Agricultural Land and Water Resources
Development II Course 1993 - 18

SMALL-SCALE HYDRO POWER GENERATION

Ministry of Agriculture, Forestry and Fisheries
Japan International Cooperation Agency
Japanese Institute of Irrigation and Drainage

SMALL-SCALE HYDRO POWER GENERATION

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SMALL-SCALE HYDRO POWER GENERATION

CONTENTS

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CONTENTS

page

SMALL-SCALE HYDRO-POWER GENERATION

1. Signicance of small-scale hydro-power generation for rural and agricultural development in developing countries.

Developing countries are expecting much from small-scale hydro-power generation. In the case of small-scale hydro-power generation, a more flexible facility scale such as the dam type or run-of-river type can be planned in rersponse to the power demand and natural conditions of a particular area as compared to large-scale power generating methods such as thermal or nuclear power generation Because of this, small-scale hydro-power generation is especially effective for supplying power to villages or islands remote from existing power generating facilities or from transmission and distibution facilities.

Also, small-scale hydro-power generation can use the potential energy of an existing water flow nearby and can be used as supple-mental local energy sources for relieving electricity shortages produced by existing power generating facilites or the unstable supply of electricity by fossil fuels which must be imported from foreign countries. Especially where existing agricultural water use facilities such as dams and channels can be utilized or where the small-scale hydro-power generation can be planned in combination with agricultural water use facilities, small-scale hydro-power generation is significant in reducing maintenance and operation costs through effective utilization of the potential energy of water flow, in addition to existing energy sources for operating agricultural water use facilities.

Stabilization of electricity supply to the farming asreas in the developing countries will promote both the modernization of people's living and the development of an agricultural infrastructure using irrigation and drainage pumps as well as the introduction of various processing facilities for agricultural products, thereby developing agriculture in the region as a whole.

Therefore, in formulating agricultural development projects in developing countries in the future, it may become necessary to review the possibility of small-scale hydro-power generation more frequently.

(1) Energy problems in rural and remote areas.

-1. Efficient, modernized, mechanized agriculture depends greatly on big volumes of energy consumption, especiaslly oil'consumption.

Payment in foreign currency for importing oil is one of the reasons for financial stress in some countries.

If the power source for modernized agriculture can be changed from oil to hydro-electric power, the cost of energy consumption will drop remarkably, as the cost of local water is free.

-2. In rural and remote areas villages are scattered widely over the land in most cases. The cost for construction of power transmission network including such scattered villages becomes huge and the consdtruction work may be technically difficult sometimes because of particular geographical conditions.

However, the small of micro-scale hydro-power generation with closed power transmission lines for each individual rural district can facilitate comparatively small construction costs.

-3. Generally speaking, the costs of construction of the dam and the water conducting hydro-power generation facilities are huge and the construction periods are very long.

However, in case of a mini or micro-scale hydro-power generation facility, the existing irrigation dam and irrigation channel can be utilized and the natural river can also be utilized only with the water intake weir.

(2) Utilization of electricity in rural areas

-1. Illumination of houses, schools, hospitals and other public facilities.

-2. Power source for agricultural machines and agro-industry such as rice mill, thresher, sawing mill, flour grinder, starch processing factory, fruit juice plant, etc.

-3. Power source for refrigerator, heater and air conditioner at hospital and dispensary.

-4. Power source for irrigation pump station and drainage pump station.

-5. Power source for raw water intake pump or deep well submersible motor pump, and water purification facilities.

2. Difinition of small-scale hydro-power generation.

(Page 8 Chapter 2)

(1) Small-scale	; Less than 3,000 KW	(in Japan)
(2) Mini-scale	; 110 KW - 1,000 KW	(Guide line only)
(3) Micro-scale	; Less than 100 KW	(〃)

(4) Difference among pump and hydro turbine

Pump

(Transference of energy)

- Electric energy is converted to mechanical energy by means of electric motor. Mechanical energy is converted to water pressure(head) by means of pump.

(Equation to calculate the head)

- Pump total head

$$Hp = Ha + h$$

Hp: Pump total head (m)

Ha: Actual head

h: Sum of each kind of loss heads.(m)

Ex: Friction loss in the water feeding pipe, Friction loss in the valves, etc.,

(Equation to calculate the power)

- Pump shaft horsepower

$$Pp = \frac{9.8 \times Q \times Hp}{t}$$

Turbine

(Transference of energy)

- Potential energy of water is converted to mechanical energy by means of turbine. Mechanical energy is converted to electric energy by means of generator.

(Equation to calculate the head)

- Effective head for turbine

$$Ht = Ha - h$$

Ht: Effective head for turbine (m)

Ha: Actual head

h: Sum of each kind of loss heads.(m)

Ex: Friction loss in the penstock, Friction loss in the turbine inlet valves, etc.,

(Equation to calculate the power)

- Turbine output

$$Pt = 9.8 \times Q \times Ht \times t$$

Pp: Pump shaft horsepower(KW)	Pt: Turbine output(KW)
Q : Flow quantity (m^3/sec.)	Q : Flow quantity(m^3/sec.)
Hp: Pump total head (m)	Ht: Effective head for turbine(m)
p: Pump efficiency(%)	t: Turbine efficiency(%)
9.8: Specific gravity (m/sec^2)	9.8: Specific gravity (m/sec^2)

3. Rough estimation of small-scale hydro-power generation facilities.

(1) Rough estimation of effective head (Page 70. 3.8 (2))

Effective head is obtained by subtracting the total head loss from the gross head. The effective head, together with the discharge, are basic data for hydropower stations, and thus the effective head should be finally determined by accurately calculating the head loss. However, in the early stage of surveying or planning, such basic data are not available in many cases. Even so, a rough estimate should be made within the possible range at that time. If even the calculations explained in the planning in Chapter 4 cannot be made in the early stage, the head loss is roughly estimated against the whole head between the intake water level and the tailwater level, which can be roughly estimated in Paragraph (1). In this case, about 7 to 9 % of the head between the intake water level and the tailwater level is taken as the approximate head loss; however, this has to be revised as the planning progresses, of course.

(2) Rough estimation of maximum discharge (Page 71 3.8 (3))

The maximum discharge is determined by the usable water volume for power generation governed by reservoir operation or river flow-duration. The rough estimation is made by considering the conditions of power demand in the development area based on these hydraulic conditions(refer to Paragraph 4.3 (2)"Maximum discharage).

-1. The maximum discharge of the turbine will preferably be determined at the minimum flow rate of river flow-duration. If determined so, the maximum output of the turbine would be secured through the year.

-2. Data of flow-duration are preferably to be based on the data for a period of several years. In Japan, such data are based on the date for a period of 10 years at least.

(3) Rough estimation of generated output (Page 71 3.8 (5))

When effective head is H (m) and the discharge is Q (m^3/s), then the generated output P(KW) can be obtained from the following formula:

$P = 9.8 \times Q \times H \times \ t \times g \times$ (KW)...............(3.19)

where, t is the efficiency of water turbine and g is the efficiency of generator.

(4) Electric demand and supply survey (Page 28 3.2)

-1. Range of power supply area

The existing power transmission and distribution lines and future plans for transmission and distribution line construction in the vicinity of the development area should be surveyed, as well as the relationship between the power and the relevant power system network.

-2. Estimation of power demand

For determining the scale of power generation and positioning the power plant, it is important to survey present power demand and also future demand in the project area. Final determination of the scale of power generation should be governed by both the characteristics of usable water (flow-duration curve, head, etc.) and from the viewpoint of power demand.

Estimation of power demand can be generally made by micro and macro estimating methods. The latter is based on national economic indexes etc., but, for a small-scale hydropower station, the micro approach is more realistic.

The micro estimating method employs the causal relationship between the elements forming the contents and causes of power demand. For example:

1) Estimation related to population trend. In this case, it should be noted that if the non-electrified area is electrified, people may move from adjacent districts to the electrified area, thereby creating a larger demand than predicted.

