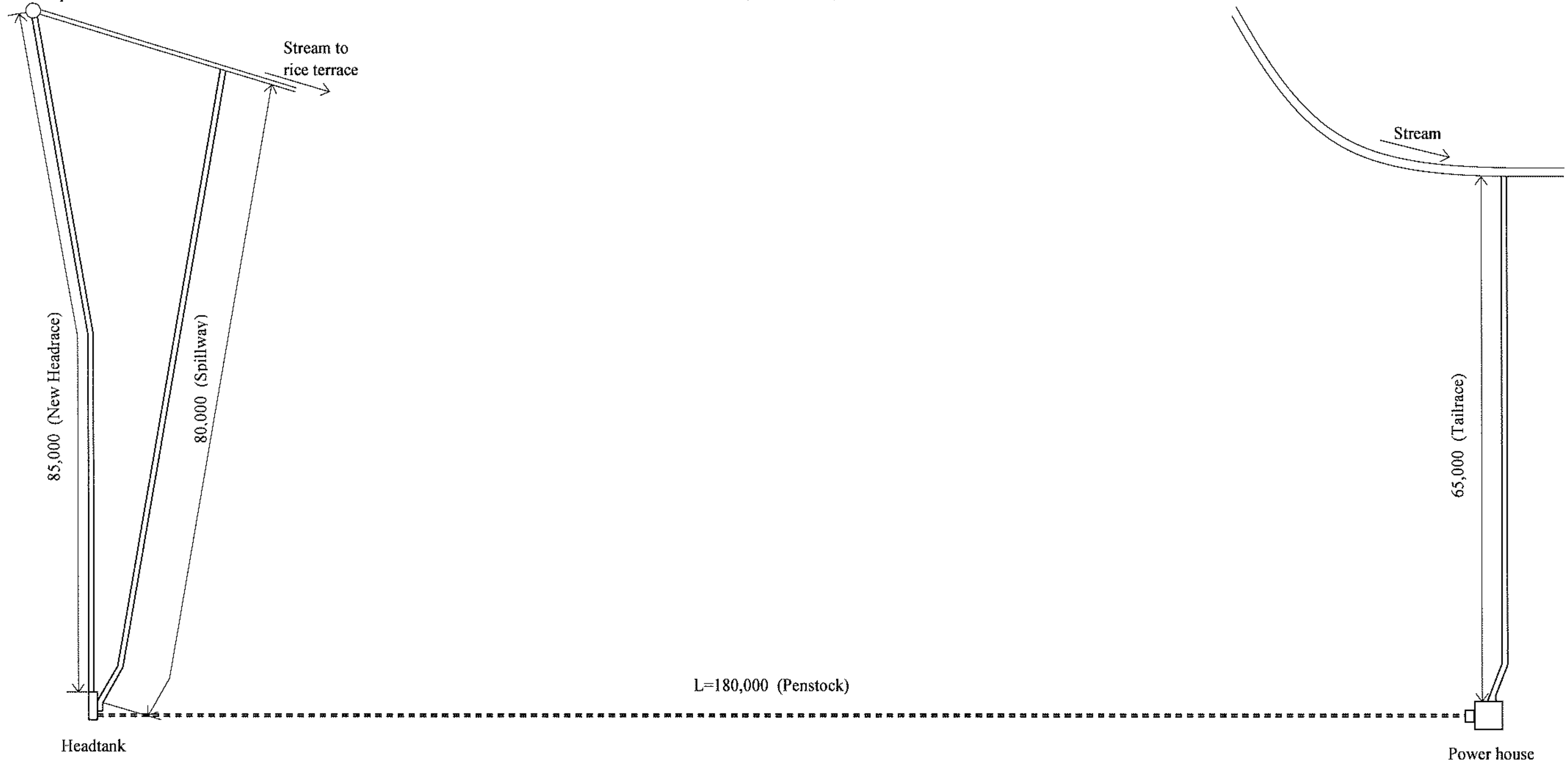
Appendix

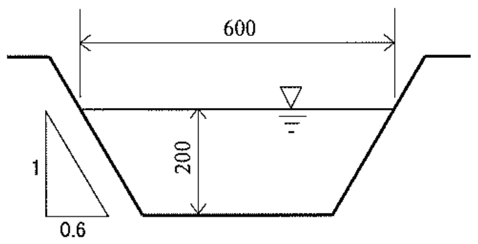
Diagrams of Mai Theu Village Hydro

Follow-up Study to Renewable Energy Master Plan
in the Northern Part of the Socialist Republic of Vietnam
(JICA)

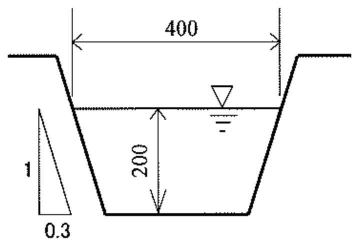
Channel & Penstock Layout
(S=1:500)



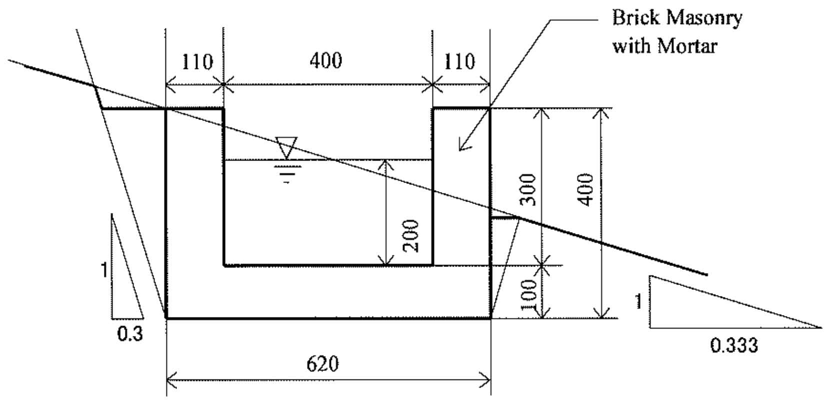
Existing Channel improving i=1/500
(S=1:10)



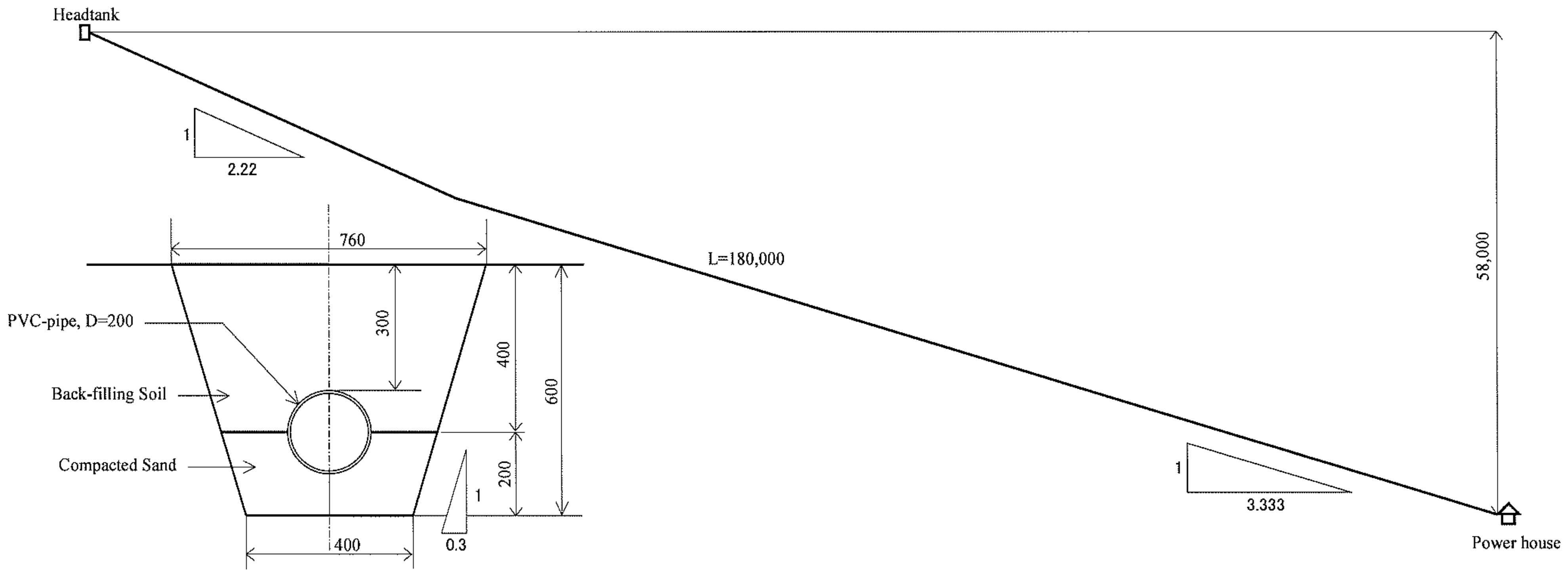
Existing Channel improving i=1/250



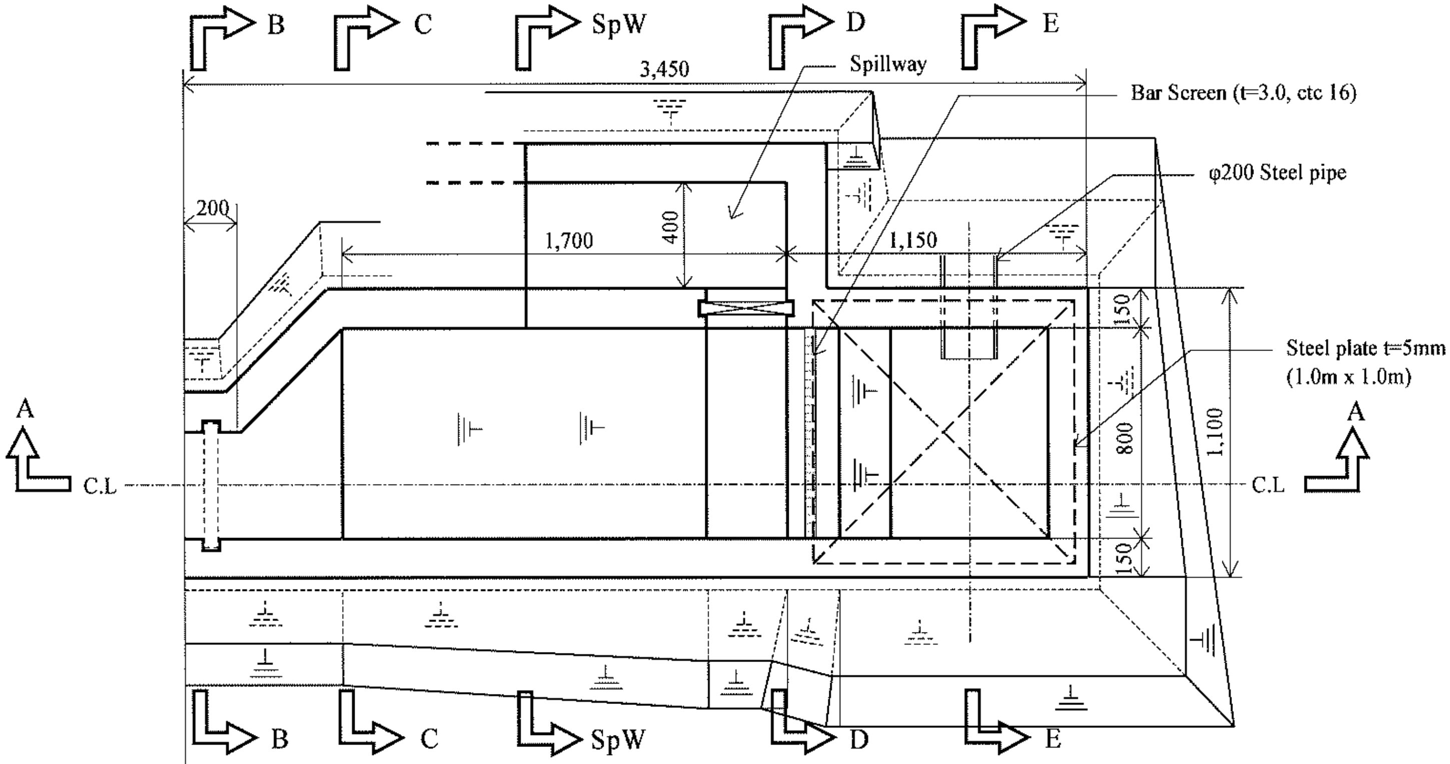
New Channel i=1/250
(S=1:10)



