.94	5.50	1.66	0.499	2.180	9.839
1.00	5.76	32.1	0.34	7.25	45.45	5.00	1.51	0.454	3.710	10.674
0.90	4.84	29.4	0.30	6.50	41.04	4.52	1.37	0.410	6.55	12.850
0.80	4.00	26.7	0.26	5.75	36.71	4.04	1.22	0.367	12.37	17.997
0.70	3.24	24.0	0.22	5. 00	32.46	3.57	1.08	0.325	24.74	29.715
0.60	2.56	21.3	0.18	4.25	28.29	3.11	0.94	0.283	55.40	59.733

STONE - LINED CANAL in LOOSE GRAVEL

Table 3.

Depth	Excavation	Walls	Floor Blocage	Floor concrete	Plaster	Total Money Invested	Interest Taxes Insurance	Depreciation	Maintenance	Friction Losses	Total Cost per annum per unit length.
meters	$d^2+0.6d+0.09$ £.L.	$29.9d+10.1$ £.L.	$0.8d+0.12$ £.L.	$10d+3$ £.L.	$4d+2$ £.L.	£ L.	11% of C.	C/30 £.L.	0.005 C £.L.	$1/1.164d^{5.334}$ £.L.	£ L.
1.35	2.72	50.40	1.20	16.50	7.4	78.22	8.62	2.61	0.391	0.173	11.794
1.30	2.56	48.90	1.16	16.00	7.2	75.82	8.35	2.53	0.379	0.212	11.471
1.25	2.40	47.40	1.12	15.50	7.0	73.42	8.09	2.45	0.367	0.260	11.167
1.20	2.24	45.90	1.08	15.00	6.8	71.02	7.82	2.37	0.355	0.326	10.871
1.15	2.10	44.40	1.04	14.50	6.6	68.64	7.56	2.29	0.343	0.410	10.603
1.10	1.96	42.90	1.00	14.00	6.4	66.26	7.30	2.21	0.331	0.518	10.359
1.05	1.82	41.40	0.96	13.50	6.2	63.88	7.04	2.13	0.320	0.668	10.158
1.00	1.70	39.90	0.92	13.00	6.0	61.52	6.77	2.05	0.308	0.890	9.988
0.95	1.56	38.40	0.88	12.50	5.8	59.14	6.51	1.97	0.295	1.130	9.905
0.90	1.44	36.90	0.84	12.00	5.6	56.78	6.25	1.90	0.284	1.47	9.904
0.80	1.11	33.90	0.76	11.00	5.2	51.97	5.72	1.73	0.260	2.87	10.580
0.70	1.00	30.90	0.68	10.00	4.8	47.38	5.22	1.58	0.237	5.73	12.767

STONE - LINED CANAL in ROCK

Table 4.

Depth	Excavation	Walls	Floor Blocage	Floor concrete	Plaster	Total Money Invested	Interest Taxes Insurance	Depreciation	Maintenance	Friction Losses	Total Cost per annum per unit length.
"	$4d^2+1.6d-0.16$	$24d+7.2$	$0.4d-0.06$	$7.5d-0.25$	$4d+1.4$	"	"	"	"	"	"
1.50	11.56	43.20	0.54	11.00	7.40	73.70	8.11	2.46	0.368	0.098	11.036
1.40	10.24	40.80	0.50	10.25	7.00	68.79	7.57	2.29	0.344	0.142	10.346
1.30	9.00	38.4	0.46	9.50	6.6	63.96	7.04	2.13	0.320	0.212	9.702
1.20	7.84	36.0	0.42	8.75	6.2	59.21	6.52	1.97	0.296	0.326	9.112
1.10	6.76	33.6	0.38	8.00	5.8	54.54	6.00	1.82	0.272	0.518	8.610
1.00	5.76	31.2	0.34	7.25	5.4	49.95	5.50	1.66	0.250	0.860	8.270
0.90	4.84	38.8	0.30	6.50	5.0	45.44	5.00	1.51	0.227	1.47	8.207
0.80	4.00	26.4	0.26	5.75	4.6	41.01	4.51	1.37	0.205	2.87	8.955
0.70	3.24	24.0	0.22	5.00	4.2	36.66	4.04	1.22	0.183	5.73	11.173
0.60	2.56	21.6	0.18	4.25	3.8	32.39	3.56	1.08	0.162	12.80	17.602