2) Estimation based on diffusion ratio of household and commercial electric appliances in the case of power demand for electric lamps; and

3) Estimation based on the change in power consumption rate in individual industry due to industrial structural change and technological renovation in the case of industrial power demand.

The survey and estimation of power demand should be made with respect to maximum power demand and power demand for every unit period such as day/month/year.

The guidelines on necessary electric power for each equipment are given on pages 31 to 45.

4. Functions of each kind of hydro turbine (Page 178 6.2)

(1) Horizontal shaft pelton turbine

Range : Medium to high effective head
(around over 70 m)

(2) Horizontal shaft francis turbine

Range : Effective head 30 - 300 m
Large to small scale power generation

(3) Cross flow turbine

Range : Effective head 5 - 100 m
Mini & micro power generation
(Up to 1,000 KW)

(4) S-type tubular turbine

Range : Effective head 3 - 20 m

(5) Reverse running pump - turbine

Range : Effective head up to 100 m
Micro power generation
(Up to 100 KW)

5. Small-scale hydro-power generation facilities

(1) Intake dam or weir (Page 130 5.2)

The river water is taken and conducted into head race at this intake dam or weir which is equipped with a screening facility to remove foreign materials in the river water.

(2) Settling basin (Page 151 (5))

Usually some silt or sand is drifting in the river water; especially during flood season and rainy season the turbidity of the river water becomes a big value.

If silt or sand flowing into the head race settles on the bottom, the cross section area of the head race should be decreased and accordingly the water flow quantity should be decreased. Furtheremore, the silt or sand causes the penstock and turbine to wear out.

Therefore, the silt or sand must be settled at the settling basin which has a larger cross section area than head race and enough length so that the silt or sand can be dropped down on the bottom.

(3) Head race

(Page 153 5.3)

The river water is conducted into head tank through head race. In some cases, the construction cost of head race may become 50 percent of the total construction cost of small-scale hydro-power generation facilities. Accordingly, it must be determined carefully to select the route of head race, and the head race must be designed carefully so that the construction cost of head race will be lower.

(4) Head tank (Page 156 (2) 1)

The river water is saved once at head race, and then it falls down to turbine inlet through penstock. In most cases, head tank is constructed by reinforced concrete.

(5) Penstock ((Page 160 5.4)

Penstock is made of steel pipes in most cases. The penstock must have enough strength against the water-hammer pressure which may arise when the load is shut down.

☆ Note

The above-mentioned ardticles,(1) to (5), are special technology not only for hydro-power generation but also for agricultural civil construction work.

(6) Power station equipment

-1. Turbine inlet valve
-2. Hydro turbine
-3. Generator
-4. Governor
-5. Generator control panel

(7) Power transmission equipment

-1. Voltage step up transformer
-2. Power transmission line
Power cable, cabling poles, etc.,

(8) Power distribution equipment

-1. Voltage step down transformer
-2. Power distribuion line
Power cable, cabling poles, etc.,

(9) In-house wiring and equipment

-1. Watt-hour meter
-2. Fuse switch
-3. In-house wiring materials
-4. Bulbs and fluorescent lamps

6. Technical and economic cooperation by the Japanese Government for implementing small-scale, hydro-power generation projects in rural and remote areas.

(Page 9 and 10 of brochure of J.A.C.E.M.)

The Ministry of Agricultlure, Foresty and Fisheries(M.A.F.F.) intends to give necessary assistance for implementing small-scale hydro-power generation projects in the rural and remote areas of developing countries.

The Japan Agricultural Engineering Mechanization Association (J.A.C.E.M.), which was established under M.A.F.F., will assist in the realization of such projects. A detailed explanation of J.A.C.E.M's purposes can be found on pages 9 and 10 of the J.A.C.E.M. brochure.

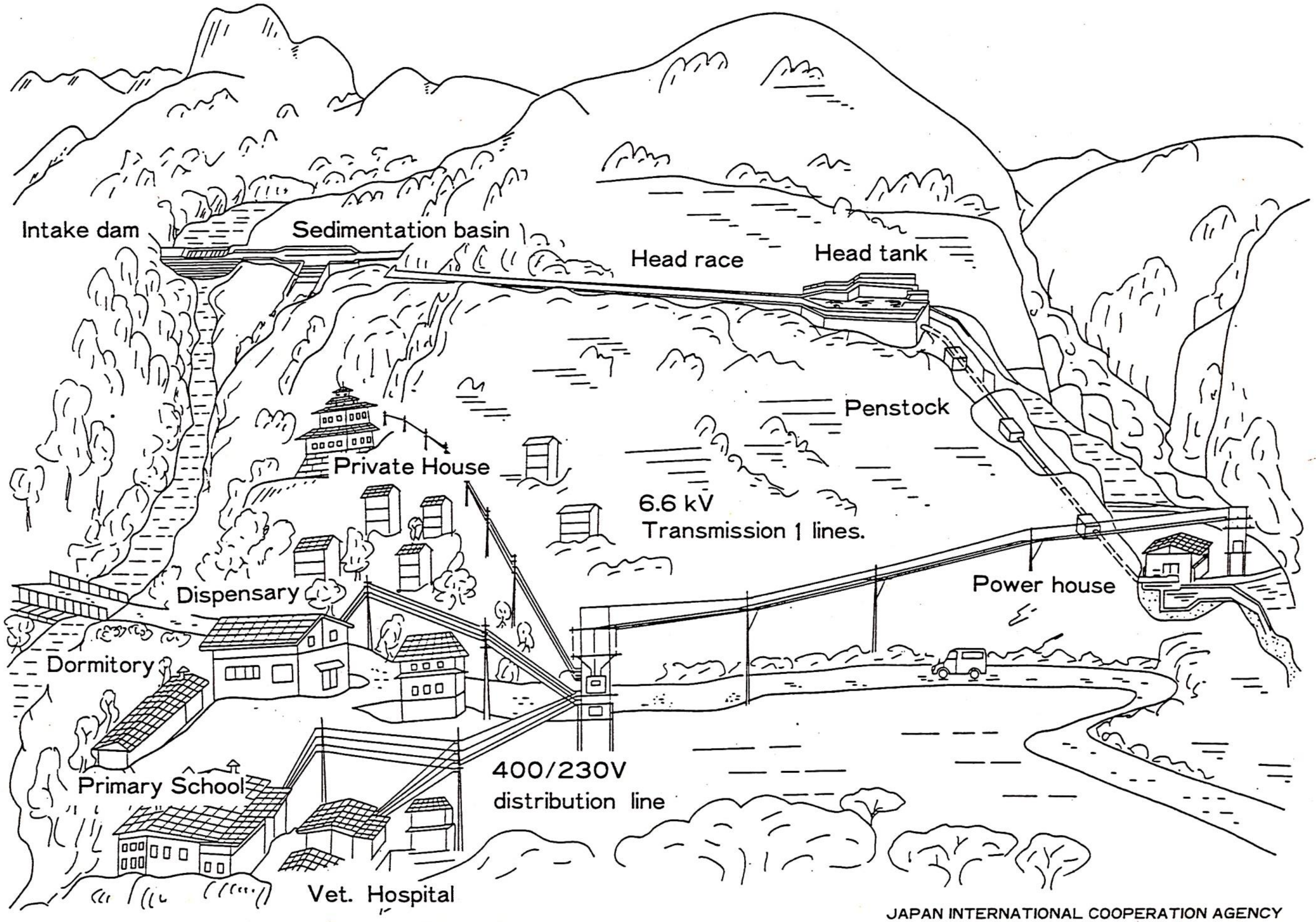
J.A.C.E.M. is :

-1. An association recognized by the Japanese Government.

-2. Comprised of leading Japanese manufacturers (9 corporations)

THE KINGDOM OF BHUTAN

ESTABLISHMENT PROJECT FOR MICRO HYDRO POWER FACILITIES



JAPAN INTERNATIONAL COOPERATION AGENCY

MICRO HYDRO POWER FACILITIES
FOR
THE KINGDOM OF BHUTAN

In response to a request from the Government of the Kingdom of Bhutan, micro hydro power facilities have been constructed by the Government of Japan under an exchange note concluded in fiscal year 1985.

