SYNTHETIC METHODOLOGY FOR THE CALCULATION AND PRELIMINARY SPECIFICATION OF MICRO HYDRO POWER STATIONS

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ORGANIZACION LATINOAMERICANA DE ENERGIA

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1. SCOPE

We think that it would be overly pretentious to consider this document a "manual" in the broadest sense of that term, if we understand a manual as dealing broadly with the various aspects related to a subject, but with sufficient depth for each of its aspects. The author has attempted, instead, to present a simpler instrument, almost a simplified methodology for approximating the design of Micro Hydro Power Stations, and thus has evolved the almost excessively synthetic nature of this presentation of the material. Obviously, such approximation obliges us to leave aside some useful comments and recommendations, as well as a demonstration of the formulas employed.

This document is directed especially to young engineers or those who have had no professional experience in the field of hydroenergy; and it is within the scope of professionals from any of the engineering specialties, as long as their training has included the fundamentals of hydraulics and energy.

The intention herein is not to provide large doses of originality in the ideas set forth; actually, an effort has been made to the contrary, in order to present practical solutions for the application of some of the non-conventional technologies as yet only slightly disseminated, as in the case of penstocks in non-metallic materials.

The basic principles contained herewith are applicable to any type or size of plant; however, some methodological aspects- related to the simplification of the project engineering and to the application of some non-conventional technologies- prove particularly relevant for the lower power ranges, and this applicability is reduced as the power capacity increases. For that reason, we chose to include the term "micro hydro power stations" in our title; according to the classification system adopted by OLADE, this term corresponds to those stations with a power range lower than 50 kW, as is explained in the following section.

In addition, despite the fact that hydroenergy technology is of a universal nature, those elements which the author has judged to be most relevant for Latin America are those which have been stressed herein, especially insofar as the Spanish terminology used and its regional equivalencies, the technologies and equipment with the greatest prospects for regional availability, and the emphasis on medium and high falls.

With regard to the contents of this document, aspects of a general nature are presented: classification and definitions, simplified methods for the evaluation of the energy demand and of the hydro resources, and basic procedures and calculations involved in specifying a hydro power plant.

2. CLASSIFICATION AND DEFINITIONS

2.1. CLASSIFICATION

We have adopted the system proposed by OLADE:

a) according to power capacity and heads:

	POWER RANGE	HEAD (m) LOW	MEDIUM	HIGH
Micro Hydro Power Stations	Up to 50	Less than 15	15-50	More than 50
Mini Hydro Power Stations	50-500	Less than 20	20-100	More than 100
Small Hydro Power Stations	500-5000	Less than 25	25-130	More than 130

CHART No. 1 POWER RANGES AND HEADS

- The ranges of power and head are only indicative.
- The low, medium, and high heads approximately correspond to the typical use of Axial Flow, Francis or Michell-Banki, and Pelton turbines, respectively.
- The term "Small Hydro Power Stations" also refers to all of the stations with power ranges of up to 5000 kW.
- The present document is destined for use mainly in Micro Hydro Power Stations with medium and high falls.

b) according to the form of capture:

- Run of the river
- With a reservoir or dam

c) according to the type of regulation:

- Regulable (control of the flow at the turbine entry), either manually or automatically

- Constant load, be that due to the very nature of the load or to the dissipation of excess energy

d) according to the link with the electrical system:

- Isolated stations
- Stations linked with small electrical systems
- Stations linked with large regional or national grids.

e) according to technological features:

This is an indicative classification, referring to the nature of the principal technological elements of a plant.

- Stations with conventional technologies. These include quality civil structures for the water intake, canal, and forebay, silt removal in the intake, steel penstocks, expensive electromechanical equipment, construction with the most demanding criteria for materials and manufacturing processes, and a well-equipped instrument panel.

- Stations with non-conventional technologies. These frequently make use of existing water intakes nd irrigation canals which have been improved; a forebay installed in line with the canal, including a silt remover; penstocks in non-metallic materials; and electromechanical equipment designed and built on the basis of technologies adapted to the level of industrial development of a given country and taking into account the availability of national materials, standardized equipment, modular switchboards, and minimal instrumentation.

2.2. DEFINITIONS

We follow with a glossary to explain the main elements of a hydro power station; in some cases, alternative terms are indicated in parentheses.

a) Water intake. This can include reservoirs (dams, dikes) in the principal water course, run-of-the-river intake (lateral intake). Frequently, submerged dams (diversion dams) are installed to raise the water level at the intake entry.

b) Conduction: This can take the form of a canal or tunnel which carries water from the intake to the forebay, or even farther when irrigation canals are used.

c) Forebay (reservoir, loading chamber or tank). This structure receives the water from the canal before its entry into the penstock.

d) Silt remover (solids separator). This civil structure facilitates the settling of solid particles in suspension in the water, by reducing the velocity of the flow. It can be installed in the water intake or in the forebay.

e) Gates. These devices control the water flow at intakes and in the canals and forebay.

f) Grates (grills). These devices avoid the passage of floating solids or carry-overs above a certain size.

g) Penstocks (pressure pipes). This piping transports the water from the forebay to the turbine and permits the utilization of the head's potential energy.

h) Head (fall). This is the difference in levels between the free water surface at the forebay and the maximum utilization level in the turbine.

i) Main valve (master valve). This element serves as an insulator between the turbine and the penstock. It is not normally used for regulation purposes.

j) Turbine. This hydraulic engine utilizes the available hydraulic energy and converts it into mechanical energy.

k) Turbine-generator transmission. This system transmits energy from the turbine axis to the generator axis, either through a direct connection or through intermediate transmission by V-belts, flat belts, gears, or chains.

l) Generator. This electrical machine converts mechanical energy into electrical energy (electricity); it can be an alternator (asynchronous generator) or an asynchronous generator (inverted electrical motor).

m) Switchboard or instrument panel.

n) Transformer.

o) Transmission lines. Low and medium tensions are used for transmission from small hydro power stations to the place of consumption.

p) Distribution lines. These are used to feed low-tension household systems.

2.3. UNITS

We mainly employ the following units:

- Length and height: meters (m)
  Except for diameters and thicknesses of pipe walls, where dimensions are in millimeters (mm) and nominal values for standard piping, which are expressed in inches (in. or ").

- Speed: meters/second (m/s)

  Flow: cubic meters/second (m^3/s)

- Work: kilowatt-hours (kW-H)

- Power capacity: kilowatts (kW)
  Except for indicators for per capita installed capacity requirements, which are expressed in watts (W) and "power" specific speed (N_s), where the values for the power capacity are expressed in steam horsepower (CV).

- Speed of rotation: revolutions/minute (RPM)

- Stress: kilogram-force/square millimeter ($kg\text{-}f/mm^2$)

- Temperature: degrees-Centigrade (° C)

Appendix II gives some unit conversion factors.

3. EVALUATION OF ENERGY DEMAND

The present methodology does not attempt to analyze those aspects related to the financial-economic feasibility of projects, but rather its intention is merely to present those elements which permit the determination of techniques and alternatives for orienting the preliminary analysis of Micro Hydro Power Station projects. Nevertheless, it is worth mentioning that the depth and breadth of the studies undertaken for any specific project should be in relation to the security which is desired for the investment; and consequently, there should be a suitable ratio between the costs of the studies and the total project investment.

To this end, the analysis of the demand can be substantiated on the basis of the following aspects:

- An overall socio-economic analysis based on field information, from which prospects for energy development can be discerned.
- Application of indicators to determine installed capacity requirements.
- Application of indicators and typing of the energy demand in order to evaluate probable energy consumption.

3.1. SOCIO-ECONOMIC ANALYSIS

Objective: To determine basic information on energy requirements and demand.

Method: Direct survey (total population or a sufficiently large sample). Appreciation of prospects, forecasts, and identification of projects in productive activities with energy inputs.

Scope:

- Population:
  Magnitude, number and size of families, distribution according to

activities, income level, cultural level, etc. Typing of possible levels of satisfaction of energy needs, Historical information on growth (or stagnation); migrations.

- Economic Activities:
  Description of current productive and support activities; economic impact. Potential of the area. Identification of investment projects in activities demanding energy inputs.
  Requirements fot the development of projects; time periods.

- Transportation and Communication:
  Transportation systems (personal and freight); roads, mail service, telecommunications, etc.

- Services:
  Potable water, sewage disposal, energy availability, commerce.

- Education:
  Schools and cultural activities; educational needs and their specific energy requirements.

- Physical description of the site:
  Geographical location, distance, physical description (streets, distances, types of construction, etc.); maps of the site.

3.2. APPROXIMATE DETERMINATION OF THE INSTALLED CAPACITY REQUIRED

For preliminary evaluations- or when there is limited socio-economic information about the settlement, especially with respect to the average size of families- it is useful to employ indices for the installed capacity requirements per inhabitant, the magnitude of which depends on:

- Socio-economic and cultural levels of the population.

- Existence of electrical supply.

- Load factor: the effect of high peak loads tends to increase the installed capacity requirements. It is important to consider the levels of simultaneous consumption, mainly for households and productive activities.

- Existence of systems and education directed to the rational use of energy.

- Average size of families.

The indicators for installed capacity requirements, per capita, can vary widely in the Latin American rural areas. For the particular case of isolated populations with low levels of socio-economic development, the requirements are between some 30 W/inhabitant (ref. 1) and some 100 W/inhabitant (ref. 2). For estimates on the basis of little analysis, it is reasonable to assume a value of 50 W/inhabitant.

When more socio-economic information is available, it is better to use indicators for family units or households, since the energy needs at the domestic level are more linked to the number of housing units than to the population in general.

A minimum value would be on the order of 250 W/household, although it is possible to conceive of larger values, on the order of 500 W/household (ref. 2).

In determining the installed capacity, it is worthwhile to study the forecasts with respect to simultaneous consumption for domestic requirements and productive activities. In Micro Hydro Power Stations (under 50 kW) attending isolated populations in Latin America, it is common to find that the utilization of electricity occurs primarily during the evening (6-12 hours), for domestic purposes and public lighting. In this case, the installed capacity selected to cover the peak demand generally leaves an ample margin of plant availability for the existing productive activities and new activities underway, for these operate mainly during the day (agroindustry, services, etc.) or in the early morning (bakeries).

3.3. ANALYTICAL METHODOLOGY FOR DETERMINING THE INSTALLED CAPACITY REQUIRED AND THE ENERGY CONSUMPTION

In the previous item, some indices were pointed out to permit a preliminary estimate of the capacity to be installed; however, in order to define these requirements more accurately, it is useful to analyze the structure of the demand in greater detail, as indicated below and illustrated in Chart No. 2. It should be mentioned that this method proves applicable for isolated plants which operate discontinuously and in which the reduced scale of the energy requirements permits an adequate evaluation of the installed consumption capacity and of the probabilities of simultaneous demand.

The system consists of analyzing the energy requirements as a function of discontinuous "periods" into which a typical day of operation can be divided, and as a function of each consumption "sector", with the "peak load" and a "specific load coefficient" determined for each "period" and "sector", as follows:

a) Peak Load (C_p) for each daily "period" and "sector": This is established by identifying the requirements of installed consumption capacity (C_i) which could operate, corrected with a probability factor for simultaneity (f_s). For greater security, and whenever it is considered possible that the peak load is equivalent to the installed consumption capacity, $f_s = 1$ will be assumed. In general, this factor will have a value lower than one (1), unless the requirements for starting up the electric motors are such that they oblige the consideration of values larger than one (1).

$$C_p = f_s \times C_i \qquad \begin{array}{l}(C_p \text{ in kW})\\ (C_i \text{ in kW})\end{array}$$

b) Specific Load Coefficient (f_c) for each daily "period" and "sector": This is defined as the ratio between the "mean load" (C_m) in kW and the "peak load" (C_p).

The daily "periods" are groups of hours, in the same day, during which it is expected that the plant will be functioning continuously; these depend on the characteristics of the demand anticipated during a 24-hour period. For example, in a plant destined exclusively to night-time lighting, one single "period" can be considered: from 6 p.m. to 11 p.m. As a maximum, we point out three more or less typical periods of energy utilization for an isolated settlement with a reasonable diversification of demand:

Period 1: This could be defined as 2 a.m.-5 a.m., hours occupied by activities such as breadmaking.

Period 2: This could be defined as 7 a.m.-5 p.m., hours characterized mainly by the demand of productive activities (agroindustry, services, etc.).

Period 3: This could be defined as 6 p.m.-11 p.m., hours characterized mainly by the requirements of public lighting and household consumption.

At the same time, it is necessary to define the consumption sectors; and for the purpose of analyzing the proposed demand, it is suggested that these be reduced to a minimum and broken down in the following way:

- Public lighting. Its specific load coefficient would be near one (1), reduced only by the incidence of damaged lights; a value of f_c = 0.95 can be assumed.