STONE - LINED CANAL

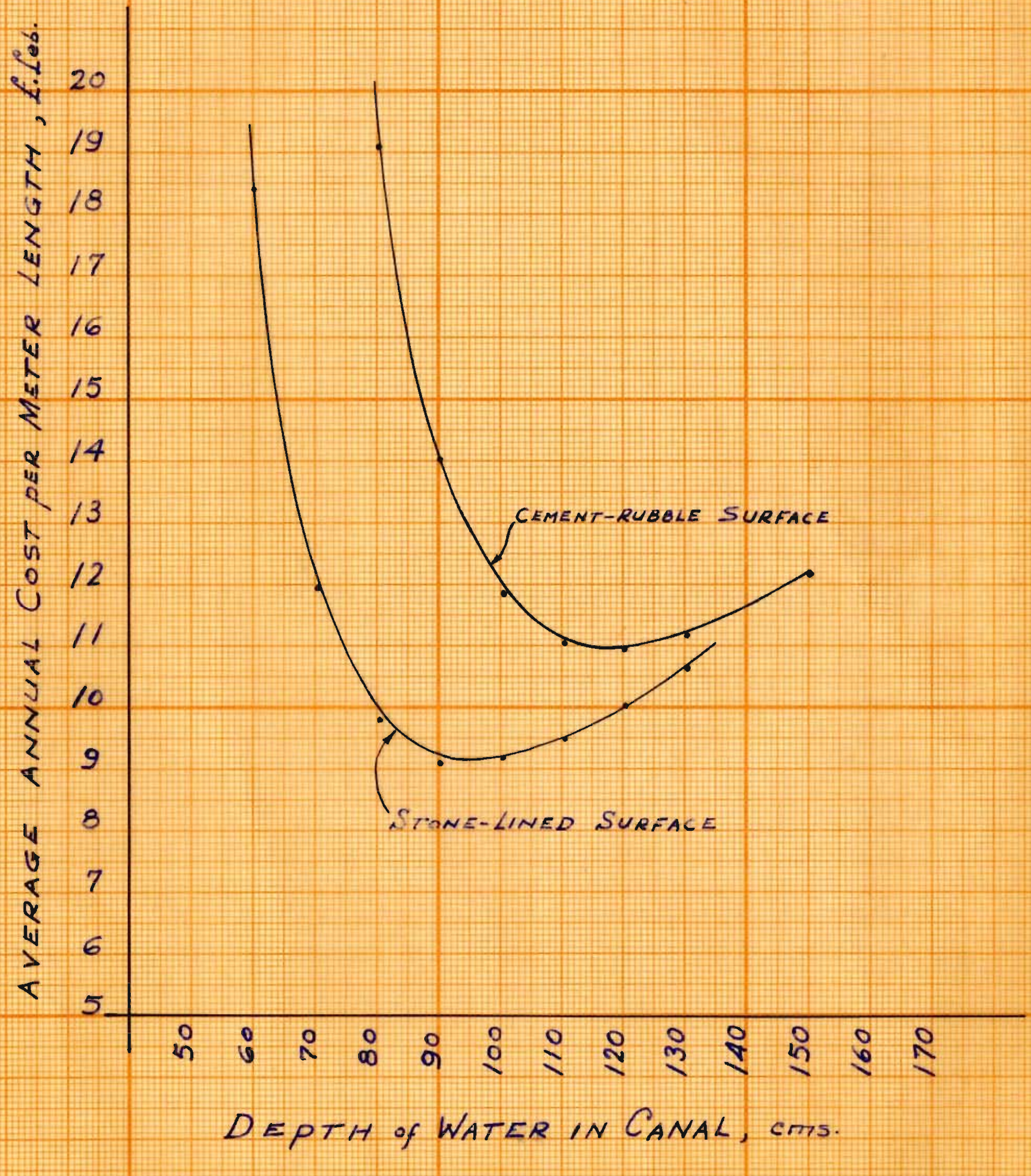
Table 5

Depth 6ms.	50% in loose Gravel	50% in Rock	Total	Average Cost per annum
	£. L.	£. L.	£. L.	£. L.
1.35	11.794			
1.30	11.471	9.702	21.173	10.586
1.25	11.167			
1.20	10.871	9.112	19.983	9.992
1.15	10.603			
1.10	10.359	8.610	18.969	9.484
1.05	10.158			
1.00	9.988	8.270	18.258	9.129
0.95	9.905			
0.90	9.904	8.207	18.111	9.055
0.80	10.580	8.955	19.535	9.767
0.70	12.767	11.173	23.940	11.970
0.60	19.143	17.602	36.745	18.372

CEMENT - RUBBLE SURFACE CANAL

Table 6

Depth 6ms.	50% in loose Gravel	50% in Rock	Total	Average Cost per annum
1.50	13.338	10.963	24.301	12.150
1.40	12.798	10.413	23.211	11.605
1.30	12.360	9.986	22.246	11.123
1.20	12.109	9.765	21.874	10.937
1.10	12.171	9.839	22.010	11.005
1.00	12.974	10.674	23.648	11.834
0.90	15.107	12.850	27.957	13.979
0.80	20.179	17.997	38.176	19.088
0.70	31.854	29.715	61.569	30.785
0.60	61.797	59.733	121.530	60.770


AVERAGE ANNUAL COST per METER LENGTH, £.Leb.
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
CEMENT-RUBBLE SURFACE
STONE-LINED SURFACE
50
60
70
80
90
100
110
120
130
140
150
160
170
DEPTH of WATER IN CANAL, cms.