1. Preface

The Kingdom of Bhutan is a mountainous country located on the southern slope of the Great Himalayas, bordered by India to the south, east and west. The country has a land area of about 47000 km^2 and its population in 1988 was about 1.3 million, most of whom live in the intermediate zone, which is the area extending from the border with India to the areas below elevation of 3000 meters.

A National Development Plan has been formulated by the Government of Bhutan itself to develop an industrial base, improve hygienic conditions and enhance living standards for citizens.

Electrification of rural areas is an indispensable part of the National Development Plan. The Government of Bhutan completed, under a Japanese Grant Aid Programme, construction of micro hydro power generation facilities and power transmission/distribution lines at 10 sites in 1987, utilizing the potential generating capability of relatively small rivers, streams, and irrigation channels.

These have been contributing to the people's welfare as follows.

(1) Improvement of education by prolonged time for learning.

(2) Improvement of medical services through use of such mdeical equipment as X-ray diagnostic devices, boiling sterilizers and other electric devices.

(3) More active small-scale industrial activities.

(4) Improvement of daily life by use of electric lamps and heaters.

(5) Prevention of devastation of woods and forests, and contribution to water resources preservation.

(6) Improvement of mechanical and electrical technology and technical skills for operation and maintenance for micro hydro power generation facilities through technical transfer during project implementation.

2. Basic Design Concept

The basic concept of design for generating facilities conforms to the following conditions;

(1) There will be no harm to existing irrigation water supply in deciding the maximum flow rate for each turbine.

(2) Design of intake facilities, water conducting channels and power housings should be based upon a uniform code for moulds, standards and shapes.
Operation and maintenance for such facilities must be carried out as simply and easily as possible.

(3) Power transmission and distribution line networks should be closed circuits.
Accordingly, high rates of operation of power generation equipment must be obtained to meet all requirements.

3. Outline of the facilities

NOTE: Figures in parenthese indicate future numbers.

Power House Site	MAX OUT PUT (KW)	MAX FLOW RATE (m^3/s)	EFFECTIVE HEAD (m)	PUBLIC HOUSINGS (nos)	PRIVATE HOUSES (Nos)	POPULATION (PERSONS)
RUKBJI	40	0.17	40	0 (7)	45 (65)	600
URA	30	0.42	20	8 (8)	50(104)	500
TANGSIBI	30	0.13	40	1 (6)	70(130)	620
BUBJA	30	0.10	50	5 (7)	48	130
SUREY	70	0.24	50	4 (6)	240	2000
YADI	30	0.10	50	7 (7)	115	300
PUNAKHA	30	0.13	40	7 (7)	32 (54)	180
TONGSA	50	0.21	40	13(13)	100	1600
TAMJHING	30	0.10	50	0 (6)	35 (70)	350
KEKHAR	20	0.11	30	0 (6)	27	260
TOTAL	380			45 (73)	762(953)	6540

4. Outline of Turbine / Generator Equipment

(1) Type of Turbine

A cross-flow turbine was selected for the following reasons.

1) Simple machine construction
2) Most economical
3) Easy operation and maintenanace
4) Short delivery time

(2) Control of Turbine Generator

The following control system was adopted as each power output was very small (20 to 70 KW),

1) Manual adjustment of guide vane for flow rate control
2) Dummy load heater governor for turbine speed control
3) Manual operation of inlet valve

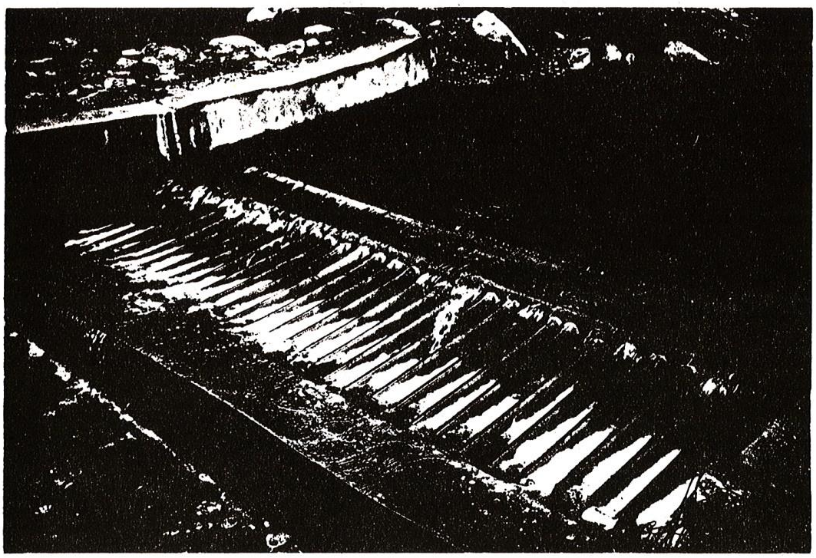
(3) Operation Method

These power generation facilities are operated free of all manual control. Therefore only one visual check per day will be necessary.

5. Operation and Maintenance System

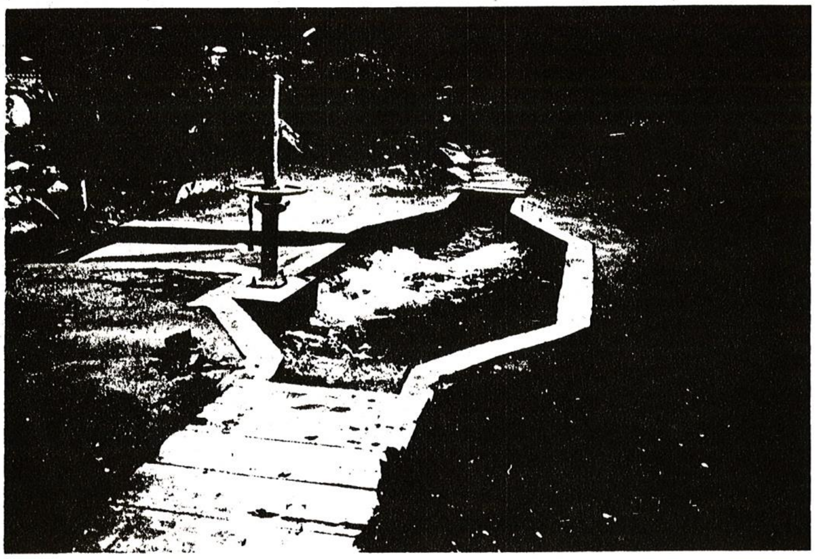
Inhabitants at each electrified area must carry out daily patrol and maintenance. The Power Department Engineer is to carry out technical checks periodically and to repair such facilities if necessary.