- Household consumption. The typical consumption characteristics should be established according to representative population groups, establishing a "typical" family and household

for each group. In addition, it should be taken into account whether or not it is thought to install devices to limit consumption, for these tend to reduce the peak loads.
In the case of isolated rural populations with low income levels, the domestic consumption will principally consist of lighting requirements , with specific load coefficients which are quite high (on the order of 80%).
For each typical household, the consumption capacity and the applicable specific load coefficients should be studied for the purpose of determining the accumulated installed capacity requirements.

- Consumption by productive activities and services. Since a Micro Hydro Power Station cannot be expected to attend a large number of units for productive activities and services, the installed capacity requirements and consumption can be approximated by analyzing the production processes and the energy requirements for each one.

The energy requirementsfor productive activities and services should be studied in accordance with the following:

- Possibilities for utilizing the existing plant availability for productive purposes during the day and in the early morning; prospects for expanding productive activities; daytime surplus availability for eventual domestic utilization.

  Limitations on the use of water during the day, due to other priorities (mainly agriculture). This can be significant for micro hydro power stations that use existing irrigation canals. Consider institutional aspects.

  The starting up of electric motors can temporarily double the power requirements of each unit (ref. 2 and 3). An adequate control based on sequences of motor start-up is a viable alternative in small settlements. Moreover, the use of low-tension starting devices can be considered; but these are expensive.

- Possibilities of the direct utilization of mechanical energy.

c) Mean Load (C_m): This is determined by the product of the peak load and the specific load coefficient.

$$C_m = f_c \times C_p \qquad \text{(in kW)}$$

d) Energy Consumption (c) for each "period" and "sector": This is determined as the product of the mean load and the number of hours (h) corresponding to the period, as follows:

$$c = C_m \times h \qquad \text{(in kW)}$$

The sum of the consumption for each period of the day determines the daily energy consumption, and the sum of each sector's consumption during the day is equivalent to the daily sector consumption.

In order to determine the annual consumption, possible seasonal elements should be taken into account in the daily consumption, along with the shutdown periods due to maintenance or limitations on the use of the water.

e) Determination of the installed capacity:

After adding together the peak loads for all of the sectors for each period, that period which requires the greatest peak load (C_p) is selected as a reference point for determining the installed capacity requirements.

In defining the installed capacity, allowances should be made for energy losses during transmission and distribution; and a qualitative appreciation should be made of the probabilities of coincidence in the peak loads of the various sectors during the same period, as well as of the limitations with respect to the continuity of service and electrical black-outs.

In addition, future demand should be projected, not only as a function of population growth but also as a function of the increase in unit demand indices, evaluating the comparative advantages and disadvantages of having a surplus of installed capacity as opposed to an eventual expansion.

It is important to note that in many Latin American countries, it is not necessary to consider growth indices for the rural population, due to the intensive migration processes towards the cities; and this phenomenon has been only partially curtailed as a result of the more widespread availability of electrical energy.

		PUBLIC LIGHTING SECTOR	HOUSEHOLD CONSUMPTION SECTOR	CONSUMPTION BY PRODUCTIVE ACTIVITIES & SERVICES	TOTAL
PERIOD "1" 2 a.m. - 6 a.m. (4 hours)	Installed consumption capacity $-C_i-$ (kW)	-	-	2.0	
	Simultaneity factor-f_s	-	-	1.0	
	Peak load $-C_p-$ (kW)	-	-	2.0	2.0
	Specific load coef.-f_c	-	-	0.8	
	Mean load $-C_m-$ (kW)	-	-	1.6	
	Energy consumption -c (kW-h)	-	-	6.4	6.4
PERIOD "2" 7 a.m. - 5 p.m. (10 hours)	Installed consumption capacity $-C_i-$ (kW)	-	-	10.0	
	Simultaneity factor-f_s	-	-	1.2(*)	
	Peak load $-C_p-$ (kW)	-	-	12.0	12.0
	Specific load coef.-f_c	-	-	0.7	
	Mean load $-C_m-$ (kW)	-	-	8.4	
	Energy consumption -c (kW-h)	-	-	84.0	84.0
PERIOD "3" 6 p.m. - 11 p.m. (5 hours)	Installed consumption capacity $-C_i-$ (kW)	8.0	20.0	-	
	Simultaneity factor-f_s	0.9	0.9	-	
	Peak load $-C_p-$ (kW)	7.2	18.0	-	25.2
	Specific load coef.-f_c	0.95	0.8	-	
	Mean load $-C_m-$ (kW)	6.84	14.4	-	
	Energy consumption -c	34.2	72.0	-	
DAILY ENERGY CONSUMPTION -c- (kW-h)		34.2	72.0	90.4	196.6

(*) Considering the start-up of the electric motor with the greatest power capacity; for the case indicated in the chart, an installed capacity of 26 kW was considered (without allowing for future increases in demand).

CHART No. 2 - ANALYTICAL DIAGRAM OF LOAD AND CONSUMPTION (A PRACTICAL EXAMPLE)

4. EVALUATION OF THE PHYSICAL ENVIRONMENT AND ESTIMATE OF THE UTILIZABLE RESOURCE

Given the framework of the present methodology, we do not intend to provide an exhaustive analysis of the methods of evaluation of the physical environment, but rather only to identify aspects to be evaluated and their limitations, with stress on known methods for calculating the main parameters of specific projects, in other words, available flow and utilizable head.

4.1. MINIMUM RECONNAISSANCE REQUIREMENTS

For individual micro hydro power station projects, the reconnaissance studies of the physical environment should be reduced to a minimum, due to their high costs with respect to the investment. It proves more recommendable to orient the studies of the physical environment towards the evaluation of basins and sub-basins, so as not only to determine the potential of a given basin but also to utilize and generalize the information obtained, in order to apply it to sets of specific projects without having to undertake such evaluations for each one individually.

The level of reconnaissance of the physical environment of a basin can include the following aspects:

- Hydrology
- Ecology
- Geology
- Geomorphology
- Geotechniques
- Availability of aggregates

In applying these to the study of basins and sub-basins for micro hydro power stations, the following should be considered:

a) HYDROLOGY

Objective: To estimate the flows utilizable for micro hydro power stations, generally determining the minimum flows, with about a 95% probability that they will be exceeded.

Methodological aspects: The determination of the minimum flow is generally obtained on the basis of the flow/duration curve; however, frequently, there are difficulties in determining this by direct methods, since many times hydrometric gauges are not available and indirect methods based on the determination and application of index values must be recurred to.

It is also possible to establish criteria for constant similarity between the sub-basins and the main basins, thus permitting the generalization of the hydrological information most probably available for the major basins, principally precipitation/duration and flow/duration curves.

The pluviometric information should be completed by establishing regression equations with the existing data; likewise, one should proceed with the available hydrometric information, generally applying interpolation criteria for the completion of the flow logs. When there are no representative hydrological series for the sub-basins, it is also possible to utilize hydrological models which simulate runoff series for the drainage area being considered. An interesting model- which would require some adaptation in order to be applied to Latin America- is the SNSF-Norway system, in which the transfer across each sub-basin is simulated by a system of tanks (ref. 4.D.).

At any rate, the minimum monthly flow, or that which predominates 95% of the time, or sometimes a lower value (depending on the exigencies of continuous run-of-the-river service) can be defined as a percentage of the multi-annual average. Equations can be establishedto relate the average annual flow to the average annual hydro yield ($m^3/s/km^2$) and to the corresponding drainage area of the basin, which jointly with the duratuin curves, indirectly determined, can give rise to linear expressions for calculating the minimum monthly flows.

The daily flows can vary considerably, with the minimum daily values generally lower than the minimum monthly ones. However, their prediction is quite uncertain, and this results in a problem apparently difficult to solve, considering that accumulation is practically negligible in the case of the run-of-the-river micro stations. Despite this difficulty, the problem is not very relevant, due to the fact that the occurence of minimum daily flows lower than the monthly ones would only temporarily affect the operation of the plant.

Ideally, it would be useful to have evaluations of the water course from which the waters would be derived for a minimum of three years Nevertheless, this only proves practical for sets of projects in a given basin and not for a specific micro station

In addition, the referential information supplied by the local population, when duly interpreted, can contribute to estimating historical flows, principally with regard to flooding. The maximum flows constitute a useful reference for the design of the civil structures, above all insofar as their protection.

b) ECOLOGY

Objective: To describe the environment in which the plants will be developed, for the purpose of calculating , on the one hand, its influence on the features of the projects (the construction, materials, and equipment to be employed) and its expected effect on conservation and, reciprocally, the effect of the installation of micro stations on the ecology of the bain or sub-basin.
Methodological aspects: This type of study is only appropriate for the evaluation of basins and not for specific projects, due to the reasons pointed out previously. In the latter case, only general comments are required on the ecological aspects.

The following aspects are included:

- Climate
- Biological zones
- Soils (from the point of view of their utilization by Man)
- Vegetation
- Fauna
- Waters and aquatic biology

c) GEOLOGY

Objective: To determine the basic characteristics and composition of the soils and sub-soils of the basin, for the purpose of establishing bases for a general orientation of the construction, mainly in its structural and seismic aspects.

Methodological aspects: It is more useful to undertake studies applicable to basins and sub-basins rather than to specific projects. The most relevant aspects of such a study are:

- Lithology (geological formations, applying stratigraphic methods)
- Structural geology (faults, volcanic orientation and activity)
- Seismology (logs, probability of seismic activity and its magnitude)

d) GEOMORPHOLOGY

Objective: To study the formation of the earth's surface and to evaluate such, so as to determine, primarily, the accumulation and deposit of sediments in the water courses, while considering the impact of these in terms of equipment erosion and, consequently, the need to design adequate silt removal systems and to select appropriate materials for the turbines (principally for the runners and the injection systems). This also permits the orientation of the final selection of project sites, taking into account possible landslides.

Methodological aspects: Identification of structures on the basis of geomorphological maps, mainly with respect to cliffs, springs, and the valley floor (water course); applicable to the global study of basins and sub-basins.

e) GEOTECHNIQUES

Objective: To study the soils with regard to their characteristics, mechanical properties, stability, and water tables, mainly in order to orient the design and construction of the hydraulic structures.

Methodological aspects: Given the enormous variations at different points, the application of geotechnical studies at the level of basins and sub-basins is limited. Consequently, in such cases, they are restricted to the descriptive aspects derived from geological studies.

The geotechnical study is particularly relevant for the study of soils in possible specific sites for the civil structures, with the aims of orienting the selection of definitive sites and defining design requirements.

The extent of its use is linked to the magnitude of the specific project, not only with respect to the cost of the study but also to the risks of the project itself. In the case of Micro Hydro Power Stations, the geotechnical studies are generally reduced to a minimum, qualitative appreciations mainly based on excavations and probes, the approximate determination of the carrying capacity of the soil and the estimation of safety factors for the design of the water intake, the forebay, some piping anchors, and foundations for the principal equipment.

f) AVAILABILITY OF AGGREGATES

Objective: To study the existence of adequate materials for aggregates (stone, gravel, sand, etc.), an important factor in reducing the project costs and in assuring the selection of suitable materials, project designs, and construction methods.

Methodological aspects: Differential study of the availablity and characteristics of the main types of materials required (granular material, stone material, quarry material, etc.).

3.2. FLOW MEASUREMENTS

Three procedures are described in this regard:

- Approximate measurement by means of a buoy.
- Measurement by means of a rectangular weir.
- Measurement by means of a triangular weir.

a) Approximate measurement by means of a buoy: This method permits a rapid and simple approximate measrurement of the waterflow in an open conduction or canal. When careful measurements are taken, the margin of error for this method is on the order of ± 20% as a result, this method should only be used for preliminary waterflow estimates.

PRINCIPLE:

This method is based on the fact that the flow is the product of the average speed of the flow through the submerged part of the canal, considering the following hypotheses:

- That the surface speed- duly corrected with a factor that depends on the material of the canal walls and on the section/wetted perimeter ratio- is equivalent to the water's average speed.
- That the mean section of the canal is the average of two or three measured sections from the length of canal chosen for measuring the speed.

INSTRUMENTS AND MATERIALS:

1 chronometer

1 rule (1-3 meters long, with graduations in mm) for measuring the width of the canal

1 plastic measuring stick (30-100 cm long, graduated in mm) to

measure the depth of the canal
1 long rule (10-30 meters long) to measure the length of the section of canal selected
1 buoy (This can be a small bottle one third full of water, a piece of wood, etc., in order to determine the water speed.)

PROCEDURE:

1. Select a length of canal upstream of the point of water utilization, but downstream of the last point of derivation of water for other purposes. The length chosen should be fairly straight and its section should be fairly uniform along its full length. A length of some 10 m is recommended.
2. After measuring and marking the chosen length, toss the buoy into the water before the initial point and time how long it takes, in seconds (t), to travel the full length. Repeat the test several times, observing if the buoy touches bottom or the edges at any point, in which case the test would be discarded. If the results are scattered within a small range, then average the times. If there is an upper group and a lower group, then average the latter, since the higher values could have been subject to some interference.
3. Calculate the surface speed:

$$V = \frac{x}{t} \qquad (m/s)$$

4. Select 2 or 3 sections that characterize the canal and divide the width of each section into 4 parts. For each section, take measurements of the initial depth, the depths in the first quarter, the center, the third quarter, and, finally, at the opposite side.