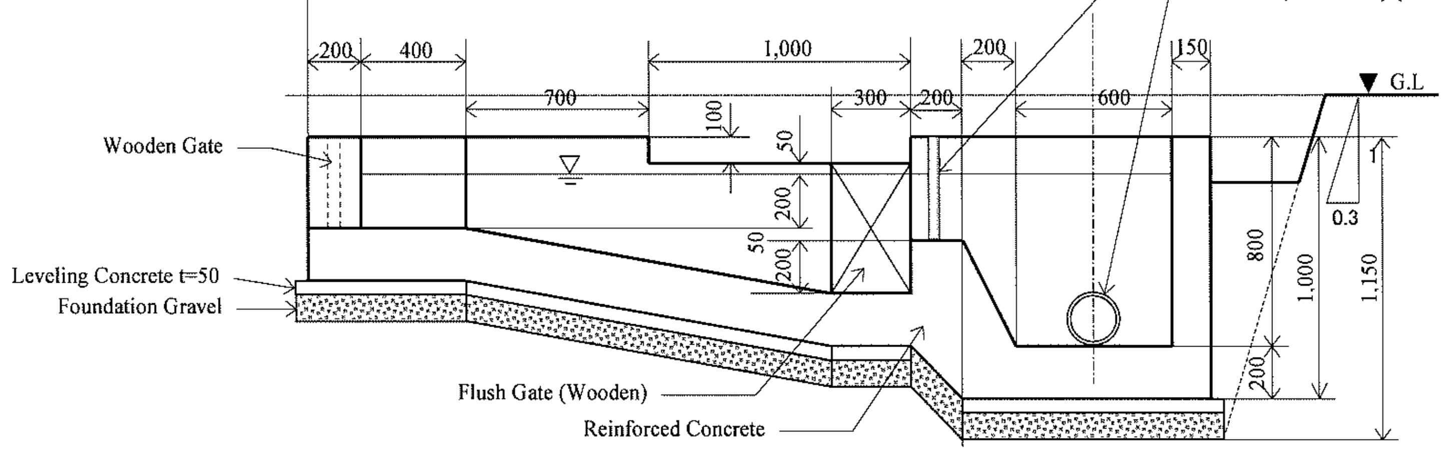
Penstock
(S=1:500)



Head Tank - 1/2
(S=1:20)

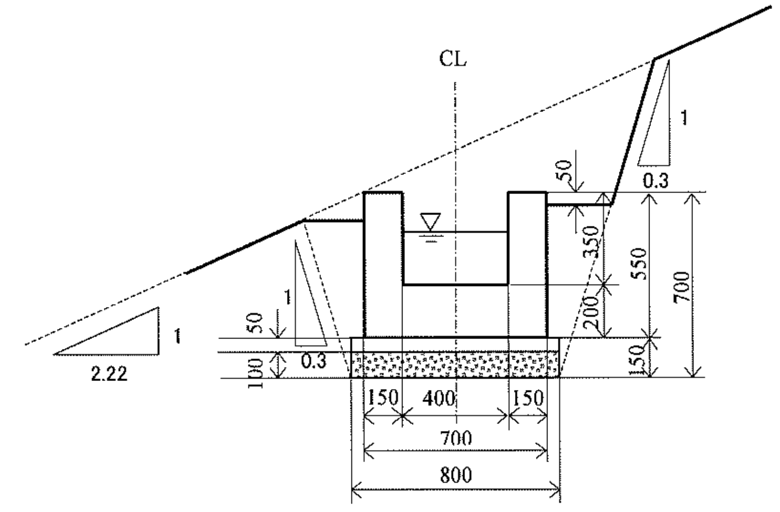


A-A Cross Section

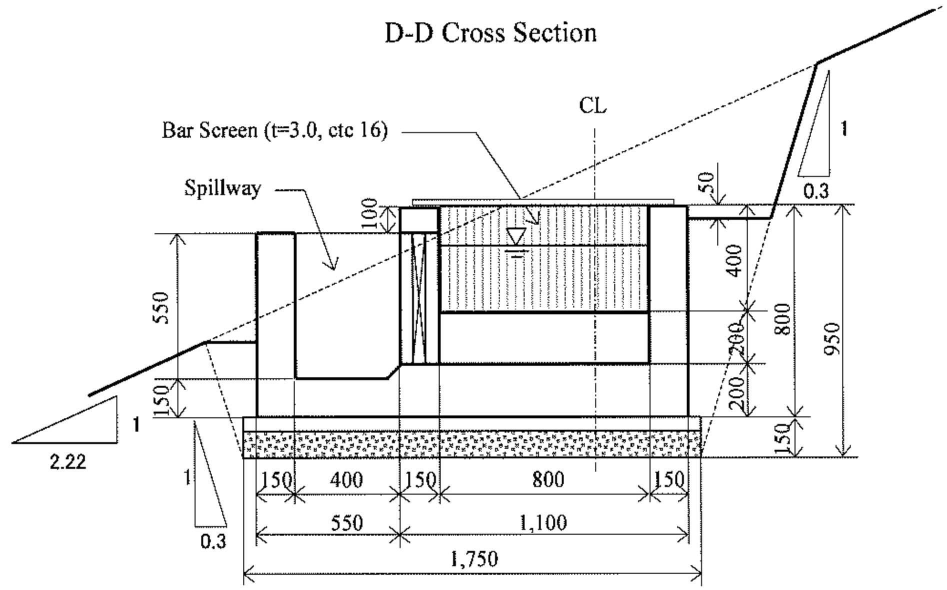


Head Tank - 2/2
(S=1:20)