APPENDIX "B"

Table 1.

Price List Used for Estimating The Cost of the Project.

Excavation in Loose Earth		L.L.	2/m3
" " Rock		"	8/m3
Cyclopean concrete		"	45/m3
Plain Concrete		"	55/m3
Cement 6 bags	: 26		
Sand and aggregate	: 12		
Steel (70 kgs)	: 35		
Labour	: 20		
	93 ≈		95/m3
Concrete lining (2 1/2 cms thick)			2/m2
Concrete (10 cms. thick) with expansion reinforcement			50/m3
Rubble masonry with mortar			23 -27/m3
Floor blacage			2/m3
Ashlar masonry			30/m3
Iron work in place			150/kgs
Rail pipes 1 1/2" ø			2/M.R.
Painting iron grilles			2.5/m2
Electric energy purchased			0.1/K.W.H.

Measurement of Cross section of the water canal of the Jounieh's Hydroelectric Power Plant on the Dog River , Beirut, Lebanon. Date: Oct. 29, 1950

Table 2.

Width meters	Depth meters	Calculated area m^2	Average Area m^2
2.00	1.65	3.30	
2.30	"	3.80	
1.90	"	3.14	
2.20	"	3.63	
2.35	"	3.88	
2.40	1.70	4.08	
2.30	"	3.91	
2.00	"	3.40	
2.00	"	3.40	
2.00	"	3.40	
2.25	"	3.83	
2.20	1.65	3.63	
2.20	"	3.63	
2.50	"	4.12	
2.00	1.70	3.40	
		54.55	3.64

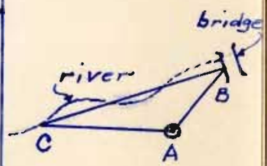
Measurement of the Gross Availabe Head between the Water level in the river at the point where the Tailrace of the Jounieh's Plant discharges (point B) and the water level in the River where the Tailrace of the Proposed Project is to be located (point C).

Date: Oct. 29, 1950

Measurement taken by Transit and Stadia

Table 3.

Transit at	Sight at	U. H. L. H.	M. H.	H ∠	V ∠
A	B	1.54 0.46	1.0	198° - 30'	-2° - 58'
	C	2.37 0.63	1.5	62° - 24'	-2° - 29'



CALCULATIONS FOR THE AVAILABLE HEAD

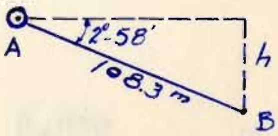
Refer to Table 3, page 58.

Between points A and B.

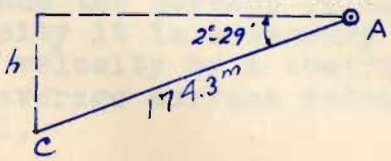
Distance = 100 × 1.08 + 0.3 = 108.3 meters

h = 108 sin 2° - 58'

= 5.6 m.



Between Points A and C.



Distance = 100 × 1.74 + 0.3 = 174.3 m.

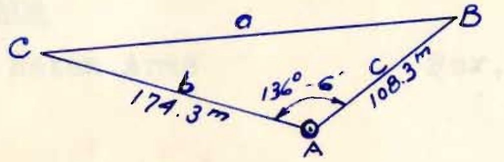
h = 174.3 sin 2° - 29'

= 7.55 m.

Between Points B and C.

7.55 - 5.60 = **1.95 m.** is availabe head

Distance Between B and C.



$$198^\circ - 30'$$
$$62^\circ - 24'$$
$$136^\circ - 6' = \angle A$$

$$a^2 = b^2 + c^2 - 2bc \cos A$$
$$= (174.3)^2 + (108.3)^2 + 2 \times 174.3 \times 108.3 \times 0.72$$
$$= 30{,}380 + 11{,}730 + 27{,}180$$
$$= 69{,}290$$
$$a = 264 \text{ meters}$$

Measurement of Velocity by the Floats Method in the Water Canal of the Jounieh's Hydroelectric Power Plant on the Dog River, Beirut, Lebanon.

Date: Oct. 29, 1950

Table 4.

Time sec.	Distance moved meters	Calculated velocity m/sec	Average Surface velocity m/sec	Mean Velocity m/sec
48.5	30	0.619		
50.9	30	0.590		
50.8	30	0.591		
53.7	30	0.557		
56.2	30	0.534		
		2.891		
		÷ 5	= 0.578	× 0.85**
				= 0.50

**Since the surface velocity is usually greater than the mean velocity it is necessary to multiply the observed average surface velocity by a coefficient (usually abmut 0.85) to reduce the average surface velocity to the mean velocity in the vertical.

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