(See illustration on page 26.)

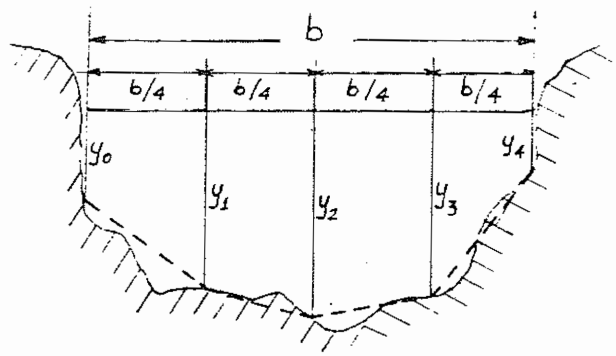


Fig. 1

5. Calculate each section by the trapeze method:

$$S = \frac{b}{4}\left[\frac{y_o}{2} + y_1 + y_2 + y_3 + \frac{y_4}{2}\right] \quad (m^2)$$

6. Calculate the section/wetted perimeter ratio for each section:

$$\frac{\left(\frac{b}{4}\right)\left[\frac{y_o}{2} + y_1 + y_2 + y_3 + \frac{y_4}{2}\right]}{y_o + \sqrt{(y_o-y_1)^2+(\frac{b}{4})^2} + \sqrt{(y_1 - y_2)^2 + (\frac{b}{4})^2} + \sqrt{(y_2 - y_3)^2+(\frac{b}{4})^4} + \sqrt{(y_3-y_4)^2+(\frac{b}{4})^2} + y_4}$$

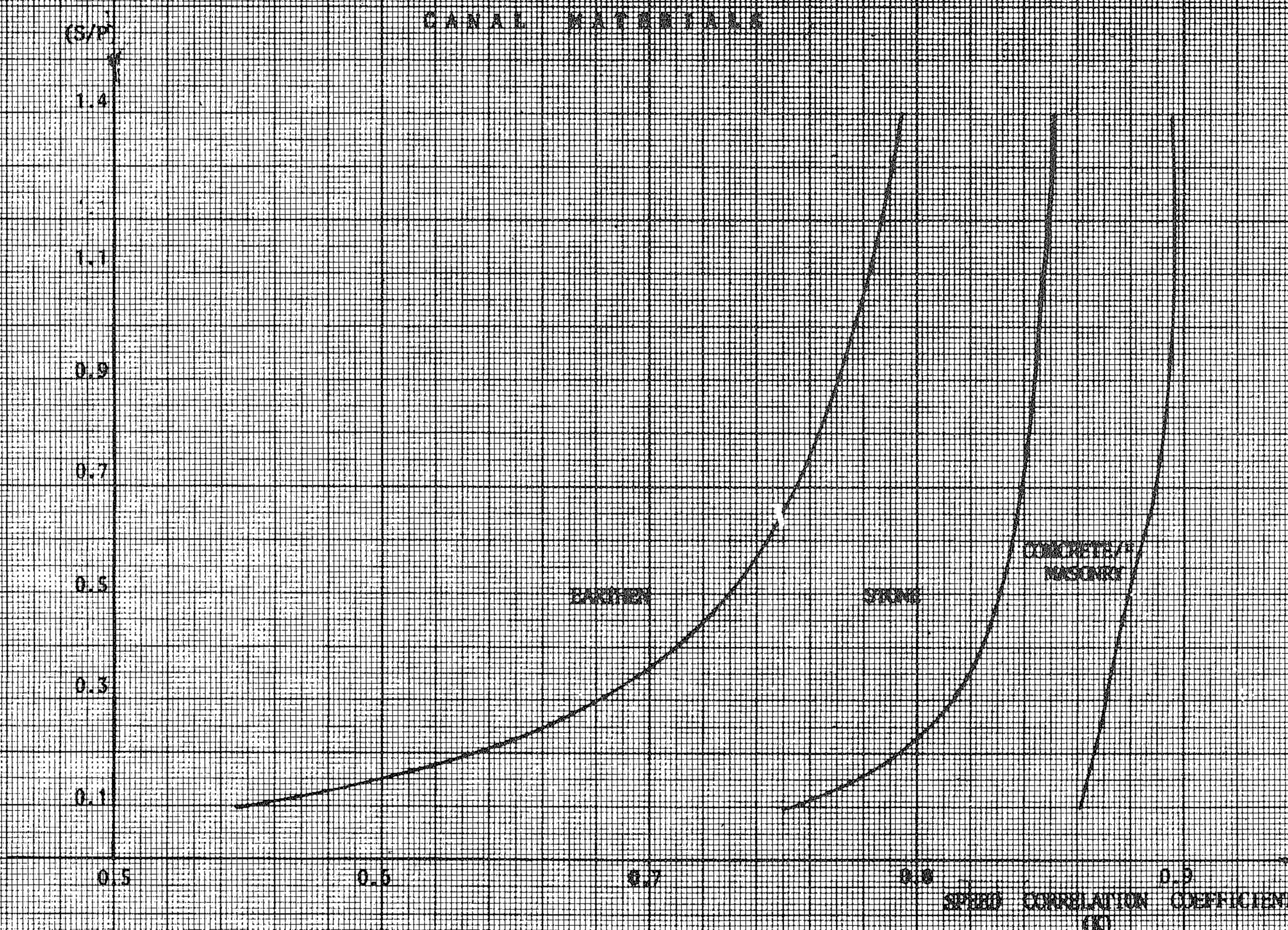
m^2/m

7. Determine the correction factor (k) of the average speed by means of a graph, Figure 1, or the following empirical equation:

$$k = A\left[L_n \left(\frac{S}{p}\right)\right] + B$$

	A	B
EARTHEN CANAL	0.0905	0.782
STONE CANAL	0.0362	0.847
MASONRY CANAL	0.0150	0.893

It is useful to calculate the value of the factor k for each section; however, when the difference between the highest and lowest S/p values for two sections is less


CANAL MATERIALS
(S/P)
1.4
1.1
0.9
0.7
0.5
0.3
0.1
0.5
0.6
0.7
0.8
0.9
EARTHEN
STONE
CONCRETE/
MASONRY
SPEED CORRELATION COEFFICIENT
(K)

than 0.1, it is sufficient to average the S/p values for all of the sections under consideration and to determine one single value for the correction factor k.

8. Calculate the flow:

$$Q = V\,k\,S = V \left[\frac{k_1 S_1 + k_2 S_2 + \ldots + k_n S_n}{n} \right] m^3/_s$$

where n = the number of sections considered (usually 2 or 3). If one single value has been determined for the coefficient k for all of the sections, the formula can be simplified as follows:

$$Q = Vk \left[\frac{S_1 + S_2 + \ldots + S_n}{n} \right] \qquad (m^3/s)$$

b) Measurement of the flow by means of a rectangular weir: The rectangular weir consists of a plate or board, usually wooden, assembled over the course of a current of water, which has a rectangular incision with a beveled edge; it is preferable to mount a thin sheet of stainless steel to serve as such.

The weir should be arranged so as to have an air space "a" below the stream of water and so that the width "b" of the rectangular incision will be less than the width of the water course "B" (Figure 2), for the purpose of avoiding distortion in the results,due to the presence of whirlpools.

It is useful to install the weir in a straight length with a relatively unifrom section. Two meters upstream of the weir (minimum one meter) a wooden stake should be driven into the ground, with its upper part level with the horizontal edge of the weir; or else, a measuring rod should be installed, with graduations above the water level and "zero" at the level of the horizontal edge of the weir.

The flow is calculated in the following way:

$$Q = \frac{2}{3}\, n\, b\, h \sqrt{2g\, h}$$

where:

Q is the flow in m^3/s.

h is the height of the free surface of the water over the edge of the weir, in meters.

g is the standard acceleration of gravity: $9.81\ m/s^2$

b is the width of the rectangular incision of th weir, in meters.

n is the weir coefficient, with the possibility if taking a mean value of 0.63, but this can be calculated using the following empirical formula, which is valid for values of b 0.1 m:

$$\frac{2}{3}\, n = 0.3838 + 0.0386\, \frac{b}{B} + 0.00053\, \frac{1}{h}$$

where B is the total width of the water course where the weir is mounted.

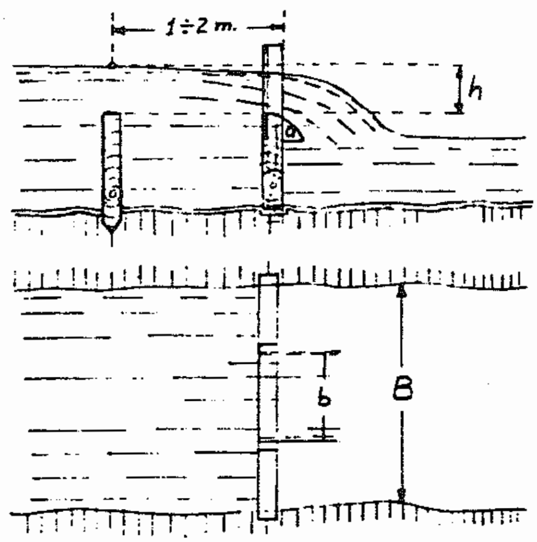


Fig. 2

With a well-installed and well-built weir, a measurement which is done correctly should have a margin of error lower than ± 10% for the measurement of the flow.

c) Measurement of the flow by means of a triangular weir: This variation is preferably used for the measurement of smaller flows below 0.2 m^3/s, and in canals with a reduced width/depth ratio, where it does not prove viable to install a rectangular weir.

The arrangement for measuring the height h is similar to that for the rectangular weir, except that here the "height" refers to the lower angle of the weir (Figure 3), using the following formula:

$$Q = 1.415\ h^{5/2}$$

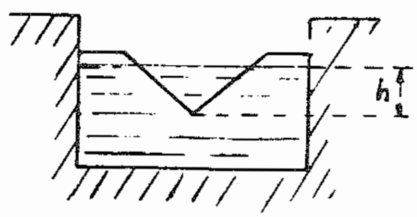


Fig. 3

3.3. APPROXIMATE LEVELING TO DETERMINE THE PROFILE OF THE FALL

We are of the opinion that there is sufficient literature regarding the procedures of topographical leveling normally employed for determining the profile of the fall and, consequently, the utilizable gross head, the length of the penstock, its supports and accessories Nevertheless, for the preliminary determination of the head and the profile, it is possible to use simpler methods which require a minimum of instruments and personnel qualifications. In the particular case of the Micro Hydro Power Stations, when it is required that the preinvestment costs be reduced to a minimum, and when non-metallic penstocks (PVC and polyethylene) are employed - these being easily adapted to the configuration of the terrain- the approximate determination of the profile of the fall, which is presented below, can prove sufficient even for the purposes of the definitive project, considering that with a carefully done measurement, the margin of error for the determination of the head will not exceed ± 3%; and this has been verified in practice by the author.

INSTRUMENTS AND MAETRIALS:

1 rule (10-30 meters long, graduated in centimeters) for measuring horizontal distances and leveling heights.

1 well-aligned wooden pole or metallis tube, approximately 3m long; optionally, it can be graduated in cm in order to simplify the measurement of heights. and it can also incorporate a lead weight (plumb) to verify verticality. The use of flexible materials or those with small sections should be avoided in order not to have distortions due to deflection.

1 carpenter's level (with bubbles and a base of no less than 30 cm).

1 cord (10-30 meters long).

At least 2 wooden stakes; however, it is useful to leave the stakes in the places where they have been driven, in which case it is necessary to have one stake for each leveling station.

2 straight poles (2 meters high, without graduations). These can be straight canes (as visual references for the initial and final leveling points).

OPTIONAL INSTRUMENTS AND EQUIPMENT:

Compass for orienting the profile.

Cord or twine, sufficiently long (100-200 m) in order to outline the profile.

Lime or powdered plaster to outline the profile; water-based paint and a brush.

PROCEDURE:

1. Visual inspection and study of the map (scale of 1:25,000 or less). If the canal has not been built as yet, or if an attempt is being made to make use of an already existing canal, it is necessary to identify alternative sites for the forebay and the powerhouse.

   To select tentative initial and final points for the penstock, consider these factors, among others:

   - Proximity to the center of consumption.
   - Maximum difference in levels between the waterways, irrigation ditches or canals.
   - Preferably choose the point from the upper level, which permits a sharp fall; in other words, consider favorably that point which has a larger "maximum slope". This permits a minimum penstock length, which in turn tends to reduce the initial investment and the load loss. In addition, consider the difficulties in tending and anchoring the penstock if the slope were quite pronounced.
   - For the forebay and the eventual location of the powerhouse, consider places protected from landslides; study the terrain in search of signs of past slides and verify this factor with the local residents.
   - Consider possible utilizable installations (gates, houses, abandoned mills, etc.) that can define the site, even though they may be outside the optimum points.
   - Preferably, the penstock should not cross areas under cultivation.
   - Consider possible irrigation rights and other legal problems and difficulties that might arise with respect to use of the water.
   - Inspect the existing water intake, for the purpose of verifying its condition and possible improvement (expansion of the flow) without further investments.
   - In the case of existing canals, verify the condition of the trough or canal which it is thought to use and the possibilities for increasing its capacity.