MICRO HYDRO FACILITIES

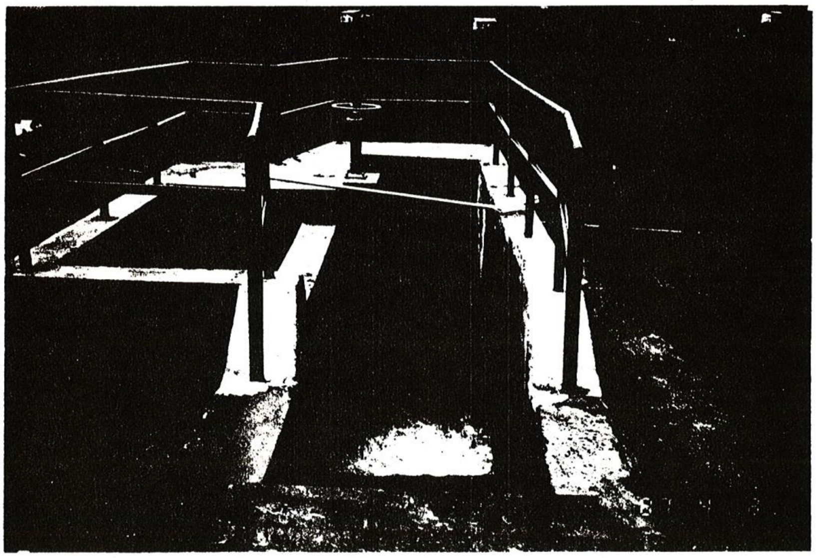


INTAKE FACILITY

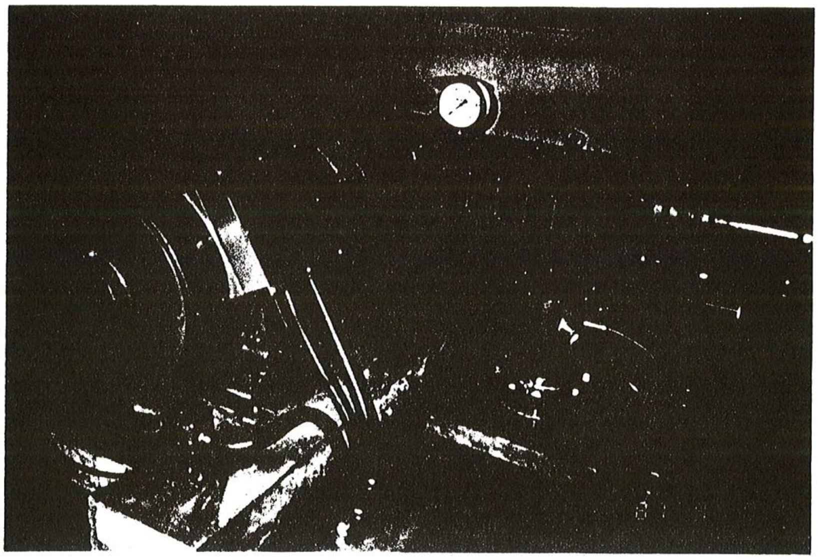
HEAD RACE



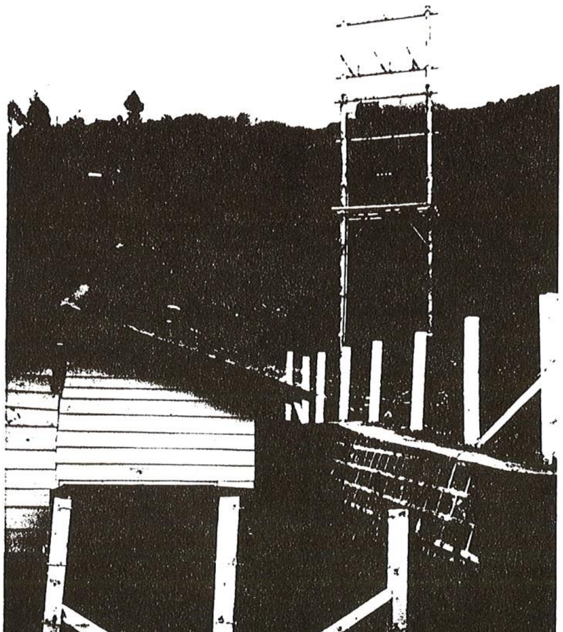
SEDIMENTATION BASIN



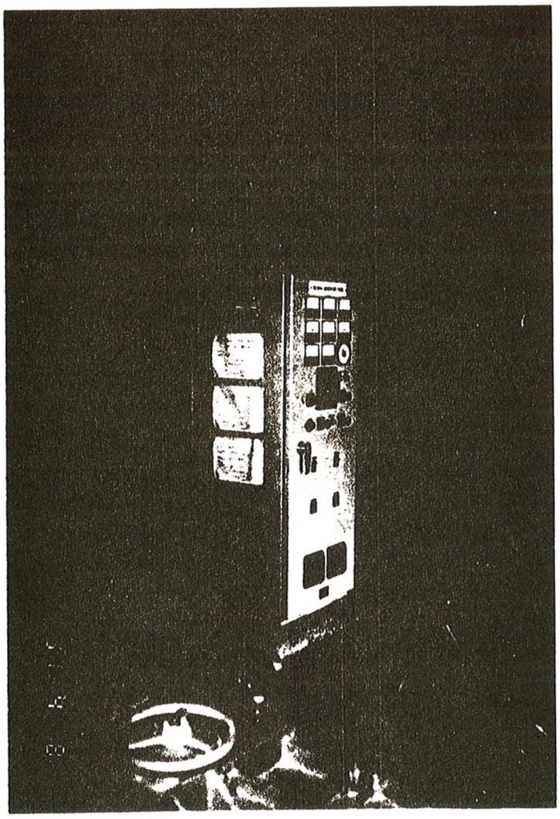
HEAD TANK