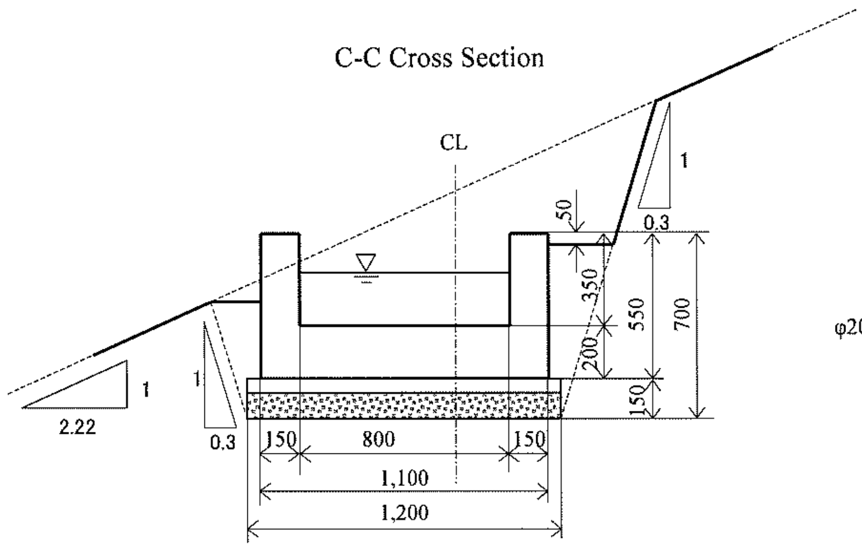
B-B Cross Section



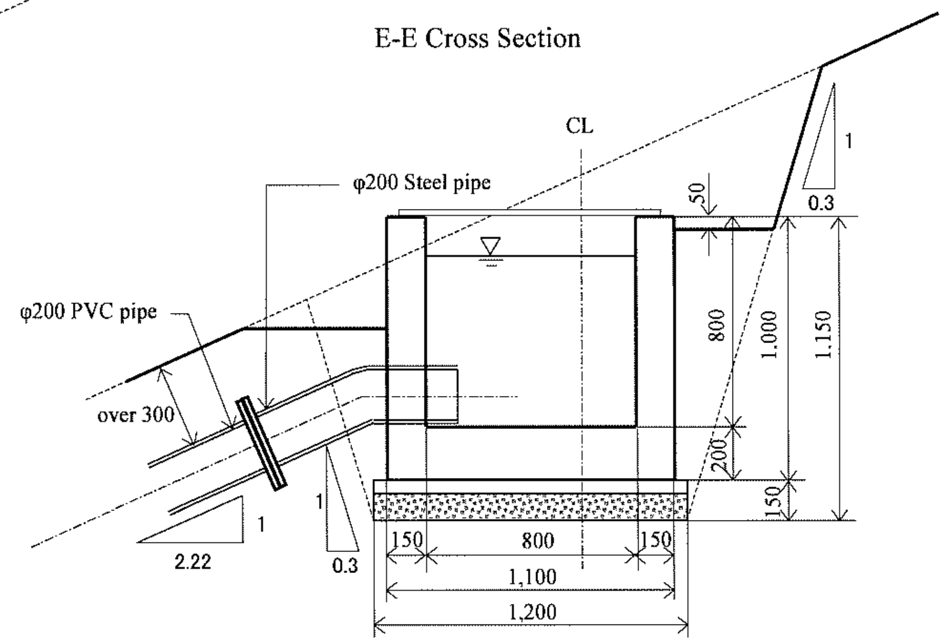
D-D Cross Section



C-C Cross Section

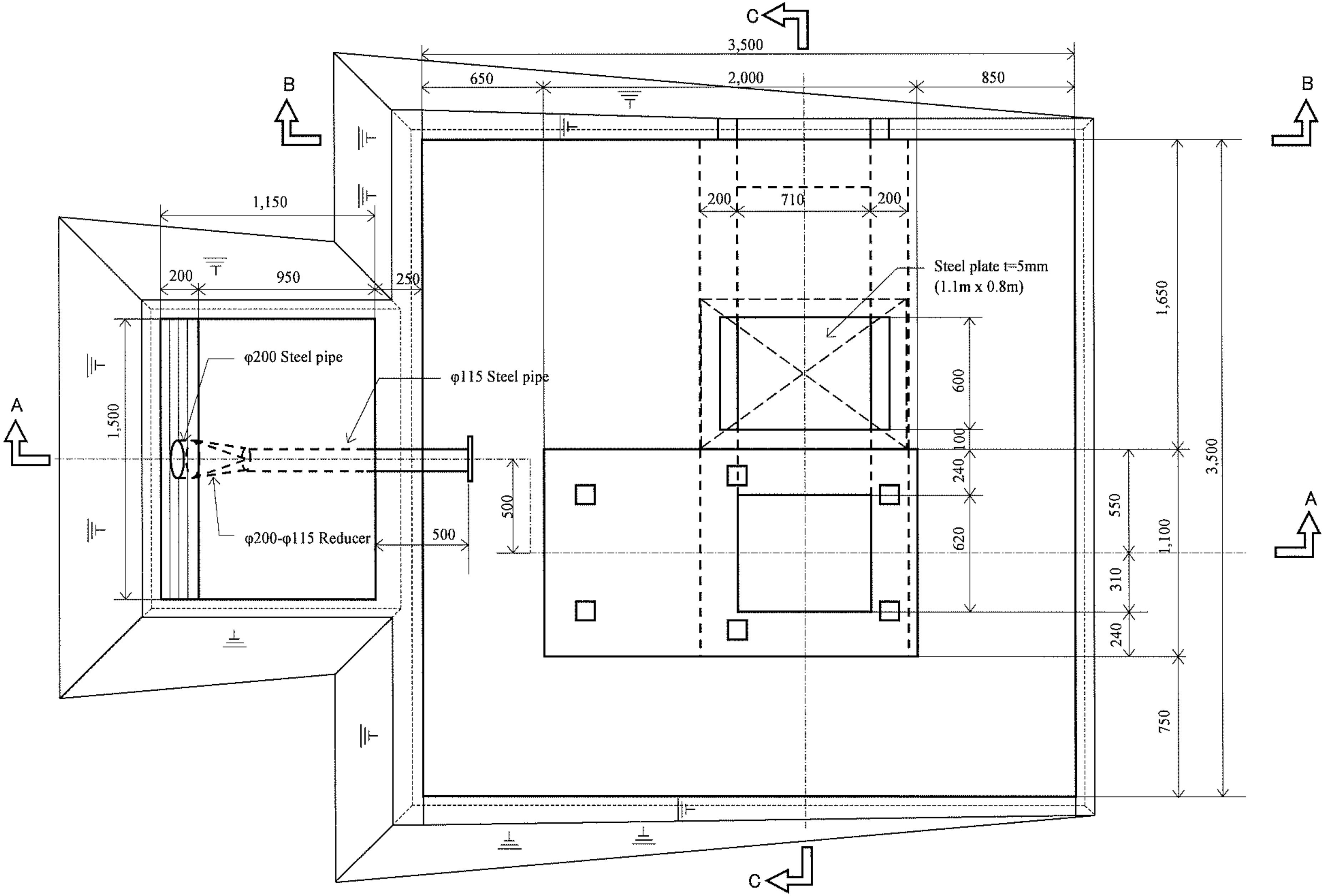


E-E Cross Section



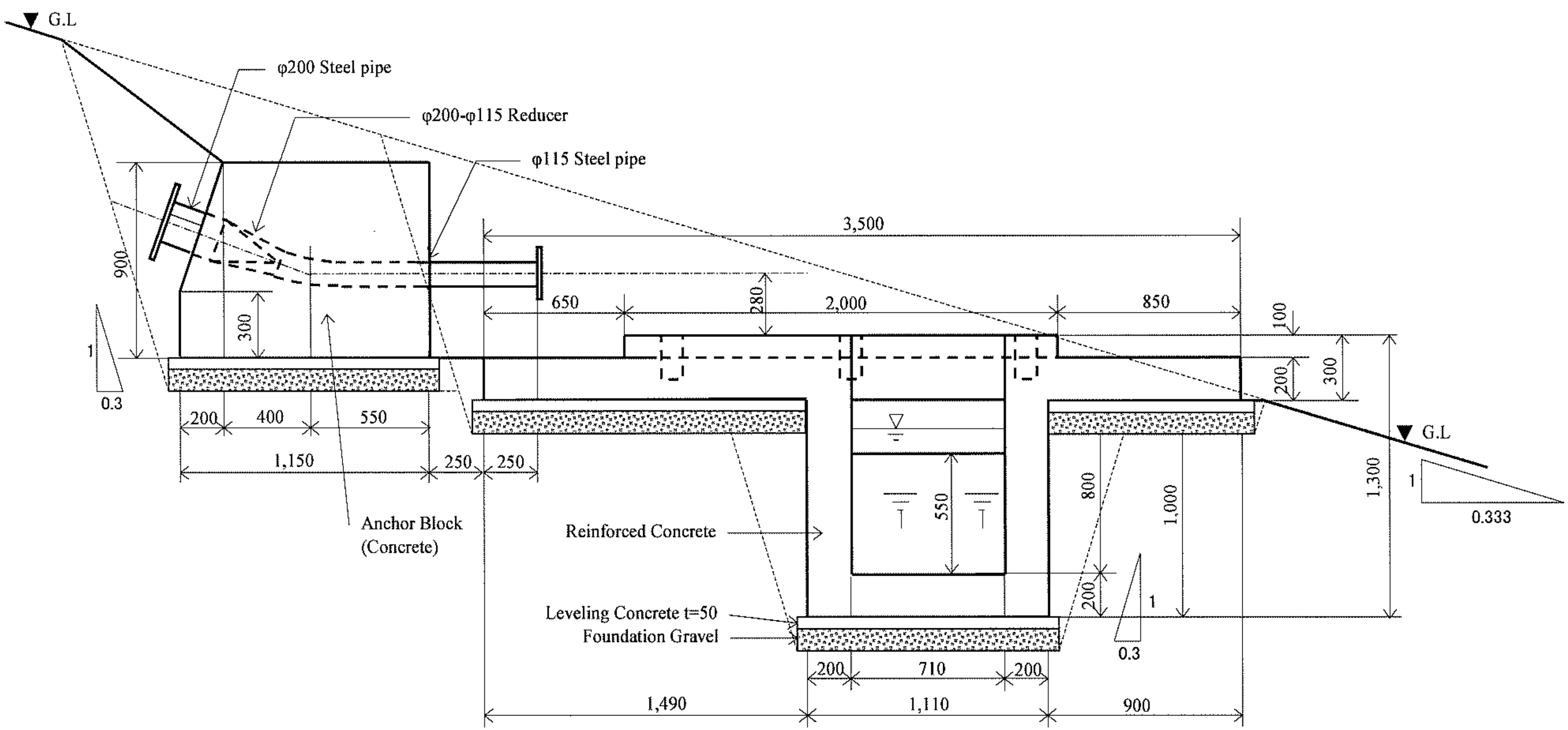
Powerhouse Foundation - 1/2

(S=1:20)

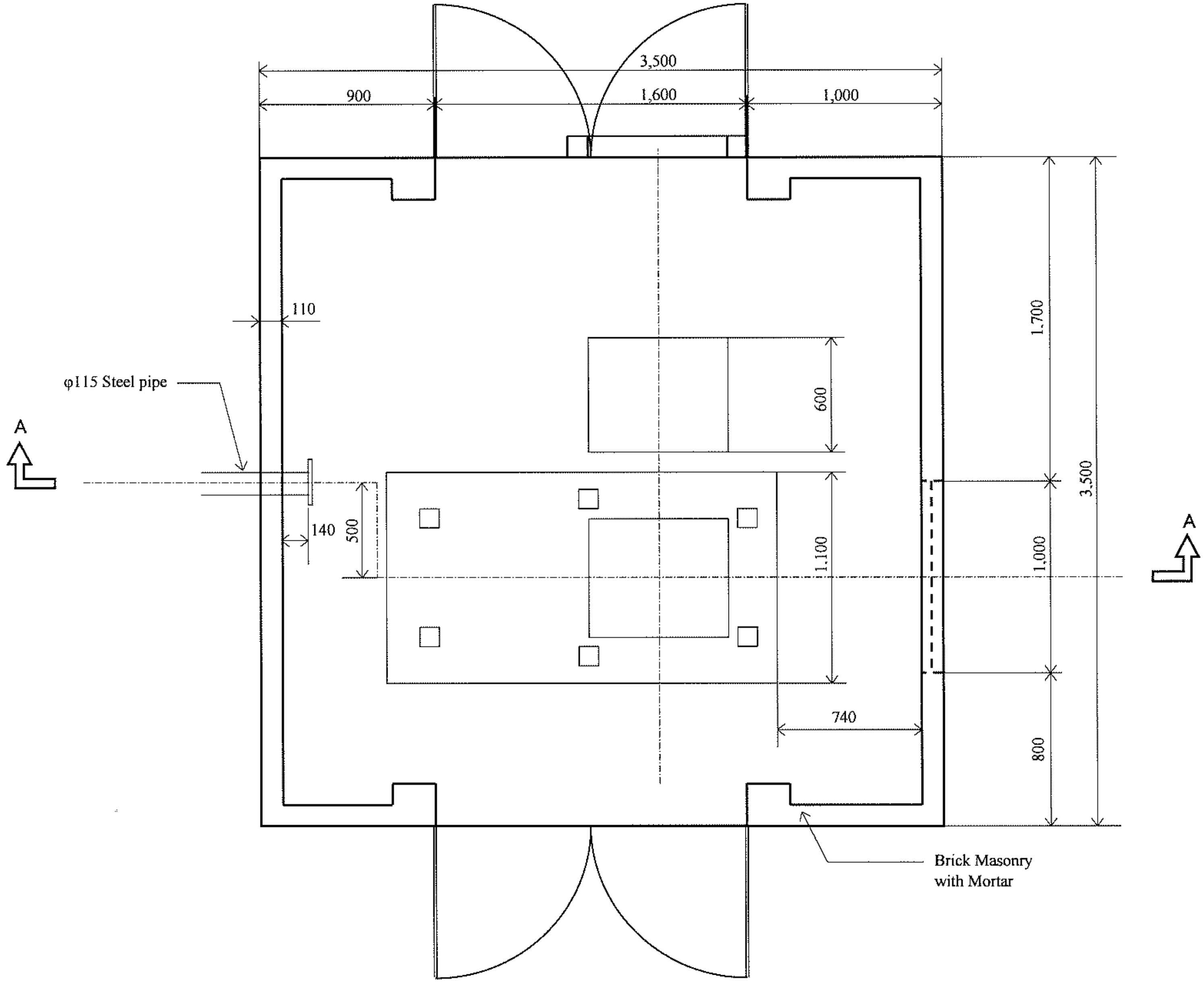


Powerhouse Foundation - 2/2

A-A Cross Section (S=1:20)

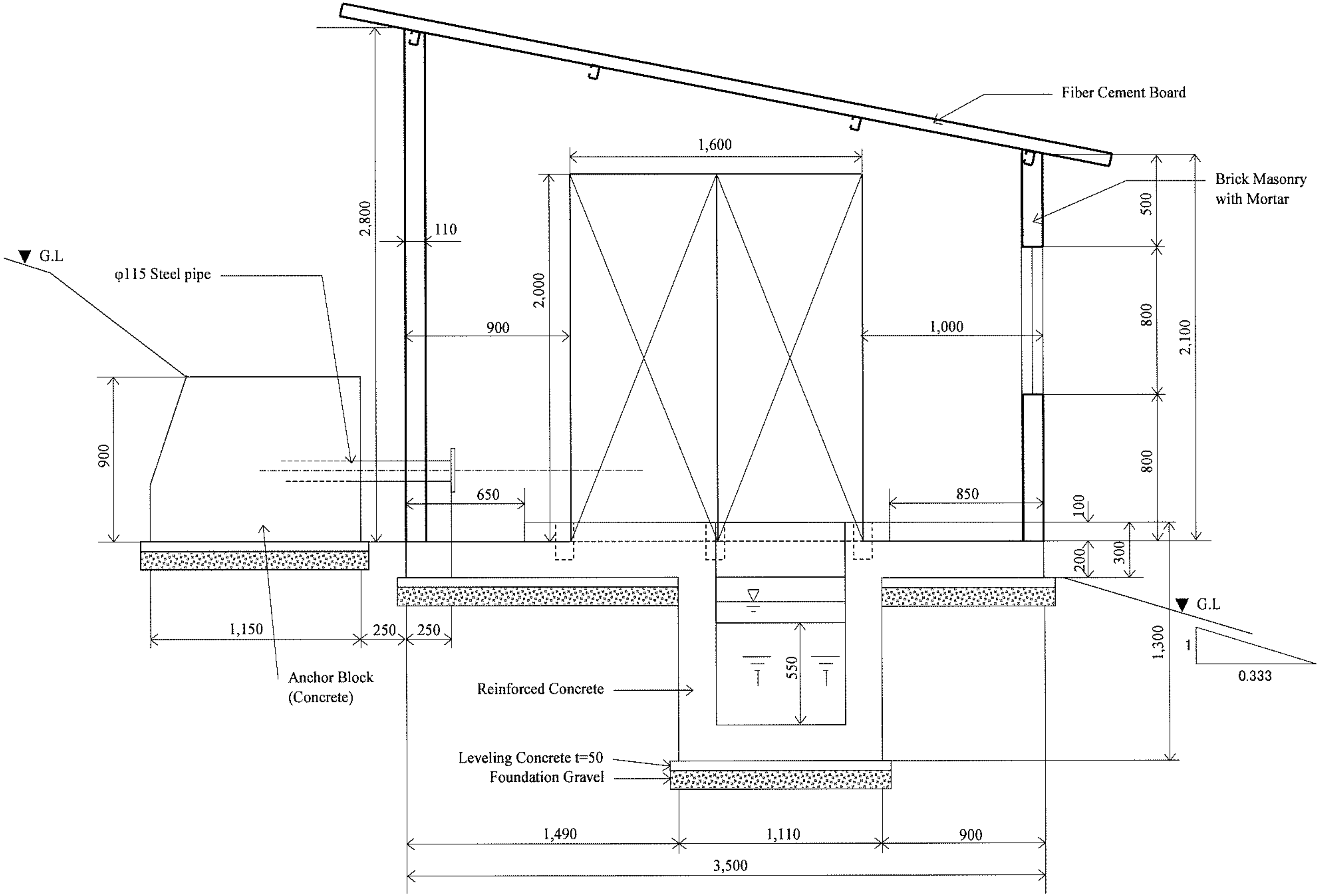


Power House - 1/2
(S=1:20)