2. Once the end points (upper and lower) have been selected, place two poles for the purpose of orienting the outline of the profile; if it is possible, stretch a cord and outline with lime. Paint some stones as landmarks.

3. If leveling is being done for an existing canal, drive a stake at the highest point and place a pole vertically in the bank closest to the upper canal. Stretch a cord from the pole to the stake, and level it at the middle (assure that the cord is tight). Measure the height of the cord above the water level to determine the negative height (-h)-with respect to the level of the first station-and the length of the cord when pulled tight (1).

4. If leveling is being done from a given point, drive a stake and continue the leveling from there.

5. Drive the second stake on the slope of the fall, at a lower point than the first and maintaining the alignment well-defined. Place the pole vertically on the stake and, similarly to the previous method, stretch and level the cord from the first stake to the pole, to determine the positive height (h) and the horizontal length (1). Repeat this procedure for successive stations until reaching the level of the discharge canal, which will constitute the last station. Record the levels where it would be possible to install the powerhouse.

6. The gross head is determined by:

$$H_b = h_{.} + h_2 + h_3 + h_4 \; . \; . \; . \; + hn = \sum_{i=1}^{n} hi \quad (m.)$$

7. The projected horizontal length of the profile will result from:

$$L = l_1 + l_2 + l_3 \; . \; . \; . \; + l_N = \sum_{i=1}^{n} l_i \quad (m.)$$

8. The effective profile length (Z) will be given by:

$$Z = \sqrt{h_1^2 + l_1^2} + \sqrt{h_2^2 + l_2^2} + \sqrt{h_3^2 + l_3^2} \ldots\ldots + \sqrt{h_n^2 + l_n^2} =$$

$$\sum_{i=1}^{n} h_i^2 + l_i^2 \qquad \text{(m)}$$

Figure 4 provides a practical example of approximate leveling with the proposed method.

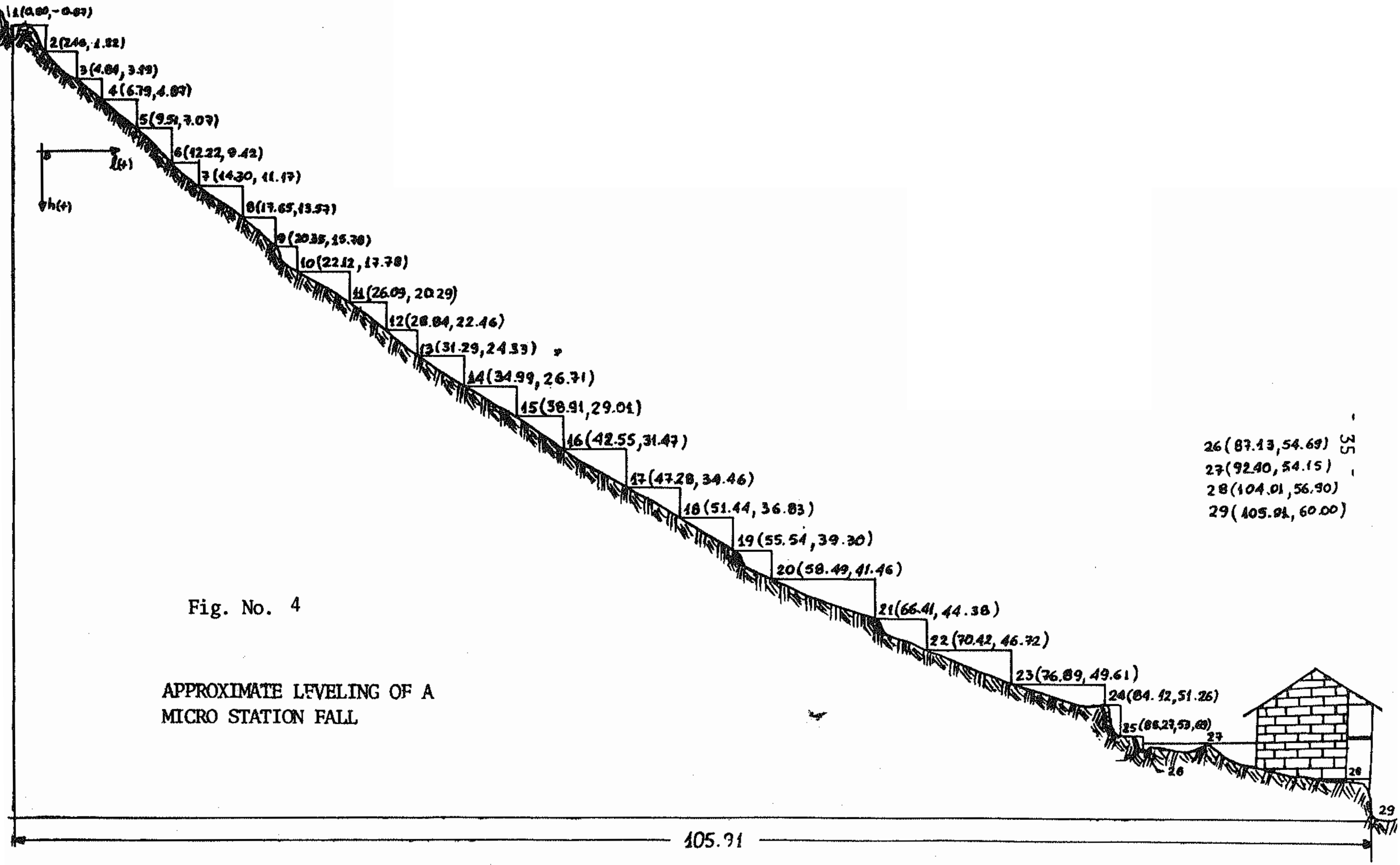


Fig. No. 4

APPROXIMATE LEVELING OF A
MICRO STATION FALL

5. PROCEDURE FOR CALCULATING AND DETERMINING TECHNICAL SPECIFICATIONS

This section develops a sequence of calculations for defining the specifications of a Micro Hydro Power Station and the main components of its electromechanical equipment.

5.1. DEFINITION OF POWER RANGES AND EFFICIENCIES

a) Power at generator terminals
Considering the installed capacity requirements which have been determined from the analysis of demand (Section 2) and taking into account transmission and distribution losses, the power required at the generator terminals can be established.
Then, a preliminary selection of the generator should be made on the basis of commercial specifications.
For micro stations, it is recommended that generators with two or four poles be used (1800 RPM and 3600 RPM, respectively, at 60 Hz).
Generally, alternators are chosen, although the use of asynchronous generators can also be considered.
In accordance with commercial specifications (catalogs), a size is selected so that the resulting power capacity will be as close as possible to that requires, or slightly greater, as follows:

$$P_g = kVA \times \cos \phi$$

where:

P_g is the power capacity of the generator (in kW)
kVA is the apparent power in kilo volt amperes
$\cos \phi$ is the power factor. Usually, it is set at a value of 0.8; however, in rural applications, where resistive loads frequently predominate, higher values (0.9-0.95) could be specified.

Once the generator has been pre-selected, from the same commercial catalog, its efficiency (n_g) must be determined; but if this is not available, an efficiency on the order of 0.86 can be assumed.

b) Power transmitted to the generator (P_{tr})

$$P_{tr} = \frac{P_g}{n_g}$$

c) Power brake of the turbine (P_t)
If there is a direct coupling between the turbine and the generator, the power brake of the turbine will be equal to the power transmitted to the generator; if there is some other form of transmission, the transmission efficiency (n_{tr}) should be considered according to the following:

$$P_t = \frac{P_{tr}}{n_{tr}}$$

	n_{tr}
GEARS	0.98
BELTS	0.95

d) Hydraulic power of the turbine (P_h)
Considering the mechanical efficiency of the turbine (n_m), determined by the presence of mechanical losses due to friction, the following results:

$$P_h = \frac{P_t}{n_m}$$

The mechanical efficiency of the turbine depends on its design characteristics; for microturbines, it is reasonable to assume n_m values in the range of 0.95-0.97.

e) Power absorbed by the turbine (P_a)
The hydraulic efficiency (n_h) of the turbine should be considered in light of the hydrodynamic characteristics of the machine, and the volumetric efficiency in light of the losses due to water which does not circulate through the runner, as follows:

$$P_a = \frac{P_h}{n_h n_v}$$

The hydraulic efficiency (n_h) depends on the type of turbine, its hydraulic design, the hydrodynamic characteristics of its cross sections, and the proportions and precision of its construction. In general, the following ranges of maximum efficiency values can be considered for machines with power capacities smaller than 50 kW:

	n_h
- Axial Flow Turbines	0.86-0.92
- Francis Turbines	0.85-0.90
- Michell-Banki Turbines (well-designed and well- built)	0.75-0.82
- Michell-Banki Turbines (rudimentary construction)	0.60-0.70
- Pelton Turbines	0.82-0.87

In well-built machines, the volumetric efficiency value is frequently negligible (n_v - 1.0). Thus, it can be incorporated into the hydraulic efficiency value or, alternatively, values on the order of 0.98-0.99 can be assumed.

In more rudimentary machines, the volumetric efficiency values can be quite low, reaching values on the order of 0.90 or less in consideration of poor adjustment or alignment or imprecise dimensions in construction or assembly, which give rise to important water leakages.

5.2. SPECIFICATIONS AND ALTERNATIVES IN THE SELECTION OF PENSTOCKS

The present section analyzes the use of steel penstocks and non-metallic ones. In the latter case, data are only presented for penstocks made with polyethylene, PVC, and asbestos-cement. It should be pointed out that it is possible to use other materials, such as fiberglass, wood, and ferrocement.

The selection of the type of penstock is determined by its availability in the diameters and thicknesses required and by economic considerations, in which not only the price of acquisition must be taken into account but also transportation costs, handling, assembly, and connection requirements as well.

a) Steel penstocks

This constitutes the most widely diffused conventional solution. Generally, penstocks built ad-hoc by means of rolling and welding are used; consequently, their diameter can be adapted to the requirements of a specific project. For small diameters, where it would be difficult to roll the penstock, standard piping (cold-formed and welded) can be used. In the following chart, the dimensional characteristics are indicated for the normal series (Schedule 40).

NOMINAL DIAMETER (in.)	OUTSIDE DIAMETER (mm.)	INSIDE DIAMETER (mm.)	THICKNESS (mm.)
2	60.33	52.50	3.91
2 1/2	73.03	62.71	6.16
3	88.90	77.93	5.49
4	114.30	102.26	6.02
5	141.30	128.19	6.55
6	168.28	154.05	7.11
8	219.08	202.72	8.18
10	273.03	254.51	9.27

STEEL PENSTOCKS - SCHEDULE 40

These can be built in various qualities of steel; but for ordinary structural steel, the following values can be assumed:

Fluency stress	$S_f = 21\ kg/mm^2$
Safety factor	1.5 over fluency stress
Design stress	$S_d = 14\ kg/mm^2$
Material density	= 7.85

Although this is the most widely disseminated option, the use of steel penstocks in Micro Hydro Power Stations is generally the most expensive alternative, not only with regard to the acquisition price, but also with respect to transportation and assembly costs because of their weight and the need to weld sections in the field and/or to install flanges.

b) Polyethylene Penstocks

These have the advantages that their cost is considerably lower than that of the steel penstocks, although higher than that of their PVC and asbestos-cement counterparts; their installation is simple, since they adapt to the configuration of the terrain due to their great flexibility; they require a minimum of anchors (immediately after each joint); they can settle directly onto the ground and they have minimal requirements with respect to the precise determination of the fall profile before their installation. Likewise, they are quite resistant to solar radiation.

An addtional advantage is their ease of transportation, for they can be rolled to a diameter 32 times greater than their nomial diameter.

Their main disadvantages are due to the need to use metallic couplings at the joints of the penstock sections; and these are costly require careful assembly, by means of forced fitting with heat, and give rise to high load losses due to throttling. Moreover, these penstocks are generally only manufactured with small diameters, which limits their application to the smallest units.

The table on page 41 gives dimensions for Class 10 penstocks, which are adequate for nominal pressures of up to 10 kg/mm^2.

NOMINAL DIAMETER (in.)	OUTSIDE DIAMETER (mm.)	INSIDE DIAMETER (mm.)	THICKNESS (mm.)
3	88.5	70.5	9.0
4	114.0	90.8	11.6
6	168.0	133.8	17.1
8	219.0	174.4	22.3
10	273.0	218.0	27.5

POLYETHYLENE PENSTOCKS - CLASS 10

Ultimate stress equivalent (traction) (25° C)	2.32 kg/mm^2
Recommended safety factor	5
Design stress	0.464 kg/mm^2

c) PVC Penstocks

Their cost is lower than that of equivalent piping in steel or polyethylene, but higher than that of the asbestos-cement penstocks.