TURBINE & GENERATOR



POWER HOUSE



CONTROL PANEL

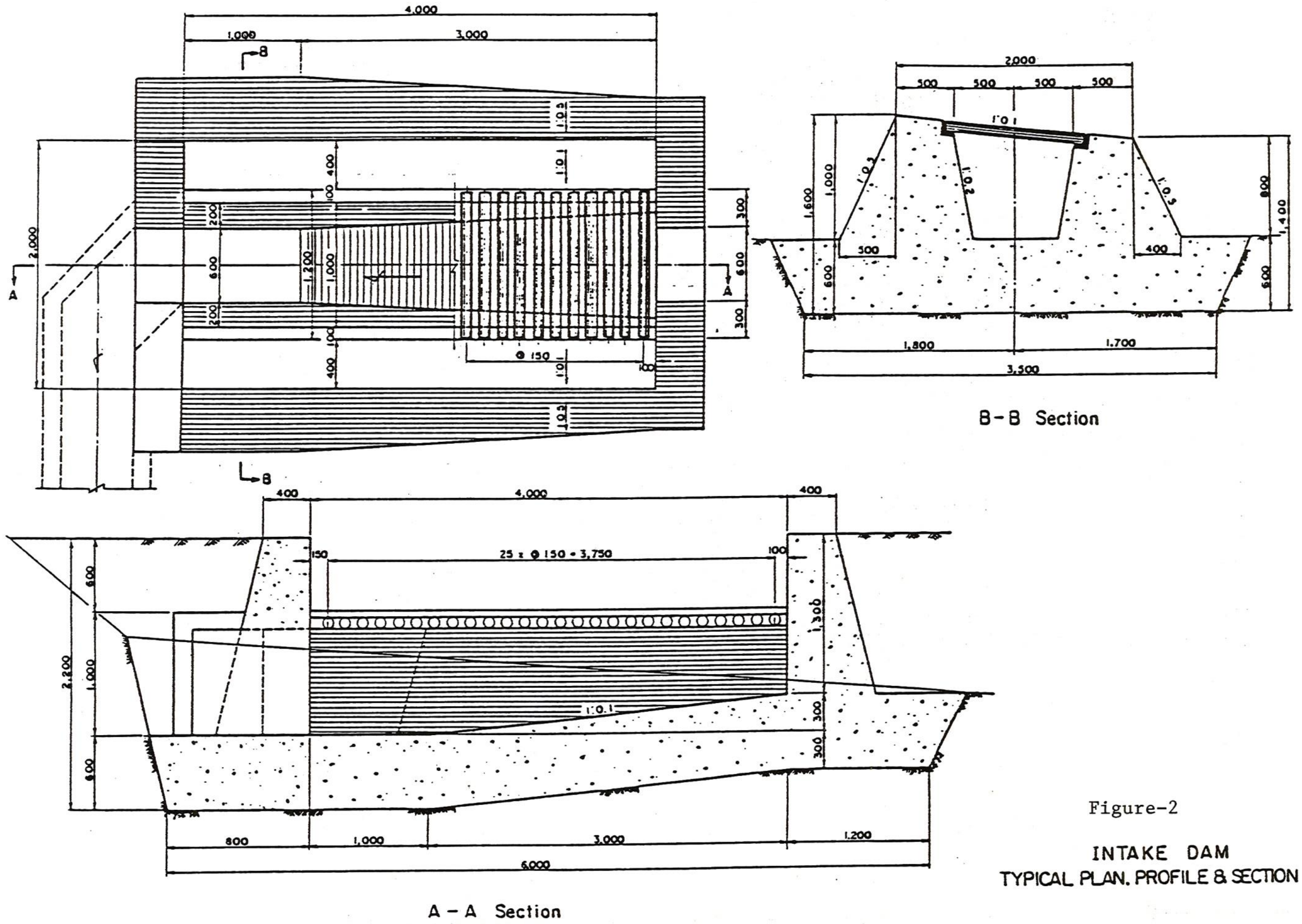


Figure-2

INTAKE DAM

TYPICAL PLAN, PROFILE & SECTION

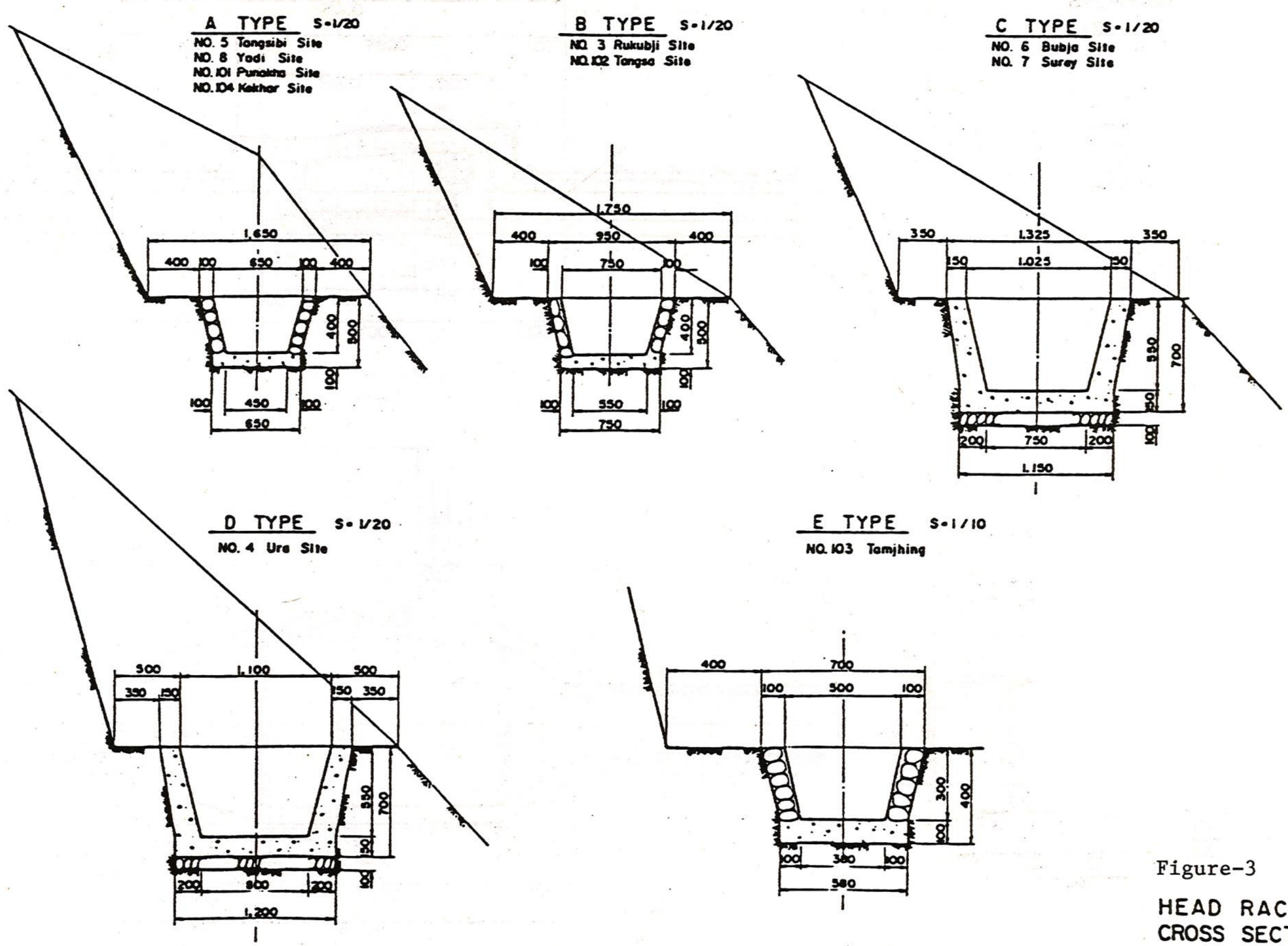
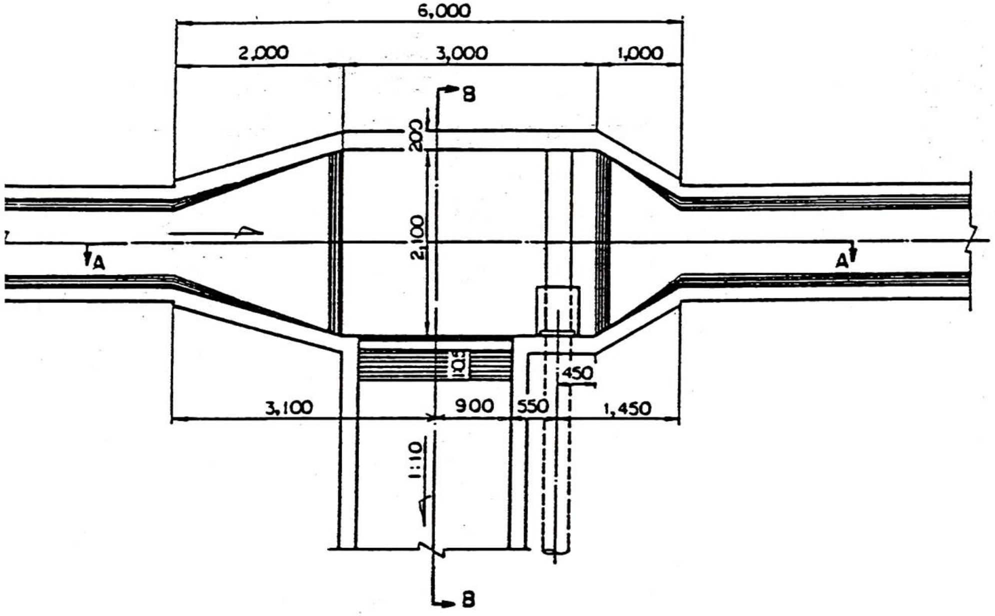
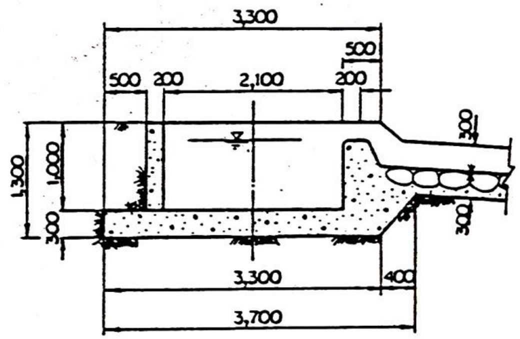