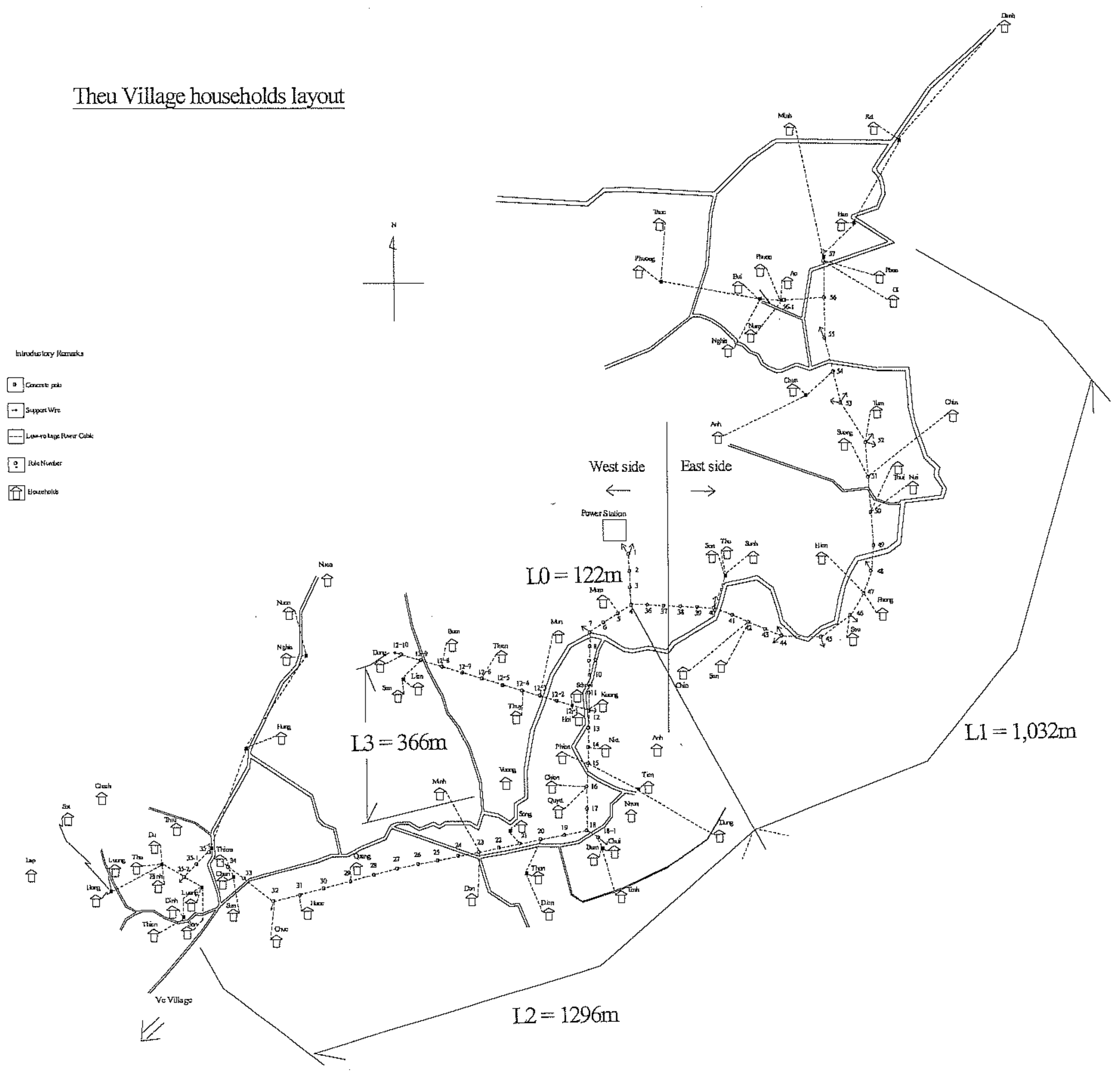


Power House - 2/2

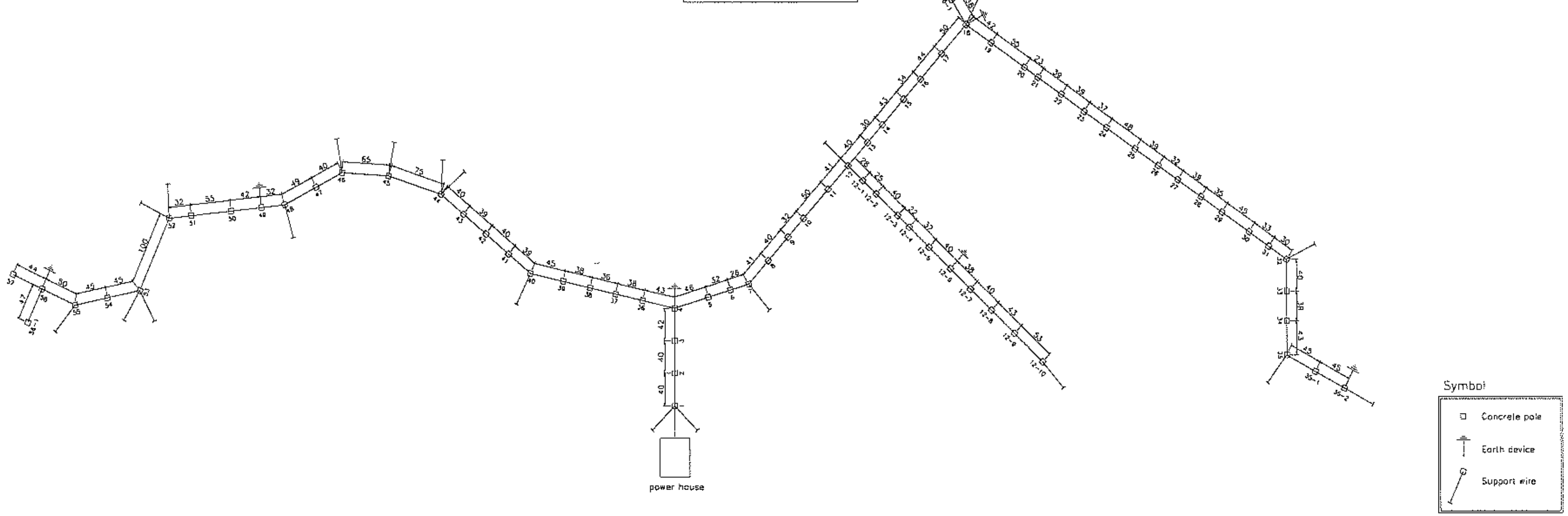
A-A Cross Section (S=1:20)



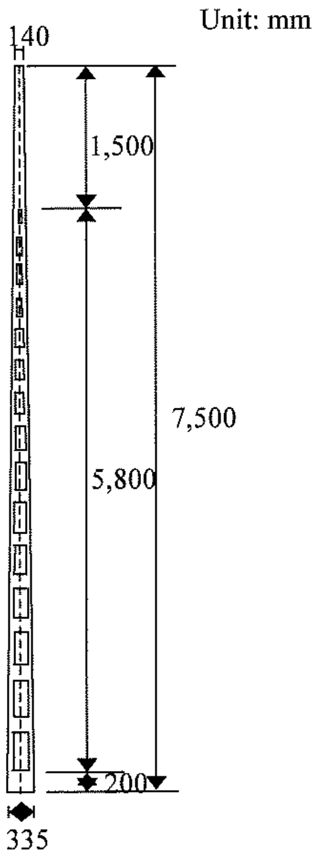
Theu Village households layout



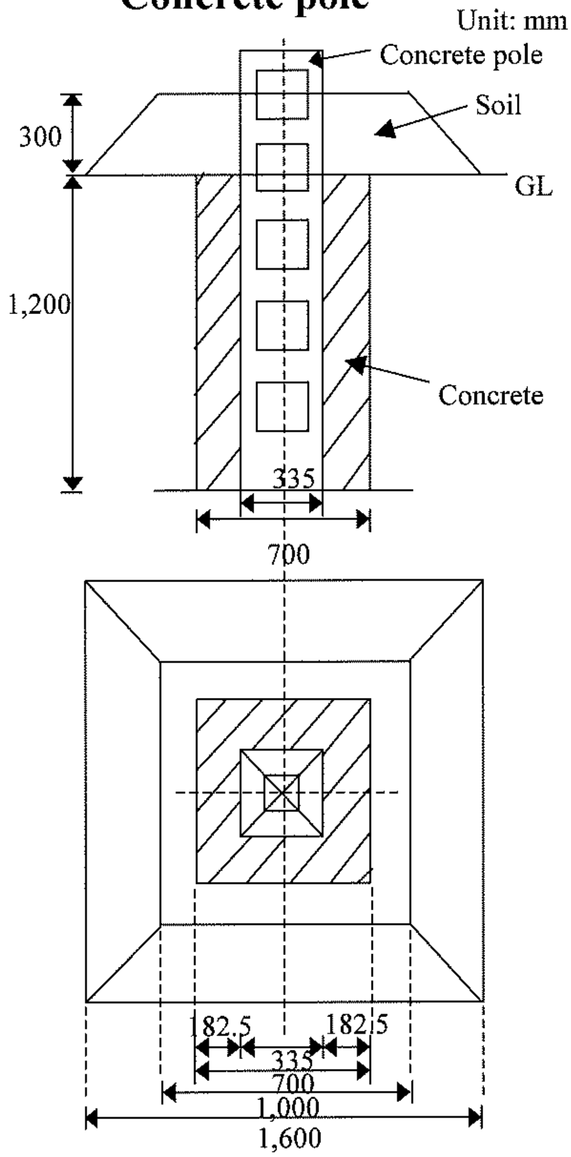
Distribution Line



Low-voltage Concrete



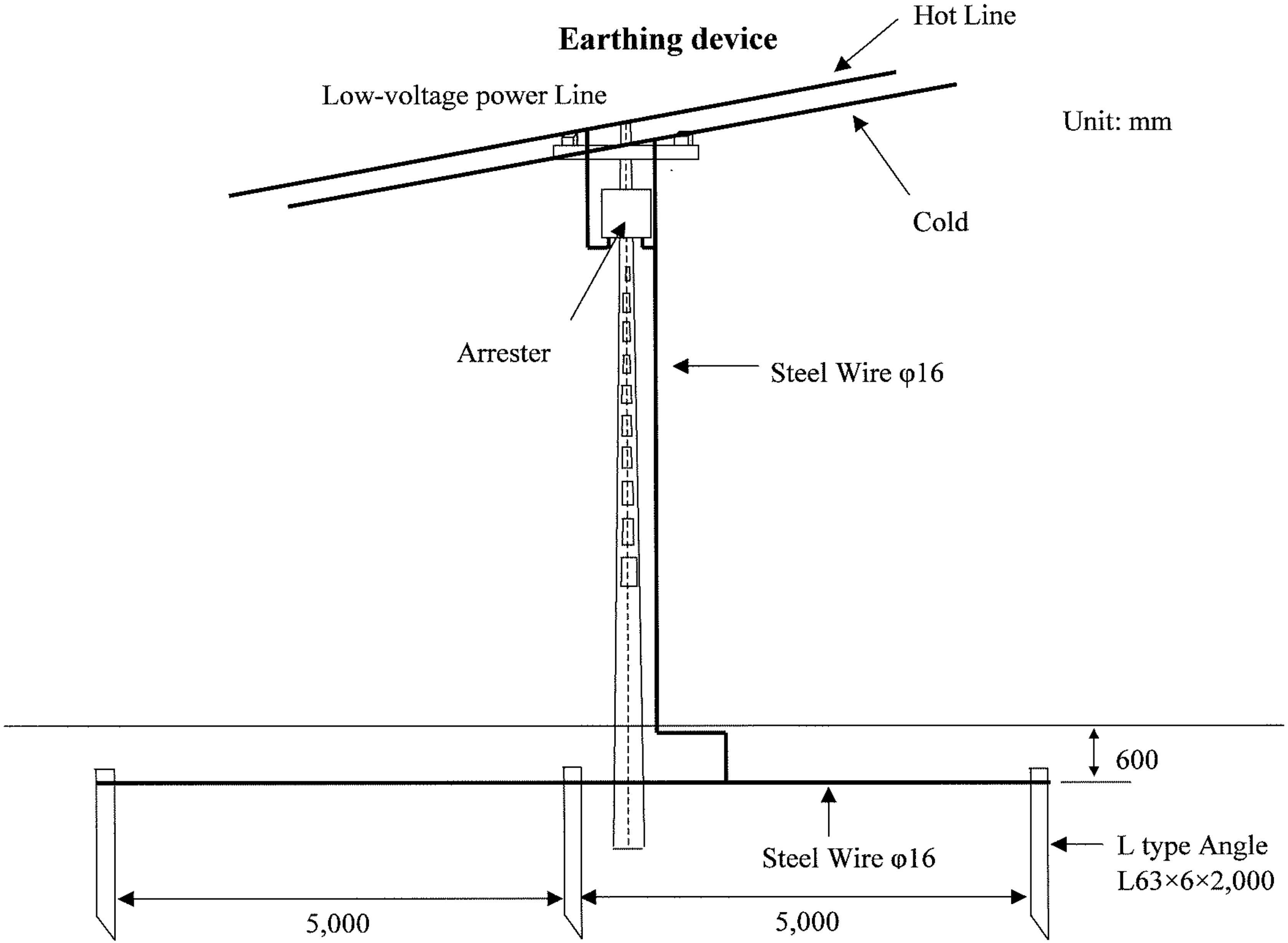
Concrete pole



Specification of Concrete pole

Item		
Type	H7.5B	H7.5C
Length (m)	7.5	7.5
Top size (Virtical×Horizontal) (m)	0.14×0.14	0.14×0.14
Bottom size (Virtical×Horizontal) (m)	0.24×0.34	0.24×0.34
Design load (kgf)	150	150
Breaking load (kgf)	380	440
Concrete volume (m3)	0.24	0.24
Concrete weight (kg)	480	480
Reinforcing bar weight (kg)	55.86	59.28
Total weight (kg)	535.86	539.28