The PVC penstocks are very flexible and they easily adapt to the configuration of the terrain due to their elasticity; furthermore, they are light and easy to transport. The joining of sections is done by means of spigots and bells, with a special glue.

Their principal disadvantagea are their tendency to deteriorate because of solar radiation and their relative fragility on impact; consequently, it is convenient to install them underground.

Their smooth interior determines smaller head losses. They can generally be obtained with diameters of up to 15 or even 20" in Class 10 (10 kg/mm^2 of nominal pressure) and Class 15 (15 kg/mm^2 of nominal pressure). The table on page 42 provides dimensions for the standard PVC penstocks for Class 10, with a nominal diameter of up to 10 inches.

NOMINAL DIAMETER (in.)	OUTSIDE DIAMETER (mm.)	INSIDE DIAMETER (mm.)	THICKNESS (mm.)
2	60.0	53.0	3.5
2 1/2	73.0	65.0	4.5
3	88.5	78.9	4.8
4	114.8	102.0	6.0
5	141.8	126.0	7.5
6	168.0	150.2	8.9
8	219.0	195.8	11.6
10	273.0	244.0	14.5

PVC PENSTOCKS - CLASS 10

Ultimate stress (traction) (25°C) = 5-5.2 kg/mm^2

Ultimate stress (bending) = 7-9 kg/mm^2

Ultimate stress (compression) = 6-7 kg/mm^2

Operating under pressure, a safety factor of 5 is recommended at 20°C.

Working stress = 1.0 kg/mm^2

Material density = 1.43

d) Asbestos-cement Penstocks

These probably constitute one of the most interesting alternatives for micro stations, mini stations, and even for small hydro power stations, due to their low cost and wide availability, in a broad range of diameters and thicknesses.

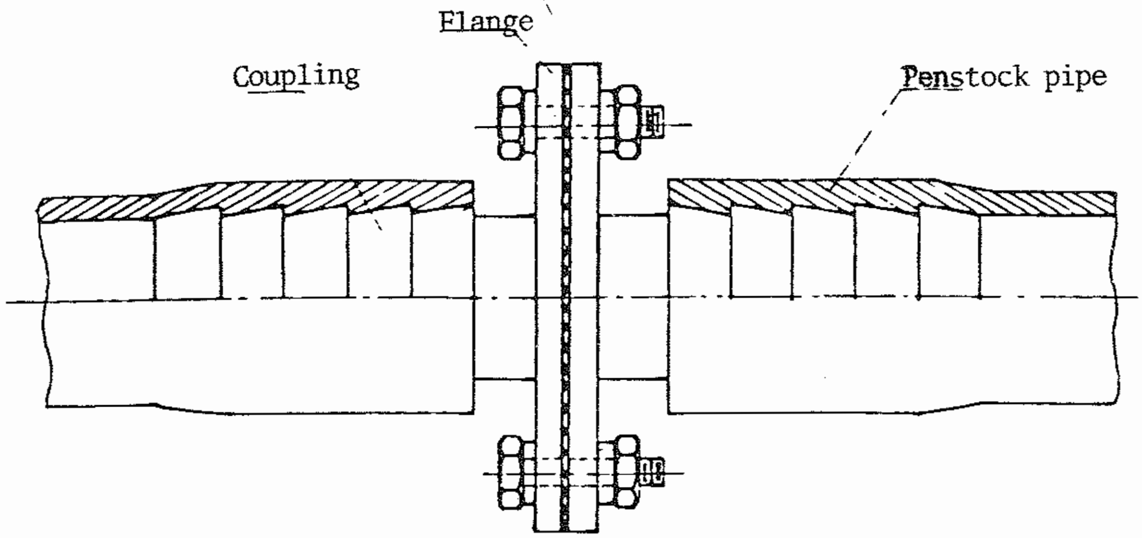
They have an excellent resistance to environmental conditions, and their assembly is simple. Their principal drawbacks are their weight- which is much greater than that of their PVC and polyethylene counterparts- and their relative fragility, which makes it advisable to install them underground.

Although they are rigid, their joints permit directional changes of up to 5° , which facilitates their adaptation to the configuration of the terrain. In addition, this flexibility at the joints allows for expansion.

Their smooth walls determine reduced coefficients for head losses, comparable to those corresponding to the PVC piping. The table below presents the standard dimensions on Class 10 asbestos-cement penstocks (up to 10 kg/mm^2 of nominal pressure), for diameters of up to 24".

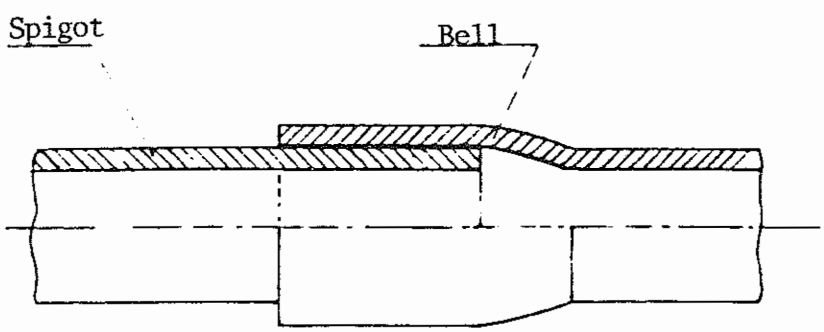
NOMINAL DIAMETER (in.)	OUTSIDE DIAMETER (mm.)	INSIDE DIAMETER (mm.)	THICKNESS (mm.)
4	124	100	12
6	178	150	14
8	238	200	19
10	298	250	24
12	354	300	27
14	412	350	31
16	468	400	34
18	526	450	38
20	584	500	42
24	698	600	49

ASBESTOS-CEMENT PENSTOCKS - CLASS 10

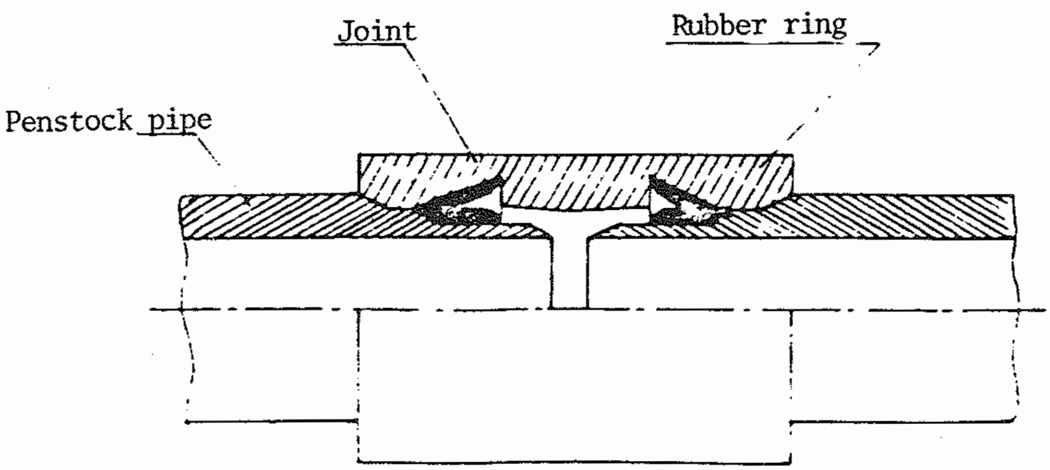


DETAIL OF THE
POLYETHYLENE PENSTOCK JOINT

Fig. No. 5



DETAIL OF THE
PVC PENSTOCK JOINT



DETAIL OF THE
ASBESTOS-CEMENT PENSTOCK JOINT

5.3. CALCULATION OF HEAD LOSSES, NET HEAD, AND REQUIRED FLOW

It is proposed that the procedure summarized below be used for the required calculations. Considering the fact that various alternatives and conditions must be tried out during the stage of design and specification, it is recommended that the calculation process indicated under item 5.1. be adapted for a programmable mini-calculator. Appendix I presents a program suitable for a Texas Instruments calculator, model TI-59.

It is necessary to determine the head losses and flow by means of repeated trials, using the data on power capcity, efficiencies, and gross head.

1. Penstock selection for the calculations.

According to the peculiarities of the application, tentatively select different sizes and types of penstocks, calculate the specifications of the station for each case, and then proceed to the final penstock selection. The calculation sequence is followed for each type or size of penstock whose application it is desired to verify.

2. Calculation of the flow.

$$Q = \frac{P_h}{9.807\ n_h n_v H_n}$$

where:

P_h = hydraulic power of the turbine
n_h = hydraulic efficiency of the turbine
n_v = volumetric efficiency of the turbine
H_n = net head
Q = flow (m^3/s)

Note: In the first trial, it is assumed that there are no head losses; consequently, the net head (H_n) will be equal to the gross head (H_b).

3. Calculation of water speed in the penstock (m/s).

$$C = \frac{4 \times 10^6 Q}{\pi Di^2}$$

Di = internal diameter of the penstock (mm)

4. Calculation of the head loss (H_w) (m)

For steel penstocks with seams:

$$H_w = \left(0.7334 + \frac{0.4827}{C}\right) \frac{L_T C^2}{Di}$$

For PVC, polyethylene, and asbestos-cement penstocks:

$$H_w = \left(0.4893 + \frac{0.8217}{Di} + \frac{2.7209}{CDi}\right) \frac{L_T C^2}{Di}$$

L_T = equivalent penstock length in meters

Note: This does not include losses at joints, valves, and directional changes. These have to be calculated separately.

5. Calculation of the utilizable net head (H_n). (m)

$$H_n = H_b - H_w$$

H_b = gross head (m)

6. Return to point 2 with the new H_n value and repeat the procedure until finding a value Q for a given approximation.

5.4. VERIFICATION OF THE MINIMUM THICKNESS FOR THE PENSTOCK WALLS

$$e_{min} = 0.001 \frac{Di\ Ht}{2\ S_d}$$

where:

e_{min} = minimum thickness of the penstock walls (mm)

Di = internal diameter of the penstock (mm)

Ht = maximum design height (m)

This is equivalent to the gross head (H_b) plus an additional tolerance due to water hammer

The margin for excess pressure due to water hammer is generally determined as a function of the water speed within the penstock, the penstock length and material, the anticipated maximum closing-up speed of the valve, and the existence of a surge tank.

At the preliminary level, it is common to assume a 20-30% margin above the gross head (H_b) when non-metallic penstocks are used.

S_d = design stress for traction of the penstock material.

Once the minimum thickness has been determined, it is compared with the real penstock thickness.

If $e_{min} > e$, then reject the penstock in question.

It should be pointed out that for the definitive design, some localized stresses deserve to be studied more carefully, mainly with respect to those at directional changes and joints.

5.5. CALCULATION OF THE PENSTOCK WEIGHT

$$W = \frac{\pi\ \rho_T}{1000} L_T\ e(Di + e)$$

where:

W_t = total penstock weight (kg)
ρ_T = penstock material density
L_T = penstock length (m)

5.6. SELECTION OF THE PENSTOCK DIAMETER

Considering the specification of materials for the penstock as a function of the technical and economic aspects seen in item 5.2., and after discounting the unsuitable alternatives due to insufficient thickness of the penstock walls, proceed to selecting the penstock which offers the best tecno-economic conditions, in a compromise between load loss and the value of an investment in a penstock with a larger diameter.

In general, the economical choices have water speeds within the penstock of between 1 and 3 m/s.

An approximation of the economic analysis will be given by the combined annual cost, expressed by:

$$C_a = \frac{V_p \times \frac{i}{100}}{1 - (1 + \frac{i}{100})^{-n}} + V_{kwh}\, P_b \times 8760 \times fc \times \frac{H_w}{H_b}$$

The minimum value for C_a permits us to select the optimum penstock.

where:

V_p = value of the penstock plus accessories, equal to: unit value of a section x length of a section/total length + no. of accessories x unit value of accessories
i = annual interest (%)
n = number of years for amortization
V_{kwh} = per kW rate
P_b = power at generator terminals

f_c = average load factor for the plant
H_w = head loss (m)
H_b = gross head (m)

The first term represents the costs of amortization and interests on the penstock and the second, the value of the energy left unproduced due to load losses'

5.7. PRELIMINARY TURBINE SELECTION

The type of turbine to be used in each case is determined by the specific speed (n_s or n_q) which corresponds to the operating conditions given by the power capacity, head, speed (RPM) and efficiency.

Figure 6 represents a nomogram for the selection of turbines in function of their principal parameters.