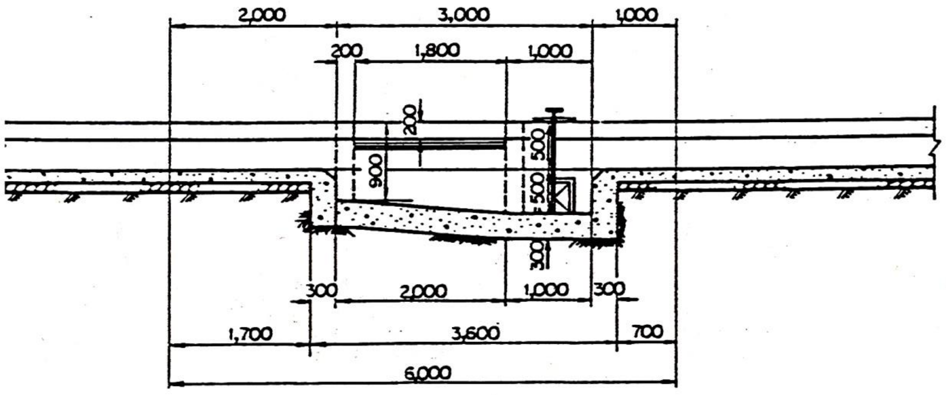
Figure-3

HEAD RACE CROSS SECTION





B - B Section



A - A Section S - 1 / 20

Figure-4
Sedimentation Basin

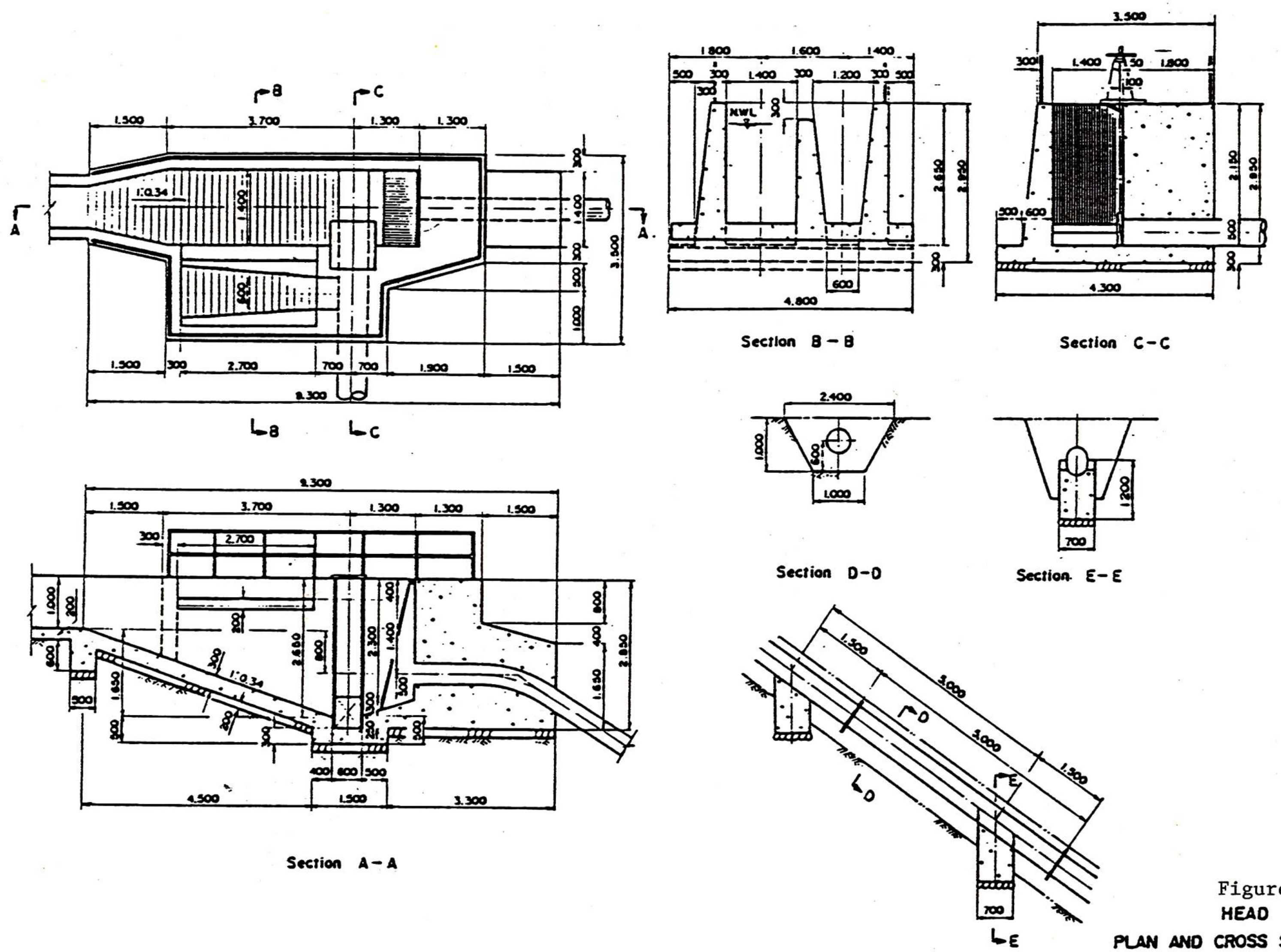


Figure-5
HEAD TANK
PLAN AND CROSS SECTION

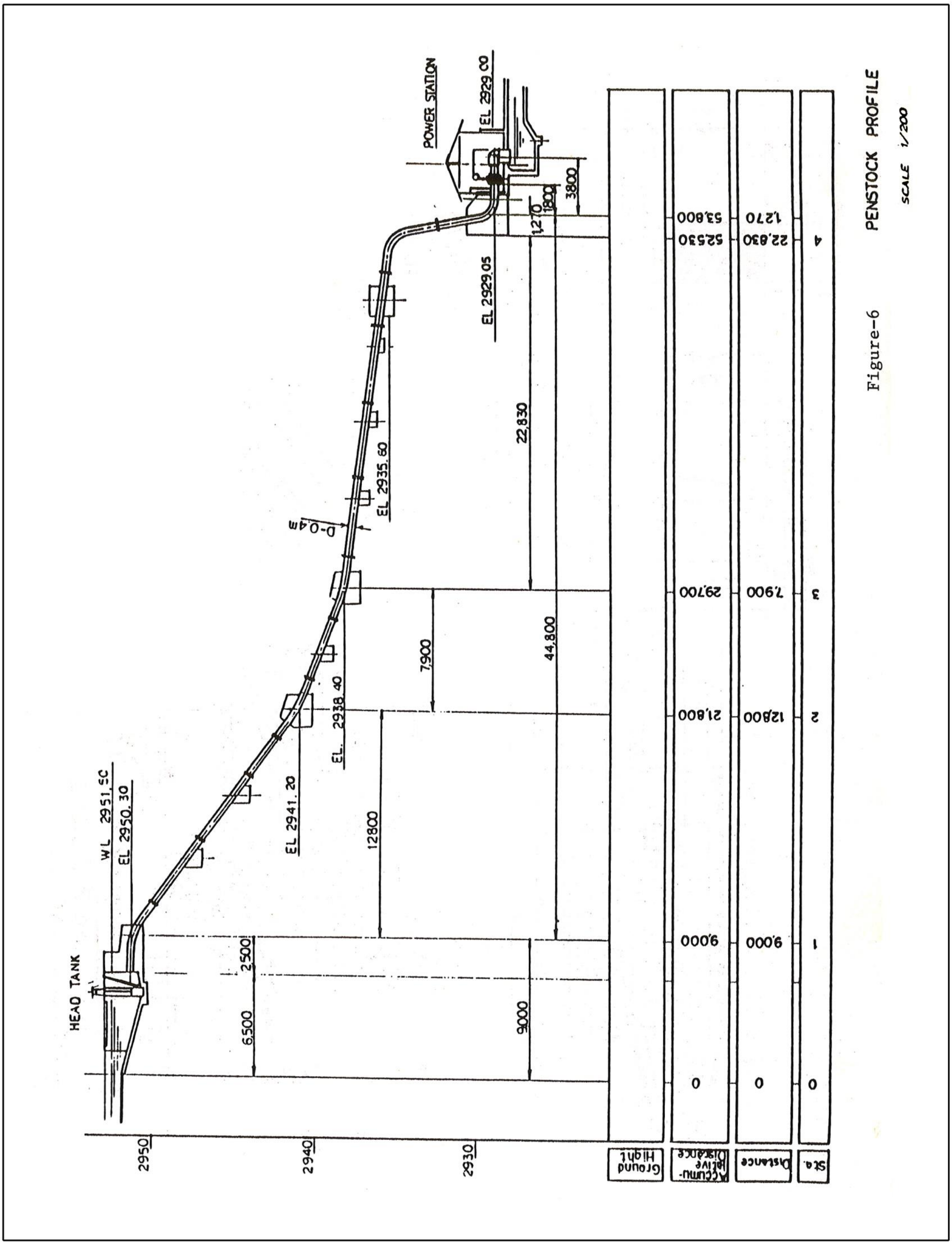

HEAD TANK
WL 2951.50
EL 2950.30
EL 2941.20
EL 2938.40
EL 2935.60
D-0.4m
EL 2929.05
EL 2929.00
POWER STATION
6,500
2500
9000
12800
7,900
44,800
22,830
1,270
1800
3800
2950
2940
2930
Ground Hight
Accumu-lative Distance
Distance
Sta.
0
1
2
3
4
9,000
21,800
29,700
52530
53,800
12,800
7,900
22,830
1,270
PENSTOCK PROFILE
SCALE 1/200