Earthing device



Village Hydro Design Manual

for Planners

Table of Contents

Introduction

Although the national grid is being extended rapidly in the countryside of Vietnam, there are many remote villages that remain unelectrified. In those villages, people long for electricity. It is natural that the villagers in remote areas will want to have electricity after they have acquired basic infrastructures such as roads, irrigation channels and schools. Often off-grid hydropower provides an economic alternative to the grid extension. However, there have been no guidebooks on how to develop off-grid electricity supply systems, which makes the implementation of off-grid electricity projects very difficult.

This "Village Hydro Design Manual for Planners" is intended to provide basic information on the design of micro-hydro power schemes that are suitable for electrifying remote villages. We named such hydro schemes "Village Hydro". In particular, this book targets off-grid electricity planners; namely the staff of the Department of Industry of Provincial People's Committee and other related organizations. It is expected that this manual can act as a reference to help the planners to develop some projects.

Acknowledgements

This manual arose from the work of our teammate, Adam Harvey, and his book: Micro-Hydro Design Manual / IT Publications.

1. Basic Components of Village Hydro

(1) Basic Concepts

A Village Hydro is an off-grid micro-hydropower generation system that aims to supply electricity to the remote areas where the grid extension is difficult for geographical or economic reasons. A Village Hydro works as an intermediate power supply system before the grid to come. Therefore, the demand for electricity in case of a Village Hydro is usually small, limited to applications such as lights, fans, radios, battery charging, and TVs. A big difference between Village Hydro and grid extension is that in the case of Village Hydro, the daily operation and maintenance of power system is the responsibility of the users themselves, the villagers. Hence, it is necessary to develop safe and easy-to-operate designs . This is a first priority in ensuring that the power system is sustainable in rural areas. To achieve this goal, the following points are important.

1) Limit the plant capacity and supply area, and focus on simplicity of design
2) Tailor the technical design to make the operation and maintenance easy
3) Use existing irrigation facilities and local technologies
4) Use equipment and materials available in Vietnam
5) Standardize the design and components

If you develop a Village Hydro plant based on these concepts, you can reduce the costs of construction and operation. Once the plant is installed, a further important step is the training of local operators. A well-organized training program and devoted instructors are essential to the success of developing a capable village organization for a Village Hydro.

A Village Hydro often faces a difficulty of decreased output and unstable operation during the dry season, or during periods when water for irrigation is in short supply. In most villages in Vietnam, this problem is unavoidable. Some ideas are required to realize sustainable operation to supply electricity even when the water flow is not enough. It is necessary to consider how to tackle this issue even in the planning process.

（2） Standard Specifications

Figure1-1 illustrates the major components of a typical Village Hydro plant. This manual presents practical ideas on how to design and develop each component.

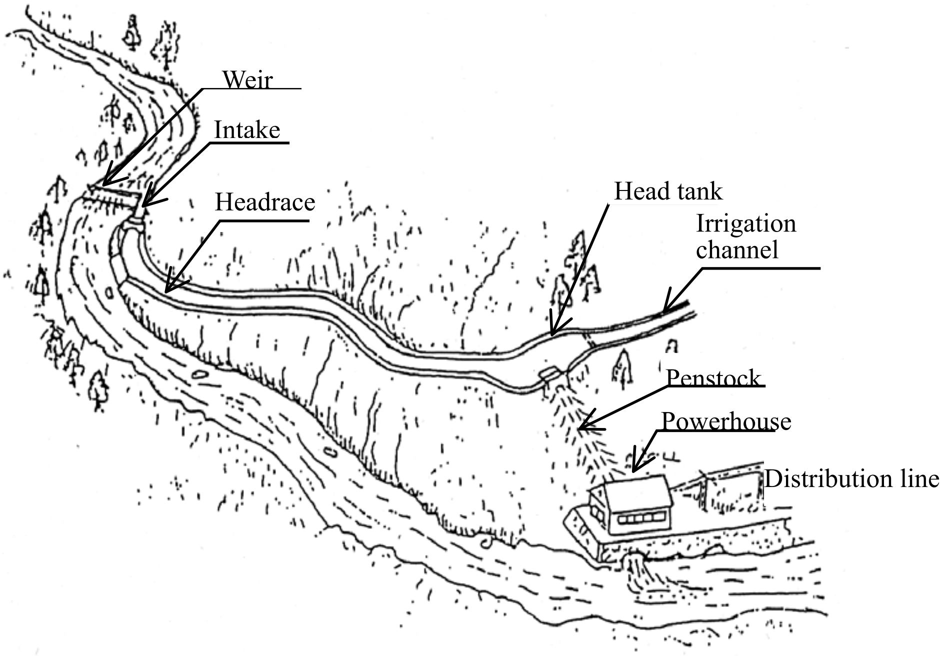
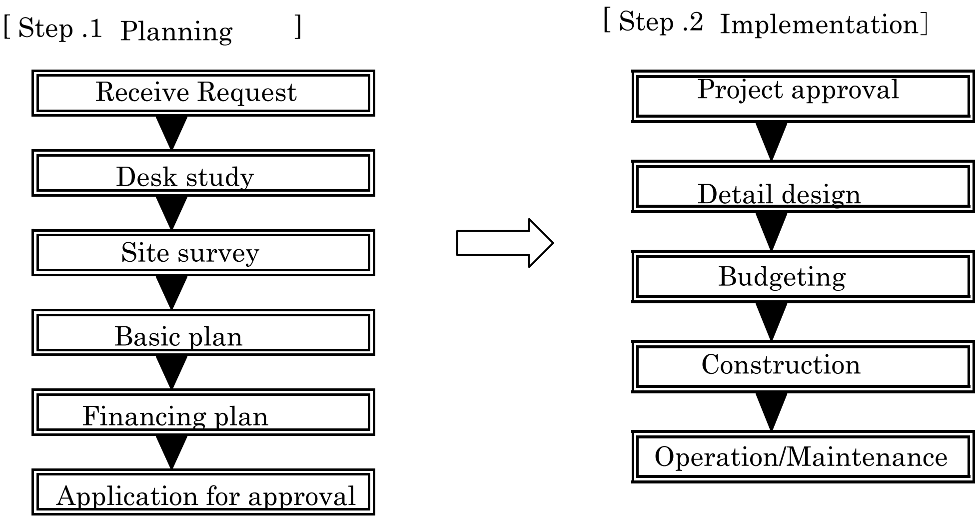


Figure 1-1 Major components of a typical Village Hydro

There will be many tasks required to develop a Village Hydro power plant. In the first stage, after receiving a request for off-grid hydropower development, the planners survey potential sites, and develop a basic plan and ask for an official approval. In the second stage, financing of the Village Hydro project is arranged, and the plant is built and the management structure is developed.



2. Site survey

2-1. Work flow

The work items in the planning phase of Village Hydro development are as follows.

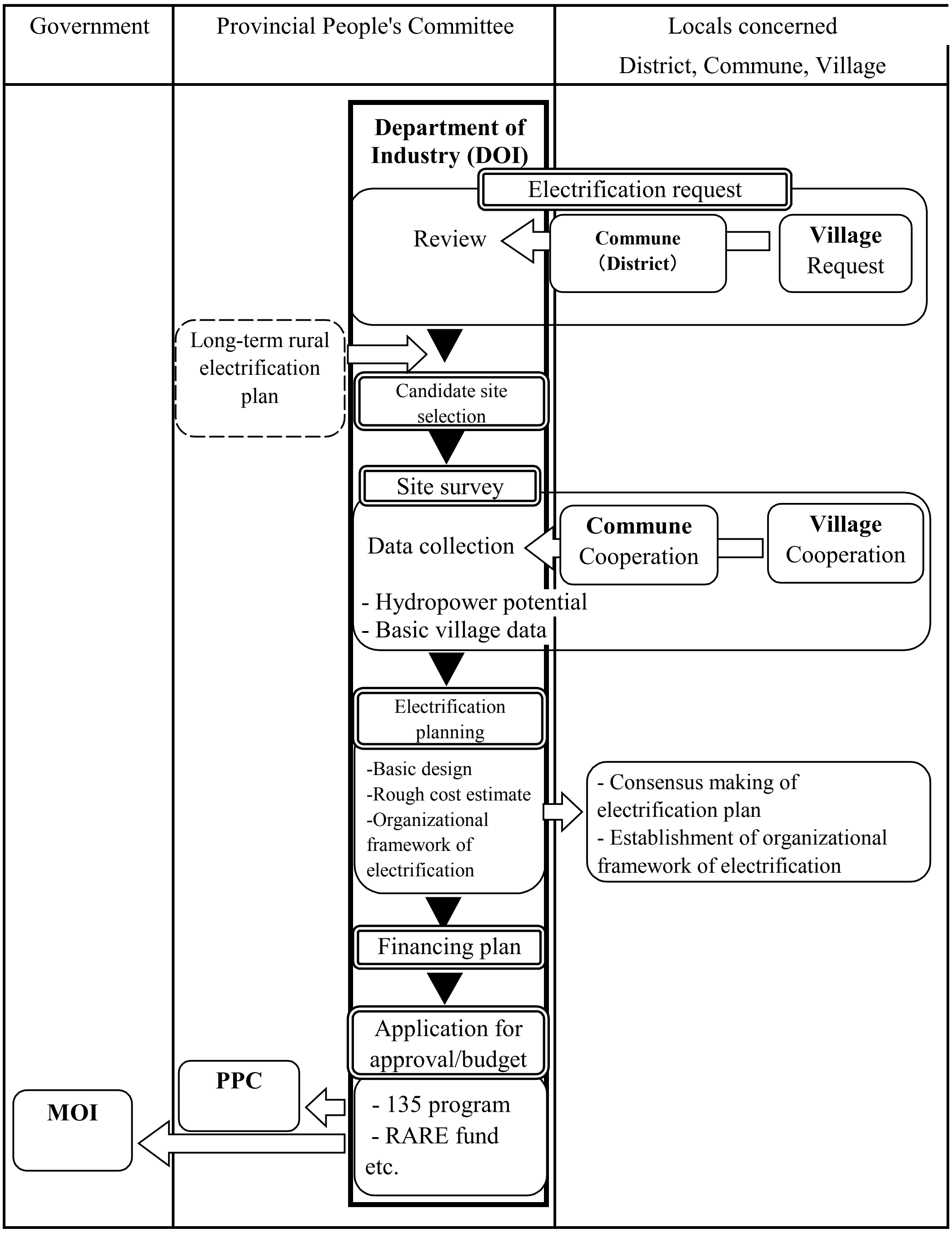


Figure 2-1 Work flow and roles of concerned organizations in the planning phase

〔1〕 Request for electrification

When a commune receives a request for Village Hydro development from an un-electrified village, it sends the request to the DOI through the district office. The target areas of Village Hydro are the villages that have high hydropower potential, enough water flow and head for power generation, all year. Accordingly, it is important for the commune to collect relevant information of hydropower potential (location, topography and water flow) before submitting the request.