There are two expressions for specific speed. The first depends on the turbine efficiency and is as follows:

$$n_s = N \frac{P^{1/2}}{H_N^{5/4}}$$

where:

P = net power capacity in CV
H_N = net head (m)
N = speed (RPM)

The second specific speed permits us to establish similarity criteri independent of efficiency; this expression is given by:

$$n_q = N \frac{Q^{1/2}}{H_N^{3/4}}$$

where:

Q = flow in m^3/s

In addition, the following equation can be deduced from the two specific speeds:

$$n_s = n_q \sqrt{\frac{1000}{75}\, n_h}$$

where:

n_h = hydraulic efficiency of the turbine (fraction)

One way to make the selection consists of consulting manufacturers' catalogs for standardized turbines; this permits the selection of a standard size of a given turbine, on the basis of data on the head and flow, which consequently determine the corresponding speed of rotation. One very illustrative example of this process appears in the document "Design and Standardization of Michell-Banki Turbines" by C.A. Hernandez.

Assuming an ad-hoc design and specification, an independent approximation of a standardized series of turbines can be made in the following way:

1. Assume a speed of rotation for the turbine (RPM), considering a speed equal to or lower than that of the generator; in general, it is best not to exceed 1800 RPM. On this basis, also define whether the turbine would be coupled directly to the generator or if there would be some kind of intermediate transmission. In the latter case, it is useful to consider the ratios of generator/turbine speed which permit a given system of transmission. In general, for transmission by belts or V-belts, it is preferable not to have values larger than approximately 3.5. For transmission by gears, larger ratios are acceptable.

2. Draw up preliminary specifications and designs for the generator/ turbine transmission system in order to determine its tecno-economic viability.

3. Using the speed of rotation for the turbine, determine its specific speed.

4. Select the type of turbine form the nomogram or from the chart in Figure 6.

5. In selecting a turbine with in-depth considerations, its principal dimension can be determined on the basis of the runner diameter.

   For the case of Michell-Banki turbines, the runner diameter is given by the following equation:

$$D_v = \frac{39.85\sqrt{H_n}}{N}$$

   where:

   D_v = runner diameter (m)
   H_n = net head (m)
   N = RPM of the turbine

   and for Pelton turbines, by:

$$D_v = \frac{41.45\sqrt{H_n}}{N}$$

   where:

   D_v = Pelton diameter (m), i.e., twice the radius determined by the axis of the jet stream tangent to the runner.

These formulas are derived from technical considerations that relate the optimal speed to the net head, for a given angle of entry for the jet and typical experimental coefficients for losses in the injector and in the runner.

6. If the predetermined runner diameter results in an unsuitable magnitude, or if it is necessary to set standardized values for the same, formulas can be adapted for determining the speed of rotation on the basis of a given runner diameter, in which case steps 3-5 will have to be repeated.

   In the case of Pelton turbines, it is worth mentioning that more than one nozzle can be used (usually up to a maximum of six). In this case, the runner diameter is proportional to the square root of the number of nozzles.

TYPE OF TURBINE	n_s	n_q	$H_{max. adm.}$
Pelton (one nozzle)	10 - 29	3 - 9	1800 - 400
Pelton (two or more nozzles)	29 - 59	9 - 18	400 - 350
Michell-Banki	29 - 220	9 - 68	400 - 80
Francis (slow)	59 - 124	18 - 38	350 - 150
Francis (normal)	124 - 220	38 - 68	150 - 80
Francis (fast)	220 - 440	68 - 135	80 - 20
Axial Flow (Helical and Kaplan)	342 - 980	105 - 300	35 - 5

Michell-Banki Turbines

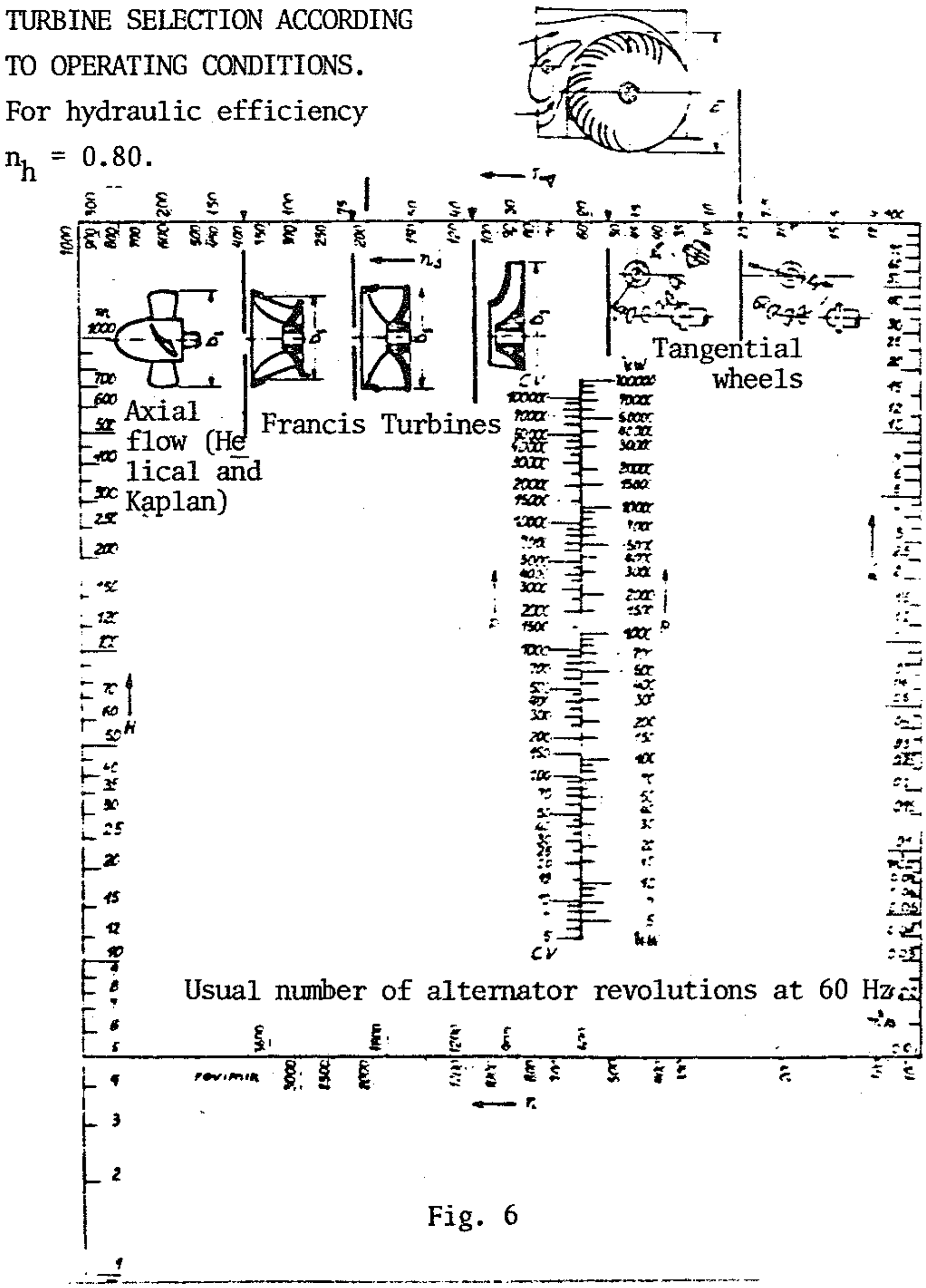


Fig. 6

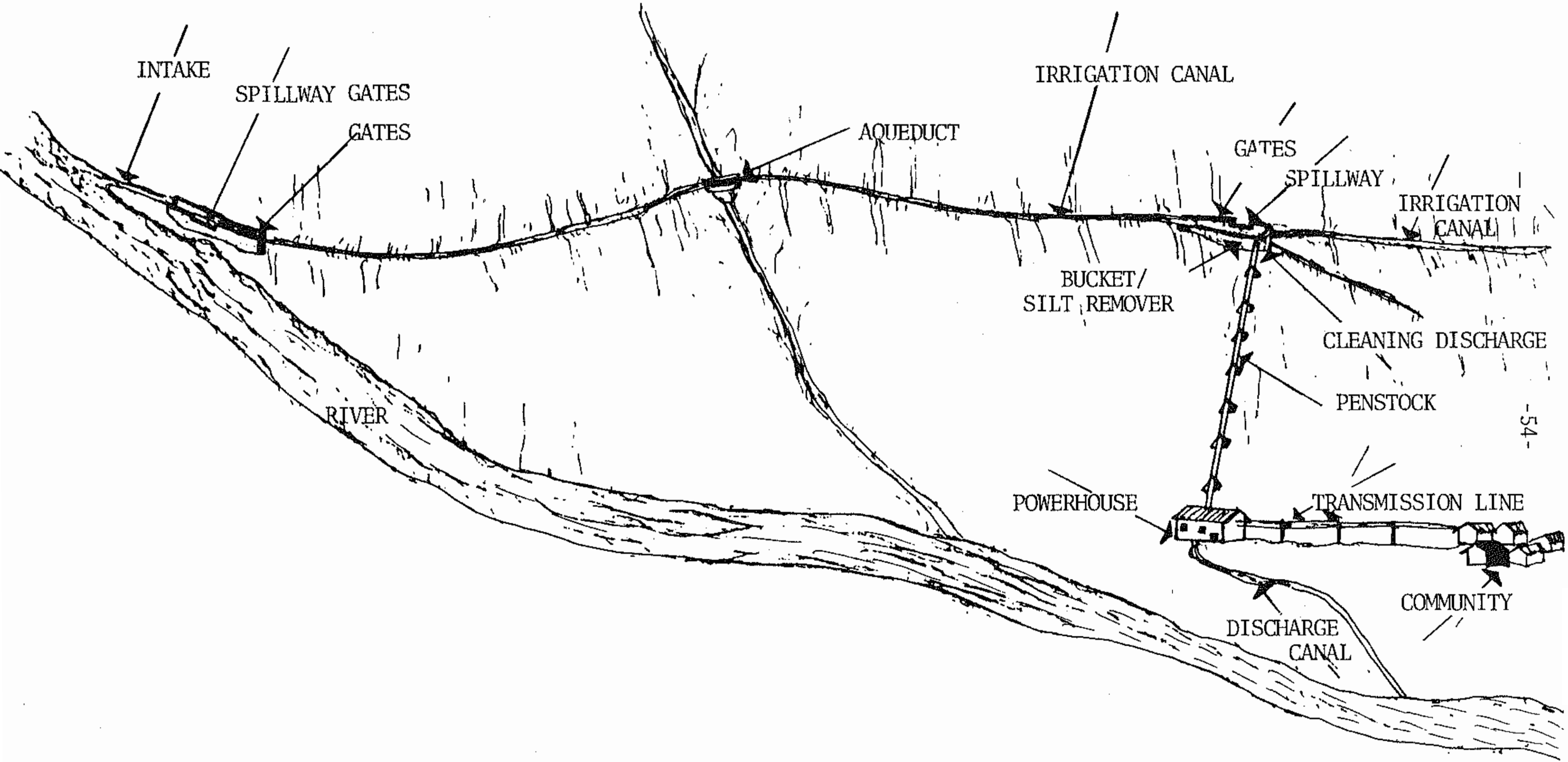


Fig. No. 7

SCHEMATIC DIAGRAM OF A MICRO HYDRO POWER STATION

APPENDIX I

PROGRAM FOR CALCULATING MICRO STATIONS ON A PROGRAMMABLE TEXAS INSTRUMENTS MINI-CALCULATOR (MODEL TI-59)

TITLE *MICRO HYDRO POWER STATIONS* PAGE *1* OF *5*

TI Programmable Program Record

PROGRAMMER *ENRIQUE INDACOCHEA* DATE *AG./1979*

Partitioning (Op 17) *7,1,9,2,9* Library Module ______ Printer *OPTIONAL* Cards *1-2-3*

*3 * Op 17*

PROGRAM DESCRIPTION

CALCULATE ONE VARIABLE WITH OTHER 3 GIVEN, AMONG HEAD (m.) (GROSS OR NET), POWER (KW) (OF THE STATION OR HYDRAULIC POWER OF TURBINE), FLOW (m^3/s) AND/OR EFFICIENCY (DECIMAL FRACTION) (SET OF EFFICIENCIES: HYDRAULIC OF TURBINE, MECHANICAL OF TURBINE, TRANSMISSION AND OF ALTERNATOR OR ONLY OF STATION (WITH ONLY STATION POWER) OR ONLY HYDRAULIC (WITH ONLY HYDRAULIC POWER OF TURBINE. LIKEWISE CALCULATE SPECIFIC SPEEDS (n_s AND n_q) OF TURBINE (RPM). CALCULATE H_W FOR PVC AND STEEL. NOTE: ASSUME $\eta_{VOL.} = 1$ FOR $\eta_{HYDRAULIC}$