Figure-6

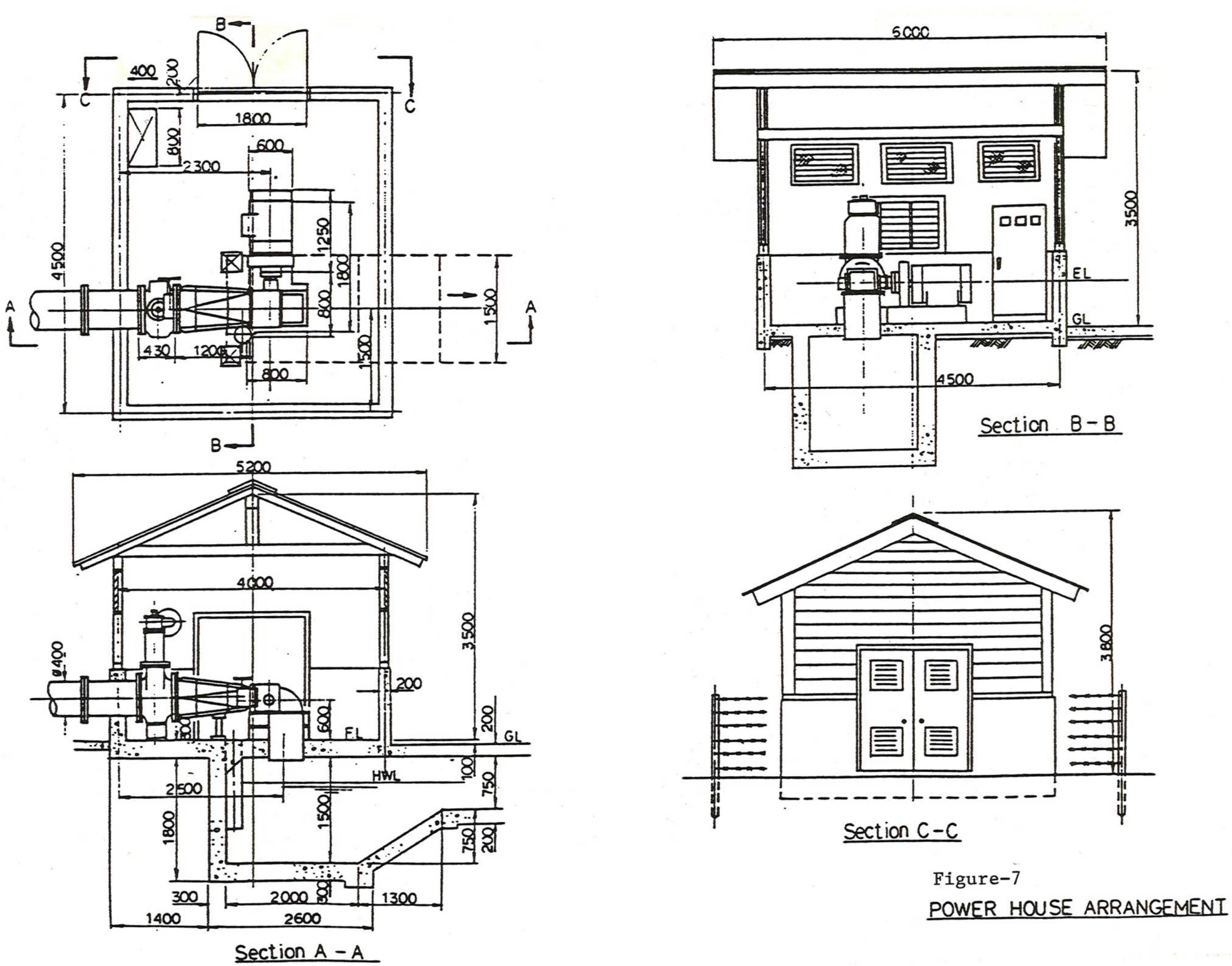


Figure-7

POWER HOUSE ARRANGEMENT

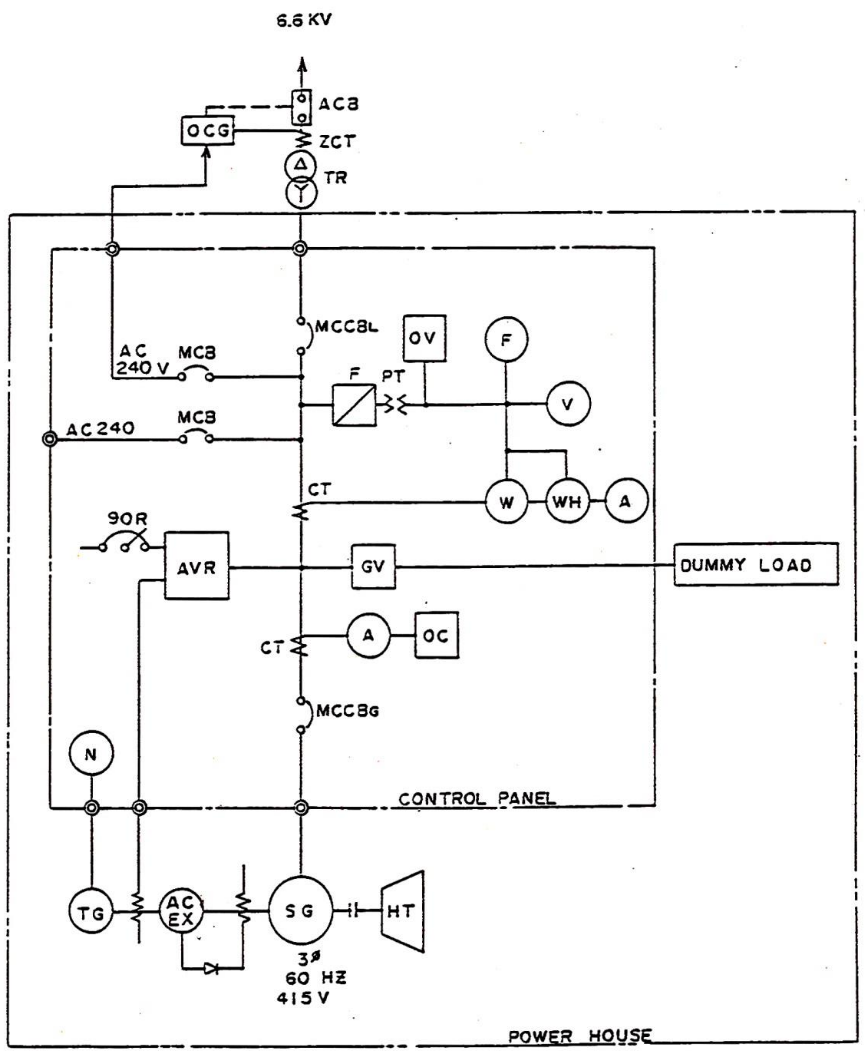


Figure-8

SINGLE LINE DIAGRAM

GOVERNOR SYSTEM

1. Operating System and Governor

There are two power transmission/distribution systems, an isolation system and a grid connection system, for micro hydro power generation facilities.

(1) With an isolation system, each power station is operated indenpendently without any relation to the other power stations, and the generated electric power is distributed to consumers through closed circuits.