〔2〕Candidate site selection

When the DOI receives the electrification request from the commune, the DOI decides whether or not the requested site is good as a candidate site of Village Hydro comparing with the grid extension plan. In this case, they should exclude those areas assessed as suitable for grid extension, even if there is no concrete grid extension plan at present.

Village Hydro can be regarded as an intermediate electrification step before the grid electrification. In this sense, it is also possible to select areas that are to be electrified by the grid more than five years later as candidates for Village Hydro development. In this case, it is important to note that the distribution cables and posts installed to supply power to village houses by the Village Hydro can be used even after the grid connection. We can therefore distinguish between the "Distribution Network" which is installed to the correct standard for grid distribution, and the Generating Station, which is replaced when grid arrives.

> [Note] It costs about $10,000/km to extend MV transmission line and about $5,000/km to extend 220V LV distribution line in mountainous areas. Meanwhile, it costs around $10,000 to build a 10kW class Village Hydro power station. (Not including distribution facilities)

〔3〕Site survey

The DOI collects detailed information on the candidate site conducting site survey. With an aim to plan a feasible micro hydro scheme, this survey should cover both hydropower potential and basic socio-economic data of the target village. It is required to conduct the survey together with the people concerned in the village and commune.

〔4〕Electrification planning

Based on the results of site survey, the DOI formulates an electrification plan that includes the following. This planning document will become necessary in the subsequent process such as application for investment capital.

① General planning: Power output, lay-out plan of facilities, electricity supply area, the number of households to be connected, etc.
② Basic design: Basic design of major facilities
③ Cost estimation for electrification: Estimation of construction cost based on the basic design
④ Management after electrification: Framework of operation and maintenance of the power system, electricity tariff, plan for major refurbishments, etc.

Management of the power plant after electrification is particularly important for the sustainable operation of Village Hydro. Accordingly, it is necessary to discuss the framework of operation and maintenance of the power plant with the villagers from the planning stage.

〔5〕Financial planning

After the electrification planning, project implementation of high priority sites will start. For this, we have to examine how to secure investment capital. For Village Hydro, it is possible to use the “135 Program”, which is a well-known infrastructure development program of GOV targeting remote communes. Also, the funds provided by foreign donors and lenders such as the World Bank can be used. The DOI will give advice as to the most suitable financing scheme. If the villagers are supposed to pay a part of the construction cost, it is necessary to discuss with them at an early stage of development planning.

2-2. Site Survey

Although the scale of Village Hydro project is small, we need to study carefully to match the power output with the electricity demand. In a site survey, as a first step of development work, basic information necessary for planning must be collected. Namely, we need to know the hydropower potential such as water flow and head, and the profile of village such as the number and location of households, existing irrigation facilities and economic condition of villagers. （See Table 2-1） In this stage, we need to focus on basic information for electrification planning, and detailed survey and examination is not necessarily required. We will continue to survey more in detail later on.

Table 2-1 Contents of site survey

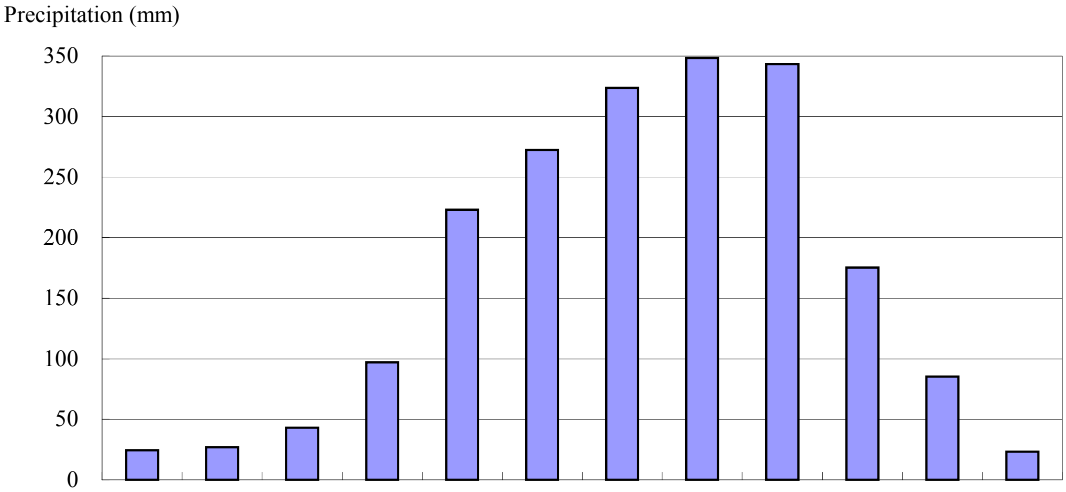
Item	Contents of survey
(1) Hydropower potential	
a． Water volume	Water volume in dry season is important
b． Channel route	Location and shape of intake, headrace route
c． Sites for head tank and powerhouse	Location, ground condition of head tank and powerhouse
d． Head	Vertical drop between the sites of head tank and powerhouse
e． Existing irrigation facilities	Location and status of use
f． Flood water level in the past	Relevance to the sites of facilities （particularly the location of powerhouse）
(2) Socio-economic data	
a． Grid	Grid extension plan, distance from the existing grid
b． Access to village	Road condition
c． Households	Number, location
d． Organization and cash income	
e． Pico-hydro and battery use	Number of users, appliances
f． Eagerness of villagers for electrification	

（1） Hydropower potential survey

a. Flow Survey

① Seasonal changes in water flow

In northern Vietnam, there is a big difference in precipitation between the dry season and the rainy season. Since Village Hydro is an off-grid power supply system, it is desirable to use the minimum water flow in the dry season as the design flow to ensure stable power generation throughout the year. However, in mountainous villages where their catchment area is generally small, the volume of water flow in the dry season is usually not enough. Therefore, Village Hydro plans in many cases must be developed based on the condition that securing sufficient power generation in the dry season is difficult. We need to make a compromise. In this case, it is required to consider additional measures to increase power output, or to restrict power consumption. The graph below shows the monthly precipitation in LacSon district, HoaBinh Province as a reference.



Season	Dry				Rainy						Dry		Total
Month	1	2	3	4	5	6	7	8	9	10	11	12	
Rainfall	24.5	27.0	43.1	97.1	223.2	272.5	323.6	348.5	343.3	175.4	85.3	23.3	1,986.8
Irrigation	No	Yes								No			

Source: Institute of Energy

Figure 2-2 Monthly precipitation in LacSon district, HoaBinh Province

② Flow measurement

Measuring the water flow is the first step of Village Hydro development. The precipitation varies with season in northern Vietnam, so does the water flow. Therefore, it is important to measure the low water flow that is critical to the stability of power supply. The Bucket method (See Figure 2-3) is a simple way to measure water flow in case of small water volume. The whole flow to be measured is diverted into a container(s) and the time it takes for the container(s) to fill is recorded. It is possible to get accurate water flow data by this method.

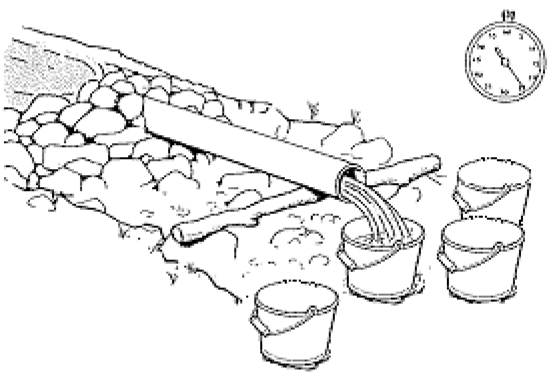


Figure 2-3 Bucket method

Another method, recommendable for channel flows, is the Float method (See Figure 2-4) to estimate water flow volume by measuring the time of a float passing over a measured distance, and the cross-sectional area of waterway. The surface velocity is reduced by a correlation factor, which depends on the characteristics of the stream – it varies from 0.4 for shallow streams to 0.8 for water deeper than 0.5m, With this Float method, errors can be big, and the method must be used with care. If the stream cross-sectional areas are not constant, averaging of A is necessary.

$$Q = Vave \times A = F \times Vs \times A$$

Q : Water volume(m^3/s), A : Underwater cross-sectional area(m^2)

Vs : Surface velocity(m/s), Vave : Average velocity(m/s)

F : Correlation factor , use 0.8 for deep water; more than 0.5m, and 0.4 for very shallow; otherwise 0.6

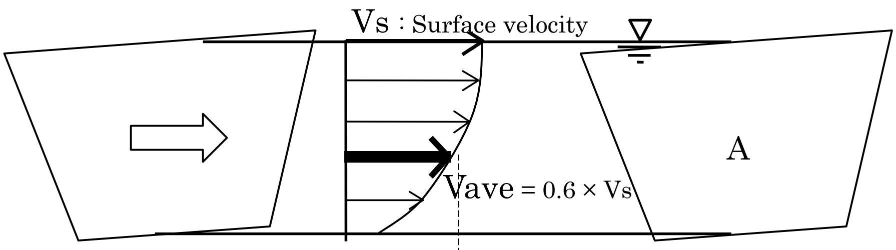


Figure 2-4 Float method

③ Head survey

The vertical distance between the sites of head tank and powerhouse is measured to obtain the value of the "head". The measurement method with a hand-level is desirable.(See Figure 2-5) This method can be very accurate if used by an experienced person.

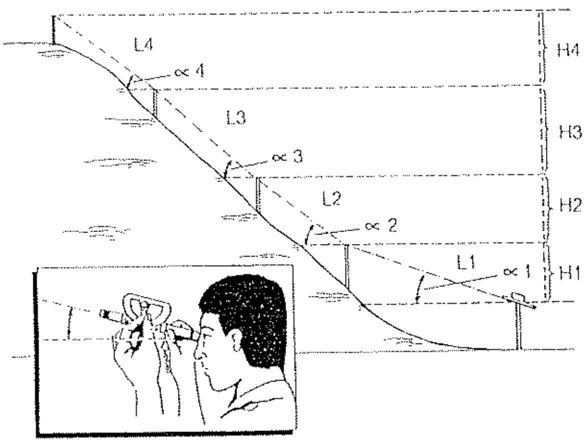


Figure 2-5 Head measurement with a hand level

If a hand level is not available, a simple method should be used to get reasonably accurate data. One example of such simple methods is to use a straight rod and level gauge. We repeat the same measurement process along the slope. （See Figure 2-6）

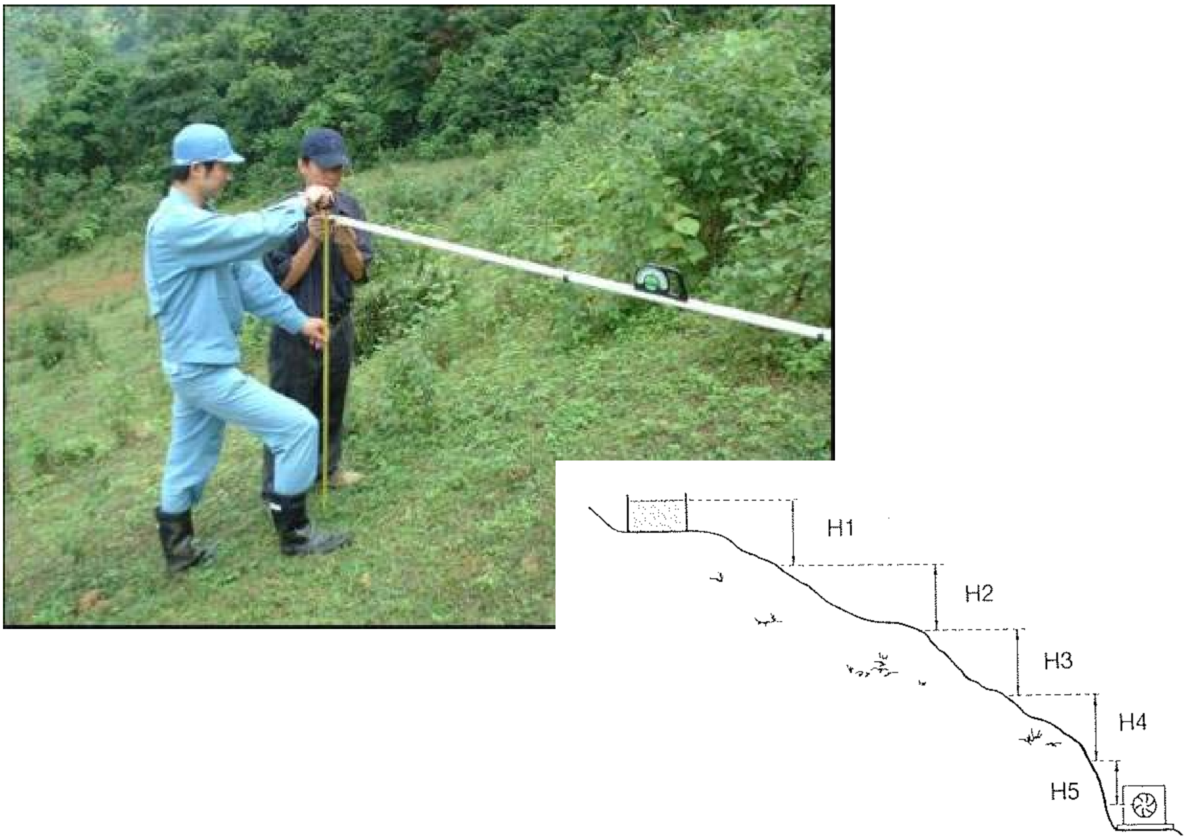


Figure 2-6 A simple head measurement method

Approximate power generation output can be calculated with the figures of water volume and head, using the following formula.