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1	INV * FIX, 3 * Op 17 - ENTER 3 BANKS	(3 CARDS 1, 2, 3)		
2	BEGIN (RST, CMs, CLR E' = 0 Rst Flgs)		2nd E'	0
3	ENTER Fig. 8 (STOP IN CASE OF ERROR)		2nd St flg 8	0
4	FEED 3 DATA FROM AMONG 4 VARIABLES (H, P, Q, η). THE UNKNOWN IS FED AS ZERO (0) FOR THE CORRESPONDING ENTRY (LBL). THESE ARE ENTERED IN ANY ORDER AFTER PROCESSING AND FEEDING ZERO TO THE LABEL OF THE NEW UNKNOWN. THERE CAN BE ONLY ONE UNKNOWN			
	4.1. ENTER HEAD (H) (IN ZERO IF H IS THE UNKNOWN)	H_b or H_n (m)	A	H_b or H_n (m) — IF POSSIBLE H_n
	4.1.1. FOR GROSS HEAD (H_b), PRESS R/S	H_b (m)	R/S	H_b
	4.2. ENTER POWER P(KW) (IN ZERO IF UNKNOWN)	P_c or P_h (KW)	B	P_c or P_h (KW) — IF POSSIBLE P_c
	4.2.1. FOR TURBINE HYDRAULIC POWER, PRESS R/S	P_h (KW)	R/S	P_h
	4.3. ENTER FLOW Q (m^3/s) (IN ZERO IF UNKNOWN)	Q (m^3/s)	C	Q (m^3/s)
	4.4. ENTER EFFICIENCY η (DEC. FRACTION) (IN ZERO IF UNKNOWN)	η	E	0 — IF $\eta = \eta_c$ STATION EFF. IF POSSIBLE
	4.4.1. IF $\eta = \eta_{HYDRAULIC}$	0	R/S	
	WITHOUT DATA ON OTHER EFFICIENCIES, THE PROGRAM ASSUMES THAT $\eta_c = \eta_h$ ∴ $\eta_m = \eta_T = \eta_A = 1$ THOUGH THE PROGRAM PRINTS THEM AS ZERO. WITH DATA FOR η, PROCEED AS FOLLOWS:			

USER DEFINED KEYS	DATA REGISTERS (INV ▪)		
A ENTER H_b or H_n	0	10 h_w (m)	20 RPM
B ENTER P_c or P_h	1	11 Q (m)	21 .GA
C ENTER Q	2	12 P_c (KW)	22 9.80665
D ENTER Di	3 η_A	13 C (m/s)	23 0.73549875
E ENTER η	4 η_F	14 P_H (KW)	24 n_q
A' BEGIN CALCULATION	5 η_M	15 CTO	25 n_s
B'	6 η_h	16 D_i (mm)	26
C' IN RPM ⇒ CALCULATE η_{ESP}	7 η_c	17 L (m)	27
D'	8 H_b (m)	18 e (mm)	28
E' BEGIN (CLEAR)	9 H_n (m)	19 σ_{DIS} ($\cancel{kg/mm^2}$)	29

LABELS (Op 08)

INV, lnx, CE, CLR, x⇌t, x², √x, 1/x, STO, RCL, SUM, yˣ, EE, (,), ÷, GTO, ×, SBR, −, RST, +, R/S, ., +/−, =, CLR, INV

FLAGS 0	1	2	3	4	5	6	7	8	9
H UNKNOWN	H UNKNOWN OR H_n DATUM	PKW UNKNOWN	DATUM η P = PHYD	Q UNKNOWN	FOR STEEL PENSTOCK			CONTROL ERROR	
NO FLAGS H DATUM	H = H_b DATUM	PKW DATUM	P = PHYD OR ? UNK.	Q DATUM	FOR PVC				

TITLE MICRO PAGE 2 OF 5 **TI Programmable Program Record**

PROGRAMMER E. INDACOCHEA DATE AG./1979

Partitioning (Op 17) Library Module Printer Cards

PROGRAM DESCRIPTION

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY	
	4.4.2. ENTER MECHANICAL EFC. OF TURBINE (DEC. FRACTION)	η_m	R/S			η_m	
	IF RELEVANT, η ASSUMES THAT $\eta_F = \eta_A = 1$, BUT PRINT $\eta_F = \eta_A = 0$. WITH DATA, PROCEED AS FOLLOWS:						
	4.4.3. ENTER TRANSMISSION EFC. (BELTS) IF RELEVANT, ASSUME $\eta_A = 1$ BUT PRINT $\eta_A = 0$. IF η_A IS DATUM, PROCEED AS FOLLOWS:	η_F	R/S			η_F	
	4.4.4. ENTER ALTERNATOR EFC. η_A (DEC. FRACTION)	η_A	R/S			η_A	
5	FEED PENSTOCK DATA						
	5.1. ENTER INTERIOR PENSTOCK DIAMETER Di (mm)	Di (mm)	0			Di	Di
	5.2. FOR PVC PENSTOCK, CONTINUE WITH 5.3. FOR STEEL PENSTOCK, PRESS R/S.						
	5.3. ENTER WALL THICKNESS e (mm)	e (mm)	R/S				
	5.4. ENTER EFFECTIVE LENGTH (PIPE LENGTH + REDUCTION LOSS)	L (m)	R/S				
	5.5. ENTER TRACTION (DESIGN) STRESS OF PENSTOCK MATERIAL σ_{DIS} (kg/mm²) {PVC 1 kg/mm², STEEL 14 kg/mm²}	σ_{DIS} (kg/mm²)	R/S			σ_{DIS}	ES
	5.6. ENTER DECIMAL FRACTION OF WATER HAMMER (·GA) RELATIVE TO GROSS HEAD	·GA	R/S				G_A

USER DEFINED KEYS	DATA REGISTERS (INV List)		LABELS (Op 08)
A	0	0	INV lnx CE CLR x⇄t x²
B	1	1	√x 1/x STO RCL SUM yˣ
C	2	2	EE ( ) ÷ GTO ×
D	3	3	SBR − RST + R/S .
E	4	4	+/− = CLR INV log CP
A'	5	5	tan Prm P→R sin cos CMs
B'	6	6	Exc Prd |x| Eng Fix Int
C'	7	7	Deg Pause x=t Nop Op Rad
D'	8	8	Lbl x≥t Σ+ x̄ Grad St flg
E'	9	9	If flg D.MS π List Write Dsz
			Adv Prt

FLAGS 0 1 2 3 4 5 6 7 8 9

1014966-1

TITLE MICRO SJ PAGE 3 OF 5

TI Programmable
Program Record

PROGRAMMER E. INDACOCHEA DATE AG./1979

Partitioning (Op 17) Library Module ____ Printer ____ Cards ____

PROGRAM DESCRIPTION

NOM. DIAM.	PVC CLASS 10			POLYETHYLENE CLASS 10			STEEL SCH. 40		
	De (mm)	Di (mm)	e (mm)	De (mm)	Di (mm)	e (mm)	De (mm)	Di (mm)	e (mm)
2"	60.0	53.0	3.5	60	47.8	6.1	60.33	52.50	3.91
2½"	73.0	65.0	4.5				73.03	62.71	5.16
3"	88.5	78.9	4.8	88.5	70.5	9.0	88.90	77.93	5.49
4"	114.0	102.0	6.0	114.0	90.8	11.6	114.30	[illegible]	6.02
5"	141.8	126.0	7.5				141.30	128.19	6.55
6"	168.0	150.2	8.9	168.0	133.8	17.1	168.28	154.05	7.11
8"	219.0	195.8	11.6	219.0	174.4	22.3	219.08	[illegible]	8.18
10"	273.0	244.0	14.5	273.0	218.0	27.5	273.03	254.51	9.27
12"	323.0	291.0	16.0						

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
6	DEVELOPMENT OF CALCULATIONS AND RESULTS	(PRESS)				
	6.1. BEGIN WITH CALC. MIN. PENSTOCK THICKNESS (mm)		2nd	A'		e_{min} (mm) EM
	6.2. CALCULATE c (WATER SPEED IN PENSTOCK) (m/s)		R/S			c (m/s) c
	6.3. CALCULATE FLOW Q (m^3/s)		R/S			Q (m^3/s) Q
	6.4. CALCULATE GROSS HEAD H_b (m)		R/S			H_b (m) H_b
	6.5. CALCULATE NET HEAD H_n (m)		R/S			H_n (m) H_n
	6.6. CALCULATE HEAD LOSS H_w (m)		R/S			H_w (m) H_w
	6.7. CALCULATE STATION POWER (GEN. TERM.) P_c (kW)		R/S			P_c (kW) P_c
	6.8. CALCULATE HYDR. POWER OF TURBINE P_h (kW)		R/S			P_h (kW) P_h
	6.9. CALCULATE COMBINED STATION EFC. $\eta_c = \eta_h \eta_m \eta_F \eta_A$		R/S			η_c (DEC. FRAC.) NC
	6.10. WRITE TURBINE HYDRAULIC EFC. η_h		R/S			η_h (") NH
	6.11. WRITE TURBINE MECHANICAL EFC. η_m		R/S			η_m (") NM
	6.12. WRITE TRANSMISSION EFC. η_F		R/S			η_F (") NF
	6.13. WRITE GENERATOR OR ALTERNATOR EFC. η_A		R/S			η_A (") NA
7	CALCULATION OF SPECIFIC SPEEDS					
	7.1. ENTER RPM AND CALCULATE n_q (METRIC)	RPM	2nd	C'		n_q RPM
	7.2. CALCULATE n_s (METRIC)		R/S			n_s n_q-NQ n_s-NS

USER DEFINED KEYS: A, B, C, D, E, A', B', C', D', E'

DATA REGISTERS (INV list): 0 1 2 3 4 5 6 7 8 9 | 0 1 2 3 4 5 6 7 8 9

LABELS (Op 08)

FLAGS 0 1 2 3 4 5 6 7 8 9

APPENDIX II

CONVERSION OF UNITS

Multiply	By	To Obtain
Ft.	0.3048	m
Ft^3/s	0.028317 (0.0283168466)	m^3/s
HP	1.0139 (1.013869794)	CV
CV	0.7355 (9.80665 x 3/40)	KW
N_s (British System) $RPM \frac{\sqrt{HP}}{(m)^{5/4}}$	4.446 (4.44603)	N_s (Metric System) $RPM \frac{\sqrt{CV}}{(ft)^{5/4}}$

APPENDIX III

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   4.E JENSEN, M. Sc. Civil Eng. J., - "Multi Purpose Aspects".

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/ ...

TITLE MICRO PAGE 1 OF 5 **TI Programmable Coding Form**

PROGRAMMER DATE

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	91	R/S		5	86	* St Flg		110	43	RCL	
1	76	* Lbl		6	03	3		1	16	16	
2	10	* E'		7	91	R/S		2	69	* Op	
3	29	* Cp		8	76	* Lbl		3	06	06	
4	22	INV		9	13	C		4	91	R/S	
5	58	* fix		060	42	STO		5	42	STO	
6	47	* Cms		1	11	11		6	18	18	
7	09	9		2	22	INV		7	75	−	
8	93	.		3	67	* x=t		8	43	RCL	
9	08	8		4	24	CE		9	16	16	
010	00	0		5	86	* St Flg		120	95	=	
1	06	6		6	04	4		1	69	* Op	
2	06	6		7	76	* Lbl		2	00	00	
3	05	5		8	24	CE		3	67	* x=t	
4	42	STO		9	91	R/S		4	42	STO	
5	22	22		070	76	* Lbl		5	03	3	
6	25	CLR		1	15	E		6	03	3	
7	81	RST		2	42	STO		7	04	4	
8	76	* Lbl		3	07	07		8	02	2	
9	11	A		4	36	* Pgm		9	69	* Op	
020	42	STO		5	01	01		130	03	03	
1	08	08		6	71	SBR		1	69	* Op	
2	42	STO		7	25	CLR		2	05	05	
3	09	09		8	91	R/S		3	76	* Lbl	
4	86	* St Flg		9	43	RCL		4	43	RCL	
5	01	1		080	07	07		5	01	1	
6	22	INV		1	42	STO		6	07	7	
7	67	* x=t		2	06	06		7	69	* Op	
8	22	INV		3	91	R/S		8	04	04	
9	86	* St Flg		4	49	* Prd		9	43	RCL	
030	00	0		5	07	07		140	18	18	
1	76	* Lbl		6	42	STO		1	69	* Op	
2	22	INV		7	05	05		2	06	06	
3	91	R/S		8	91	R/S		3	91	R/S	
4	22	INV		9	49	* Prd		4	42	STO	
5	86	* St Flg		090	07	07		5	17	17	
6	01	1		1	42	STO		6	02	2	
7	91	R/S		2	04	04		7	07	7	
8	76	* Lbl		3	91	R/S		8	69	* Op	
9	12	B		4	49	* Prd		9	04	04	
040	42	STO		5	07	07		150	43	RCL	
1	12	12		6	42	STO		1	17	17	
2	42	STO		7	03	03		2	69	* Op	
3	14	14		8	91	R/S		3	06	06	
4	22	INV		9	76	* Lbl		4	91	R/S	
5	86	* St Flg		100	14	D		5	42	STO	
6	03	3		1	22	INV		6	19	19	
7	22	INV		2	86	* St Flg		7	01	1	
8	67	* x=t		3	05	5		8	07	7	
9	23	Ln x		4	42	STO		9	03	3	SIGUE 2/5
050	86	* St Flg		5	16	16					
1	02	2		6	01	1					
2	76	* Lbl		7	06	6					
3	23	Ln x		8	69	* Op					
4	91	R/S		9	04	04					