(2) With a grid connection system, the generated power is transmitted and connected to a national grid or regional grid. In the case of connecting to a regional grid, the power capacity of the grid is sometimes small in comparison to the installed capacity of the power station.

Micro hydro power stations are usually connected to an isolated power distribution system because the site locations are in remote areas far from the existing network. In such cases, control of power generation must comply with the load demand through quick response, and few types of governor system are used.

2. Types of Governor

The governor serves to keep the generator at a constant rotation speed(i.e.to keep constant frequency) so that the generated electric power can fully satisfy the demand.

The types of governor are as follows:

(1) Manual Type

Operator adjusts water flow through manual control of a guide vane by watching the frequency meter on a generator panel so that the frequency can be kept constant. This type is available mainly for power stations of not more than 40 Kw that operate 4 to 5 hours per day. High wage rates for the station operator may become a problem in some countries.

(2) Mechanical Type

Water flow is automatically adjusted by a turbine guide vane driven by hydraulic oil to which oiperating power is directed from a turbine shaft through a v-pulley/v-belt or gear mechanism. Its construction is complicated, so maintenance work is not easy.

(3) Motor Operated/Electric Type

Guide vane mechanism is motor operated.
Although operation and maintenance are easy, equipment costs are high and electricity for control is necessary.

(4) Dummy Load Governor Type

Surplus electric power generated by the turbine is consumed as heat by a dummy load heater.
Equipment costs are low and manpower for operation and maintenance can be minimized. This type is the best control system for micro hydro power facilities of not more than 100 Kw per generator.

3. Constitution of Electronic Dummy Load Governor

Kubota's Electronic Dummy Load Governor consists of the following components.

(1) Component for designating rated frequency.

(2) Component for detecting generated frequency.

(3) Component for calculating quantity of surplus electric power used to make the generated frequency constant.

(4) Electric heater to consume surplus generated electric power.

Components(1), (2) and (3) mentioned above are shown in No.65 of Figure-9 surrounded by a dotted line, and they are incorporated in the generator control panel.

The surplus electricity is radiated as thermal energy through the electric dummy load heater(4), which may be a submerged or on-floor type.

For small quantities of generated electric power, an air-cooled electric dummy load heater can be applied.

4. Operation System of Electronic Dummy Load Governor

Surplus electric power (PD), the difference between the generated electric power (PW) and the demanded actual load(PL), is conducted to the dummy load heater so that the sum of the demanded actual load(PL) and the surplus electric power(PD) can be equal to the generated electric power (PW) by means of triac, thyristor etc.

When the demanded actual load(PL) decreases, the surplus electric power (PD) increases simultaneously so that the generated frequency(F) becomes equal to the rated frequency(Fo).
In other words, the electronic dummy load governor has a funciton to protect the generation frequency from raising.

5. Features of Electronic Dummy Load Governor

Advantages

(1) The cost is remarkably cheaper than the other types of governor system such as the mechnical governor or electric governor.

(2) Operation and maintenance of this governor system is the most simple.
In other words, it can be said that the governor system is operation and maintenance free. Anyone can operate micro hydro power generation equipment with this governor system by himself. No special techniques or training is required.

(3) The electric heater (dummy load) is so small that it can easily be installed in the power house. And its weight is so light as that it can be easily transported to the site.

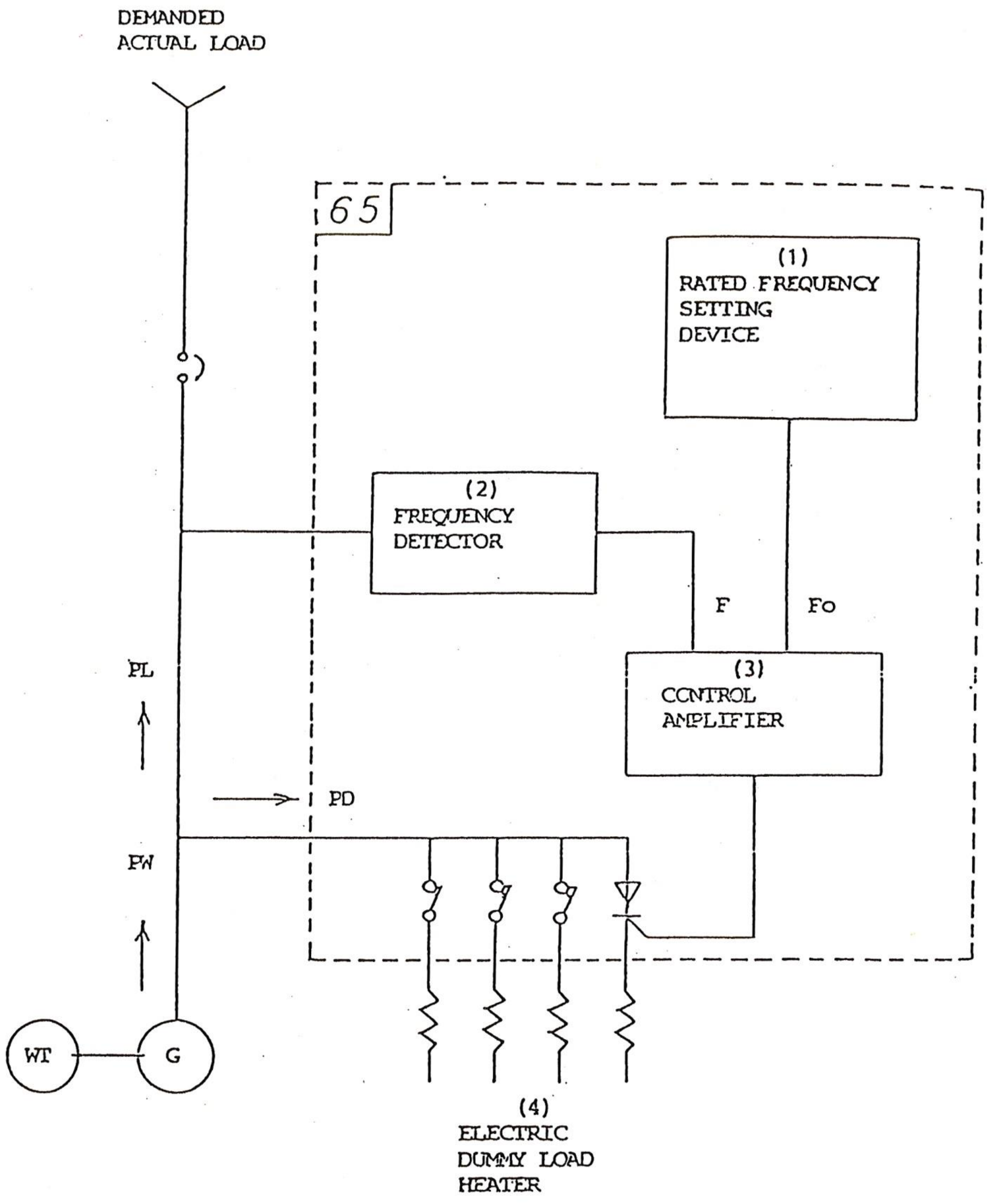
(4) The quality of electricity from this governor system is superior,so that an electronic computer can be used.

(5) The thermal energy resulting from surplus electric power can be utilized as a heat source for a house heating system, a heat conditioning system for vegetable or crop storage, a hot water supply system, etc.

Disadvantages

(1) The maximum capacity of the electric heater is limited to a certain value.
In some cases, 300 KW is considered as a limit in Europe. In Japan. 100 KW is practically applied as the maximum because of its thermal influence on the natural environment.

(2) Since the electronic control components come in a compact unit which is specially designed and manufactured, it is difficult for local engineers to carry out disassembling and reassembling work at the site.
Should a problem occur, it is recommended that the compact unit as a whole be replaced.
However, problems are not likely to occur with it.



WT : WATER TURBINE
G : GENERATOR
65 : ELECTRONIC DUMMY LOAD GOVERNOR

Figure-9