$$P = 5 \times Q \times H$$

P : Hydropower potential(kW) = Power generation output

Q : Water volume (m^3/s)

H : Head (m) = Vertical drop between head tank and powerhouse

Calculation example Water volume 50 l/sec = 0.05 m^3/sec

Head 30m

Power output $= 5 \times 0.05 \times 30 =$ 7.5 kW

b. Other survey items

① Channel route

Basically, water volume available for Village Hydro is small. It is recommended to follow local practice when you plan to take water from the river and to ensure the water running safely and smoothly. If irrigation channels already exist, their renovation should be considered to use the channels for power generation as well.

② Location of head tank and powerhouse

A head tank and a powerhouse must be built on the flat and firm ground. In addition, the condition and stability of the slope between head tank and powerhouse for laying a penstock should be studied. Often, vehicles cannot reach the powerhouse site. It is necessary to consider how to transport materials and equipment to the powerhouse.

③ Irrigation system

Information on irrigation facilities provides a good reference about hydropower potential in the village. Often Village Hydro channels are integrated with irrigation channels. It is necessary to take into account how to secure irrigation for farming when you plan a Village Hydro scheme.

④ Flood water level

The flood water level ever recorded is important to decide the location of powerhouse. We can get relevant information on floodwater in the past by interviewing the elderly in the village. The powerhouse must be built with a margin above the flood water level to protect the electro-mechanical equipment from flooding damage, and to ensure that a rise in tailwater does not reduce the power generating head.

（2） Socio-economic data

a. Grid

Village Hydro is applied to villages that have no grid extension plans. Grid systems, existing or planned, near the target village must be surveyed to evaluate the economic viability of Village Hydro.

b. Access to village

Transportation to the village is an important factor that affects the construction method and cost. We need to check the availability of roads for trucks.

c. Households

The number of houses in the village forms a basis for necessary power output. Since the distribution system of Village Hydro is based on low voltage (220V), the length of distribution lines is limited. We need to survey hamlets where houses are clustered and to measure the approximate distances between two hamlets. This information is important when we decide the power supply area and the required power output.

d. Other survey items

① Organization and cash income

It is necessary to establish an organization within the village to manage a Village Hydro plant. Any information about village level organizations is relevant to assess the capability of villagers to manage Village Hydro. Also, we need to survey whether or not the villagers can afford electricity bills and connection charges. For this reason, it is necessary to get information about their cash income and spending. This information gives an idea on how many people will apply for electricity supply by Village Hydro.

② Pico hydro and battery use

Often, low cost Pico-hydro units or car batteries are widely used in un-electrified villages. Penetration of these units into the village must be investigated because such information provides concrete ideas on how much demand we need to consider in the Village Hydro planning.

③ Eagerness of villagers for electrification

Village Hydro must be operated and managed by the villagers for many years. To achieve this, we need to confirm that they have strong eagerness for the operation, maintenance and management of Village Hydro.

(3) Mapping of village

A basic electrification plan, physical layout of components in particular, must be prepared in consideration of the data collected in the site survey. It is useful to draw a map of the village and put key information, streams, hamlets, roads and irrigation channels for example, on the map when you examine various plans of Village Hydro development. (See Figure 2-7)

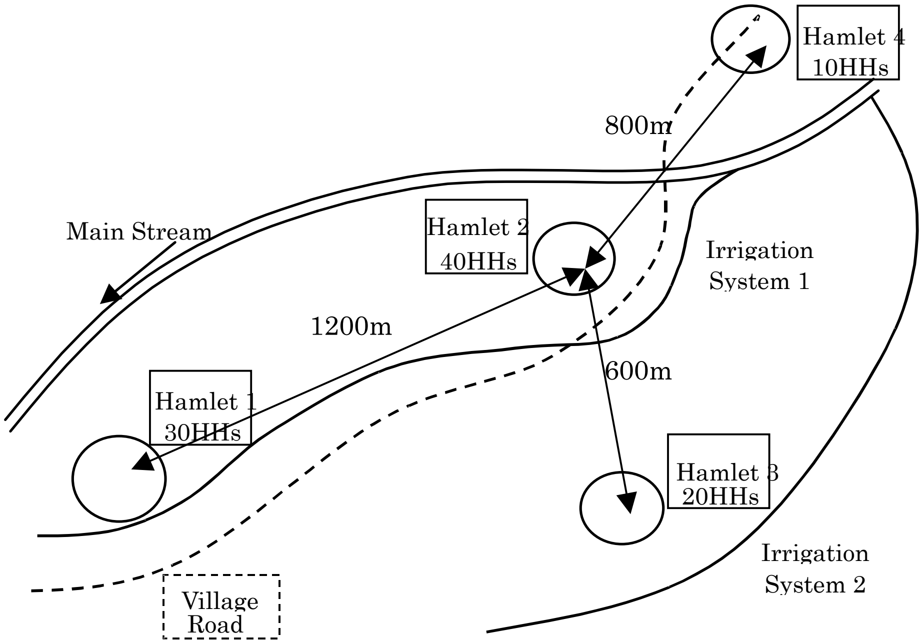


Figure 2-7 An example of village map

2-3. Planning of Electricity Supply

(1) Assessment of firm output

First, it is necessary to evaluate how much power output from the low water flow(=Q_0), the firm output (=P_0), can be secured in the dry season. The firm output can be calculated by the formula, $P = 5 \times Q \times H$. And the value of P_0 should be compared with the estimated demand in the village to assess the possibility of achieving stable electricity supply throughout the year.

(2) Balancing electricity demand and supply

The unit power demand per household used in this calculation is 70W. This corresponds to the average power consumption of a household in the villages where TVs are popular. If the target village is not rich and most households will use only lighting, use 40W instead of 70W. We need to check whether or not the firm output (P_0) meets the total demand.

$$P_0(\text{kW}) - \Sigma 0.07 \times n(\text{kW}) > 0 \quad \text{or} \quad P_0(\text{kW}) - \Sigma 0.04 \times n(\text{kW}) > 0$$

Where, P_0 : Firm output (dry season) (kW)

n: number of households

Example Q_0 50 l/sec = 0.05 m^3/sec

H 30m

$P_0 = 5 \times 0.05 \times 30 = \underline{7.5\ kW}$

n: Number of households 100

D: Electricity demand 0.07(kW)×100=<u>7kW</u>

$P_0 - D = 7.5 - 7.0 = 0.5 > 0$

It is desirable to find a good site where we can get enough power output even in the dry season. However, we need to understand that at many hydropower stations the shortage of power in the dry season happens in Vietnam. In this case, we need to consider appropriate measures to cope with this problem.

(Measures to increase power output)

- Build a reservoir to collect water when turbine not in use, and to discharge more water during peak demand hours
- Install a diesel generator as an auxiliary power source for use in the dry season

(Measures to control or decrease electricity demand)

- Switch from incandescent lamps to fluorescent lights
- Restriction of power consumption during peak hours
- Planned power outage in some areas
- Drop some households from the supply area

We need to obtain an agreement from the villagers regarding the implementation of demand restriction measures.

If supplying electricity to meet the demand of villagers in the dry season seems possible with additional measures, then, we need to decide the value of the maximum output (Pmax) in the rainy season. In the rainy season, we can use more water and, therefore, we can increase power output. The components of Village Hydro are designed based on the value of Pmax. However, we cannot increase the maximum output too much, because the plant efficiency goes down significantly when running at part-flow. With this problem, the plant operation in the dry season becomes more difficult if the design water flow is too big. The rule of thumb is Pmax should not exceed the tripled value of P_0.

$P_{max} / P_0 < 3$

Where, Pmax: Maximum output (kW)、 P_0: Firm output (kW)

A flow chart of the above-mentioned power output analysis process is shown below.

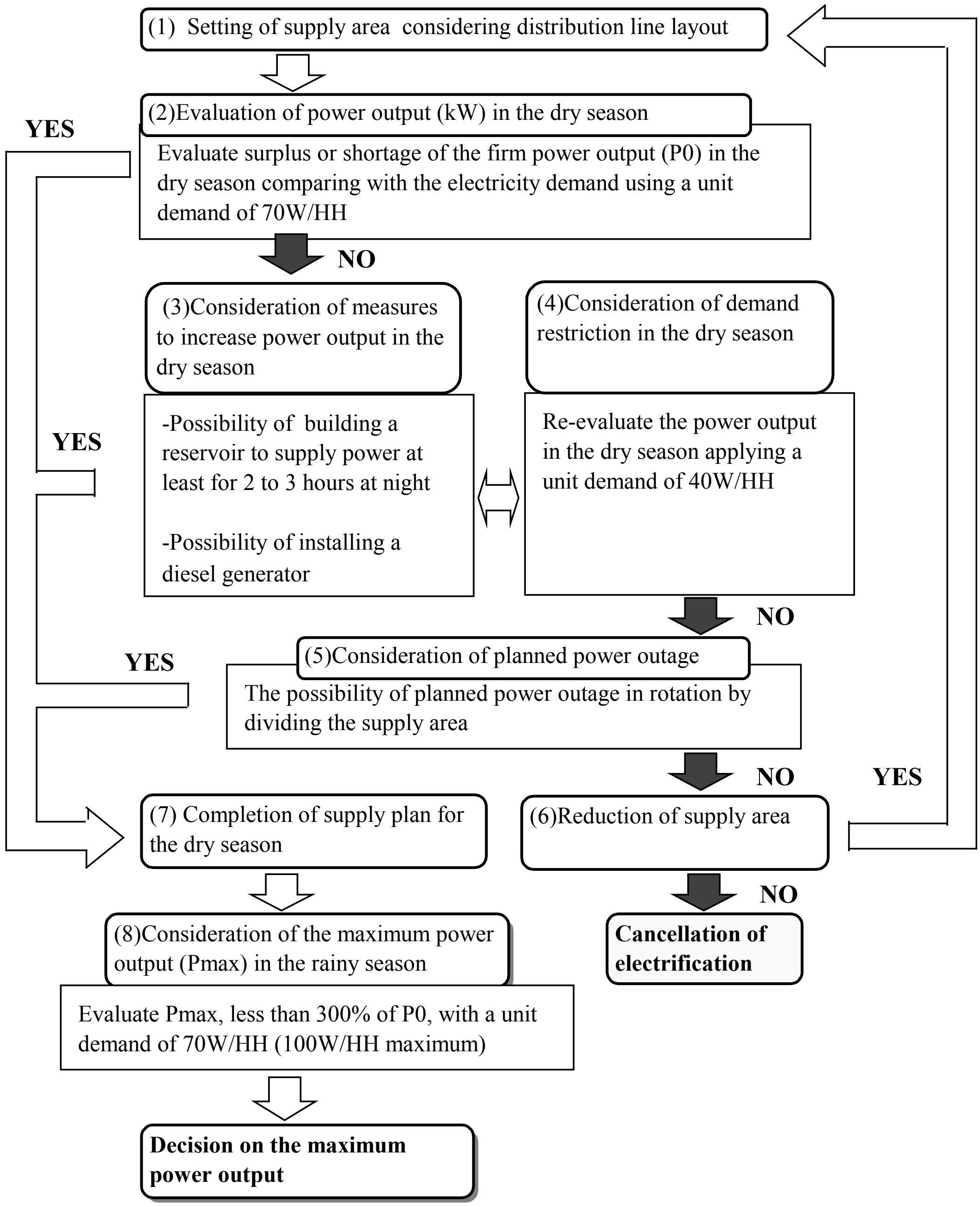


Figure 2-8 Flow chart on power output design

(3) Deciding the supply area

Village Hydro uses 220V low-voltage distribution lines, in which substantial voltage drop occurs in a relatively short distance. Sometimes, it is difficult to supply electricity to the far end households above the minimum voltage. Roughly speaking, the supply area may be limited to an area of 2 km radius of the powerhouse in case of a 10 kW Village Hydro. Another reason for not extending distribution lines long is cost effectiveness. Drawing a long-distance distribution line to connect few households cannot be justified. Thus, we need to understand that the supply area of Village Hydro is often limited, and some households in the village may not be connected. It is important to mention this point to the villagers at the early stage of Village Hydro planning.