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE MICRO PAGE 2 OF 5 **TI Programmable Coding Form**

PROGRAMMER DATE

LOC	CODE	KEY	COMMENTS
160	06	6	
1	69	* Op	
2	04	04	
3	43	RCL	
4	19	19.	
5	69	* Op	
6	06	06	
7	91	R/S	
8	42	STO	
9	21	21	
170	02	2	
1	02	2	
2	01	1	
3	03	3	
4	69	* Op	
5	04	04	
6	43	RCL	
7	21	21	
8	69	* Op	
9	06	06	
180	91	R/S	
	76	* Lbl	
2	42	STO	
3	86	* St Flg	
4	05	5	
5	01	1	
6	03	3	
7	01	1	
8	05	5	
9	69	* Op	
190	03	03	
1	69	* Op	
2	05	05	
3	00	0	
4	91	R/S	
5	42	STO	
6	18	18	
7	61	GTO	
8	43	RCL	
9	76	* Lbl	
200	16	* A'	
1	87	* If Flg	
2	04	4	
3	85	+	
4	71	SBR	
5	25	CLR	
6	71	SBR	
7	33	x^2	
8	43	RCL	
9	22	22	
210	65	x	
1	43	RCL	
2	11	11	
3	95	=	
4	42	STO	

LOC	CODE	KEY	COMMENTS
5	15	15	
6	87	* If Flg	
7	00	00	
8	75	−	
9	71	SBR	
220	53	(	
1	43	RCL	
2	09	09	
3	49	* Prd	
4	15	15	
5	87	* If Flg	
6	02	02	
7	65	x	
8	87	* If Flg	
9	03	3	
230	55	÷	
1	43	RCL	
2	12	12	
3	55	÷	
4	43	RCL	
5	15	15	
6	95	=	
7	42	STO	
8	07	07	
9	61	GTO	
240	93	.	
1	76	* Lbl	
2	55	÷	
3	43	RCL	
4	14	14	
5	55	÷	
6	43	RCL	
7	15	15	
8	95	=	
9	42	STO	
250	06	06	
1	61	GTO	
2	93	.	
3	76	* Lbl	
4	65	x	
5	43	RCL	
6	07	07	
7	65	x	
8	43	RCL	
9	15	15	
260	95	=	
1	42	STO	
2	12	12	
3	71	SBR	
4	32	x><t	
5	61	GTO	
6	93	.	
7	76	* Lbl	
8	75	−	
9	71	SBR	

LOC	CODE	KEY	COMMENTS
270	32	x><t	
1	43	RCL	
2	12	12	
3	55	÷	
4	43	RCL	
5	15	15	
6	55	÷	
7	43	RCL	
8	07	07	
9	95	=	
280	42	STO	
1	09	09	
2	71	SBR	
3	53	(	
4	61	GTO	
5	93		
6	76	* Lbl	
7	85	+	
8	71	SBR	
9	32	x><t	
290	76	* Lbl	
1	95	=	
2	43	RCL	
3	12	12	
4	55	÷	
5	43	RCL	
6	07	07	
7	55	÷	
8	43	RCL	
9	09	09	
300	55	÷	
1	43	RCL	
2	22	22	
3	95	=	
4	42	STO	
5	11	11	
6	71	SBR	
7	25	CLR	
8	71	SBR	
9	33	x^2	
310	71	SBR	
1	53	(	
2	87	* If Flg	
3	01	01	
4	94	+/-	
5	75	−	
6	43	RCL	
7	09	09	
8	95	=	
9	50	|x|	sigue 3/5

MERGED CODES

62 63 64 72 73 74 83 84 92

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE MICRO PAGE 3 OF 5

PROGRAMMER DATE

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
320	75	–	
1	06	6	
2	94	+/-	
3	22	INV	
4	28	* Log	
5	95	=	
6	77	x≥t	
7	95	=	
8	76	* Lbl	
9	94	+/-	
330	76	* Lbl	
1	93	.	
2	01	1	
3	07	7	
4	03	3	
5	00	0	
6	69	* Op	
7	04	04	
8	43	RCL	
9	21	21	
340	85	+	
1	01	1	
2	95	=	
3	65	x	
4	43	RCL	
5	08	08	
6	65	x	
7	93	.	
8	00	0	
9	00	0	
350	00	0	
1	06	6	
2	05	5	
3	65	x	
4	43	RCL	
5	16	16	
6	55	÷	
7	43	RCL	
8	19	19	
9	95	=	
360	69	* Op	
1	06	06	
2	91	R/S	
3	01	1	
4	05	5	
5	69	* Op	
6	04	04	
7	43	RCL	
8	13	13	
9	69	* Op	
370	06	06	
1	91	R/S	
2	03	3	
3	04	4	
4	69	* Op	

LOC	CODE	KEY	COMMENTS
5	04	04	
6	43	RCL	
7	11	11	
8	69	* Op	
9	06	06	
380	91	R/S	
1	02	2	
2	03	3	
3	01	1	
4	04	4	
5	69	* Op	
6	04	04	
7	43	RCL	
8	08	08	
9	69	* Op	
390	06	06	
1	91	R/S	
2	02	2	
3	03	3	
4	03	3	
5	01	1	
6	69	* Op	
7	04	04	
8	43	RCL	
9	09	09	
400	69	* Op	
1	06	06	
2	91	R/S	
3	02	2	
4	03	3	
5	04	4	
6	03	3	
7	69	* Op	
8	04	04	
9	43	RCL	
410	10	10	
1	69	* Op	
2	06	06	
3	91	R/S	
4	03	3	
5	03	3	
6	01	1	
7	05	5	
8	69	* Op	
9	04	04	
420	43	RCL	
1	12	12	
2	69	* Op	
3	06	06	
4	91	R/S	
5	03	3	
6	03	3	
7	02	2	
8	03	3	
9	69	* Op	

LOC	CODE	KEY	COMMENTS
430	04	04	
1	43	RCL	
2	14	14	
3	69	* Op	
4	06	06	
5	91	R/S	
6	03	3	
7	01	1	
8	01	1	
9	05	5	
440	69	* Op	
1	04	04	
2	43	RCL	
3	07	07	
4	69	* Op	
5	06	06	
6	91	R/S	
7	03	3	
8	01	1	
9	02	2	
450	03	3	
1	69	* Op	
2	04	04	
3	43	RCL	
4	06	06	
5	69	* Op	
6	06	06	
7	91	R/S	
8	03	3	
9	01	1	
460	03	3	
1	00	0	
2	69	* Op	
3	04	04	
4	43	RCL	
5	05	05	
6	69	* Op	
7	06		
8	91	R/S	
9	03	3	
470	01	1	
1	02	2	
2	01	1	
3	69	* Op	
4	04	04	
5	43	RCL	
6	04	04	
7	69	* Op	
8	06	06	
9	91	R/S	SIGUE 4/5

MERGED CODES

62 63 64 72 73 74 83 84 92

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PROGRAMMER DATE

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LOC	CODE	KEY	COMMENTS
480	03	3	
1	01	1	
2	01	1	
3	03	3	
4	69	* Op	
5	04	04	
6	43	RCL	
7	03	03	
8	69	* Op	
9	06	06	
490	22	INV	
1	86	* St Flg	
2	00	0	
3	22	INV	
	86	* St Flg	
	02	2	
6	22	INV	
7	86	* St Flg	
8	04	4	
9	91	R/S	
500	76	* Lbl	
1	25	CLR	
2	53	(	
3	06	6	
4	22	INV	
5	28	* Log	
6	65	×	
7	04	4	
8	65	×	
9	43	RCL	
510	11	11	
1	55	÷	
	89	π	
	55	÷	
4	43	RCL	
5	16	16	
6	33	x^2	
7	54	)	
8	42	STO	
9	13	13	
520	92	INV SBR	
1	76	* Lbl	
2	33	x^2	
3	87	* If flg	
4	05	5	
5	34	$\sqrt{x}$	
6	53	(	
7	53	(	
8	93	.	
9	04	4	
530	08	8	
1	09	9	
2	03	3	
3	85	+	
4	93	.	

LOC	CODE	KEY	COMMENTS
5	08	8	
6	02	2	
7	01	1	
8	07	7	
9	55	÷	
540	43	RCL	
1	16	16	
2	34	$\sqrt{x}$	
3	85	+	
4	02	2	
5	93	.	
6	07	7	
7	02	2	
8	00	0	
9	09	9	
550	55	÷	
1	53	(	
2	43	RCL	
3	13	13	
4	65	×	
5	43	RCL	
6	16	16	
7	54	)	
8	34	$\sqrt{x}$	
9	54	)	
560	76	* Lbl	
1	44	SUM	
2	65	×	
3	43	RCL	
4	13	13	
5	33	x^2	
6	65	×	
7	43	RCL	
8	17	17	
9	55	÷	
570	43	RCL	
1	16	16	
2	54	)	
3	42	STO	
4	10	10	
5	92	INV SBR	
6	76	* Lbl	
7	34	$\sqrt{x}$	
8	53	(	
9	53	(	
580	93	.	
1	07	7	
2	03	3	
3	03	3	
4	04	4	
5	85	+	
6	93	.	
7	04	4	
8	08	8	
9	02	2	

LOC	CODE	KEY	COMMENTS
590	07	7	
1	55	÷	
2	43	RCL	
3	13	13	
4	34	$\sqrt{x}$	
5	54	)	
6	61	GTO	
7	44	SUM	
8	76	* Lbl	
9	53	(	
600	87	* If flg	
1	01	01	
2	54	)	
3	53	(	
4	43	RCL	
5	08	08	
6	75	−	
7	43	RCL	
8	10	10	
9	54	)	
610	48	* Exc	
1	09	09	
2	92	INV SBR	
3	76	* Lbl	
4	54	)	
5	53	(	
6	43	RCL	
7	09	09	
8	85	+	
9	43	RCL	
620	10	10	
1	54	)	
2	48	* Exc	
3	08	08	
4	92	INV SBR	
5	76	* Lbl	
6	32	x><t	
7	53	(	
8	53	(	
9	43	RCL	
630	06	06	
1	55	÷	
2	43	RCL	
3	07	07	
4	54	)	
5	87	* If flg	
6	03	03	
7	35	1/x	
8	65	×	
9	43	RCL	SIGUE 5/5

MERGED CODES

62 63 64 72 STO 73 RCL 74 SUM 83 GTO 84 92 INV SBR

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TITLE MICRO PAGE 5 OF 5

TI Programmable Coding Form

PROGRAMMER DATE

LOC	CODE	KEY	COMMENTS
640	12	12	
1	54	)	
2	42	STO	
3	14	14	
4	92	INV SBR	
5	76	* Lbl	
6	35	1/x	
7	55	÷	
8	43	RCL	
9	14	14	
650	54	)	
1	35	1/x	
2	42	STO	
3	12	12	
4	92	INV SBR	
	76	* Lbl	
5	18	* C'	
7	42	STO	
8	20	20	
9	03	3	
660	05	5	
1	03	3	
2	03	3	
3	03	3	
4	00	0	
5	69	* Op	
6	04	04	
7	43	RCL	
8	20	20	
9	69	* Op	
670	06	06	
1	65	x	
2	43	RCL	
	11	11	
4	34	$\sqrt{x}$	
5	55	÷	
6	43	RCL	
7	09	09	
8	45	y^x	
9	93	.	
680	07	7	
1	05	5	
2	95	=	
3	42	STO	
4	24	24	
5	03	3	
6	01	1	
7	03	3	
8	04	4	
9	69	* Op	
690	04	04	
1	43	RCL	
2	24	24	
3	91	R/S	
4	69	* Op	

LOC	CODE	KEY	COMMENTS
	06	06	
	65	x	
	53	(	
	04	4	
	00	0	
700	55	÷	
	03	3	
	65	x	
	43	RCL	
	06	06	
	54	)	
	34	$\sqrt{x}$	
	95	=	
8	42	STO	
9	25	25	
710	03	3	
1	06	6	
2	69	* Op	
3	04	04	
4	43	RCL	
5	25	25	
6	69	* Op	
7	06	06	
718	91	R/S	
719			

LOC	CODE	KEY	COMMENTS

MERGED CODES

62 · 72 STO · 83 GTO
63 · 73 RCL · 84
64 · 74 SUM · 92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

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APPENDIX II

CONVERSION OF UNITS

Multiply	By	To Obtain
Ft.	0.3048	m
Ft^3/s	0.028317 (0.0283168466)	m^3/s
HP	1.0139 (1.013869794)	CV
CV	0.7355 (9.80665 x 3/40)	KW
N_s (British System) $RPM \frac{\sqrt{HP}}{(m)^{5/4}}$	4.446 (4.44603)	N_s (Metric System) $RPM \frac{\sqrt{CV}}{(ft)^{5/4}}$

APPENDIX III

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