The following is an example of dropping one hamlet from the supply area. The Hamlet 4 cannot be connected due to a large voltage drop. However, we can provide battery charging service to the villagers in Hamlet 4.

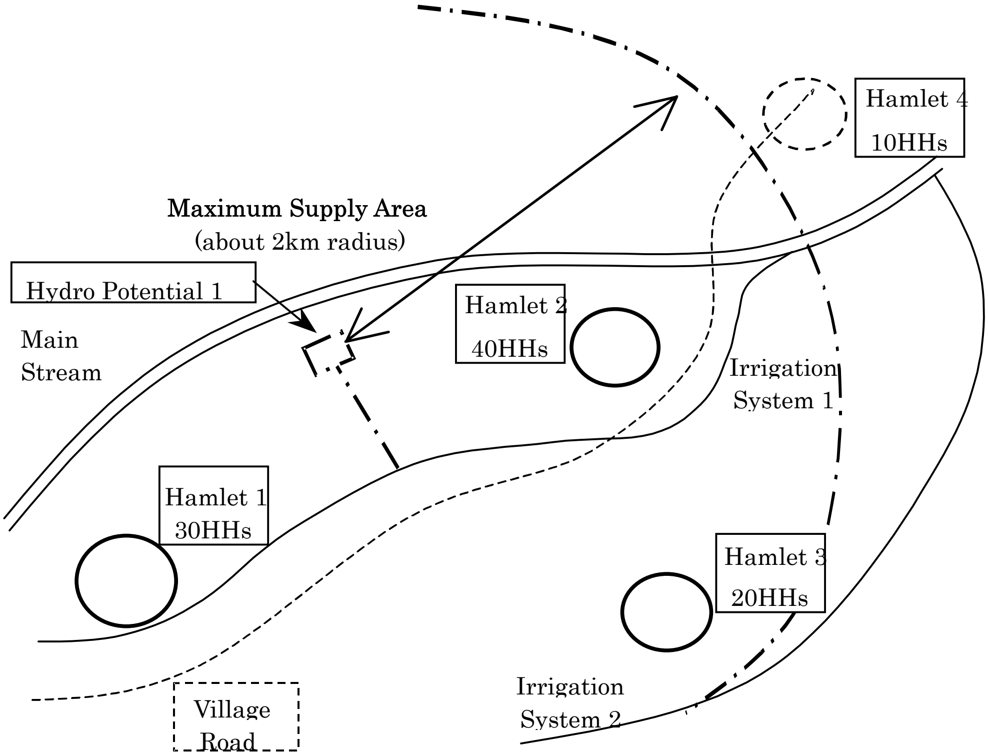


Figure 2-9 An example of limited supply area

3. Design Work

3-1. Work flow

The work items in the implementation phase of Village Hydro development are as follows.

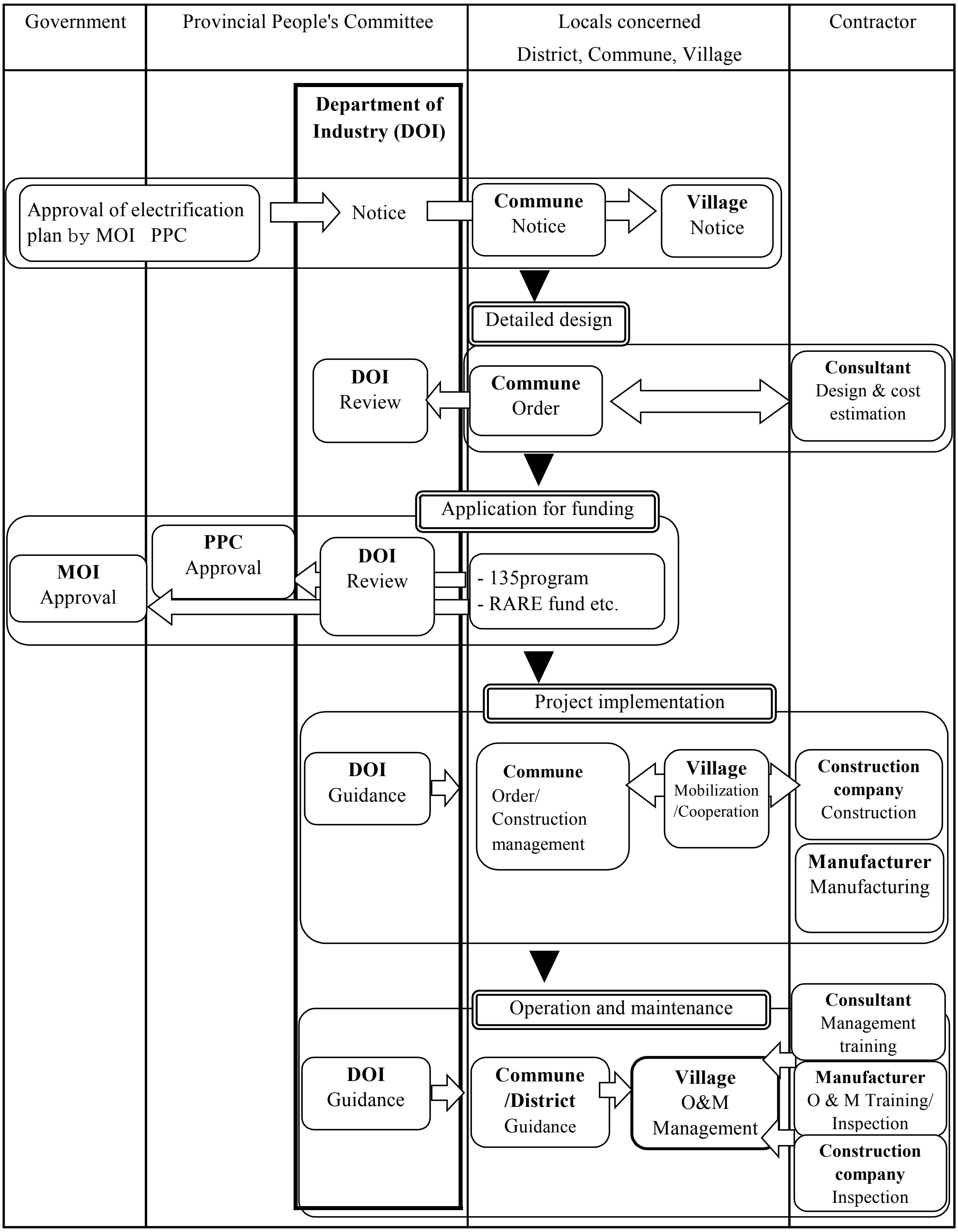


Figure 3-1 Work flow and roles of concerned organizations in the implementation phase

〔1〕**Detail Design**

After our Village Hydro plan is approved by the authorities, we go into the implementation phase. The commune where the target village is located places an order for detailed design work to a consultant. The consultant conducts detailed design of Village Hydro components and also estimation of the project cost. It is important to select a consultant that has experience in micro hydropower schemes, because special knowledge and expertise are required for the design of electro-mechanical equipment.

〔2〕**Application for permission**

When an estimate of construction cost is obtained after the detail designing, the commune applies for a permission for the Village Hydro project and an arrangement for the investment capital to the DOI. The DOI carries out a technical review on the detail design and make necessary arrangements for project financing. When the technical review is finished and the financing is completed, the DOI issues permission for the Village Hydro project.

〔3〕**Implementation of project**

Based on the approved budget, the commune in consultation with the consultant selects a contractor to construct the Village Hydro plant. It is important that the villagers are involved in the construction work and carry out the renovation of irrigation facilities. Also, many villagers will be hired as paid workers. Therefore, the construction period should be coordinated with the annual farming timetable in the village.

〔4〕**Training on operation & maintenance**

Operating a Village Hydro plant is a first-time experience of the villagers. Since there are a lot of tasks necessary for properly operating and maintaining the power plant, it is important to give detailed instructions to the villagers by providing training courses and documentation. The villagers cannot master necessary skills unless they receive good instructions and formal hands-on training from the designers, manufacturers and contractors. If the instructions and training given to the villagers are insufficient, they are ignorant and easily cause disastrous problems. The power plant may be stopped for a long time. To avoid this, preparation of a complete set of O&M documents and provision of proper training courses and spare parts should be a part of the construction contract. The DOI should pay full attention to this point.

3-2. Civil structures

In order to simplify the design process of Village Hydro's civil structures, standardization is important.

Table 3-1 Standard civil structures of Village Hydro

Structure	Standard Materials, construction method	Note
Weir	Local technology	Usually combined with irrigation system
Intake	Local technology	Usually combined with irrigation system
Silt basin	Brick masonry with mortar	
Headrace	Unlined or brick masonry with mortar	Usually combined with irrigation system
Reservoir	Storage pond (existing)	If water flow in the dry season is low
Head tank	Reinforced concrete	
Penstock	PVC pipe (high pressure type) or steel pipe	PVC pipe up to 60m head
Powerhouse	Reinforced concrete (foundation) Fiber-concrete (roof) Brick masonry with mortar (wall)	
Tailrace	Brick masonry with mortar	

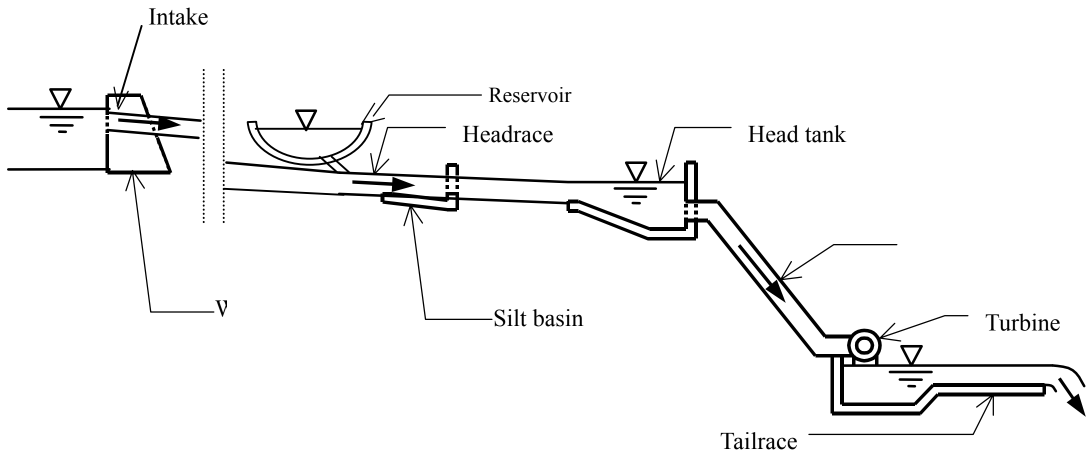


Figure 3-2 Civil structures of Village Hydro

In Vietnam, farming rice fields is widely performed even in the mountainous areas. Hence, it is expected that we can utilize local technology on irrigation and existing irrigation structures for Village Hydro development to save costs and to achieve sustainability.

a. Weir and intake

In designing a weir and an intake, both necessary structures to take water from the stream, we need to consider how to use the natural features of the river such as the course of river and conditions of riverbed as much as possible. Also, it is important to use local practice in building the structures, so that the villagers can easily repair or rebuild the structures if they are damaged by flood flows. Often the villagers are requested to renovate existing irrigation facilities to accommodate Village Hydro.

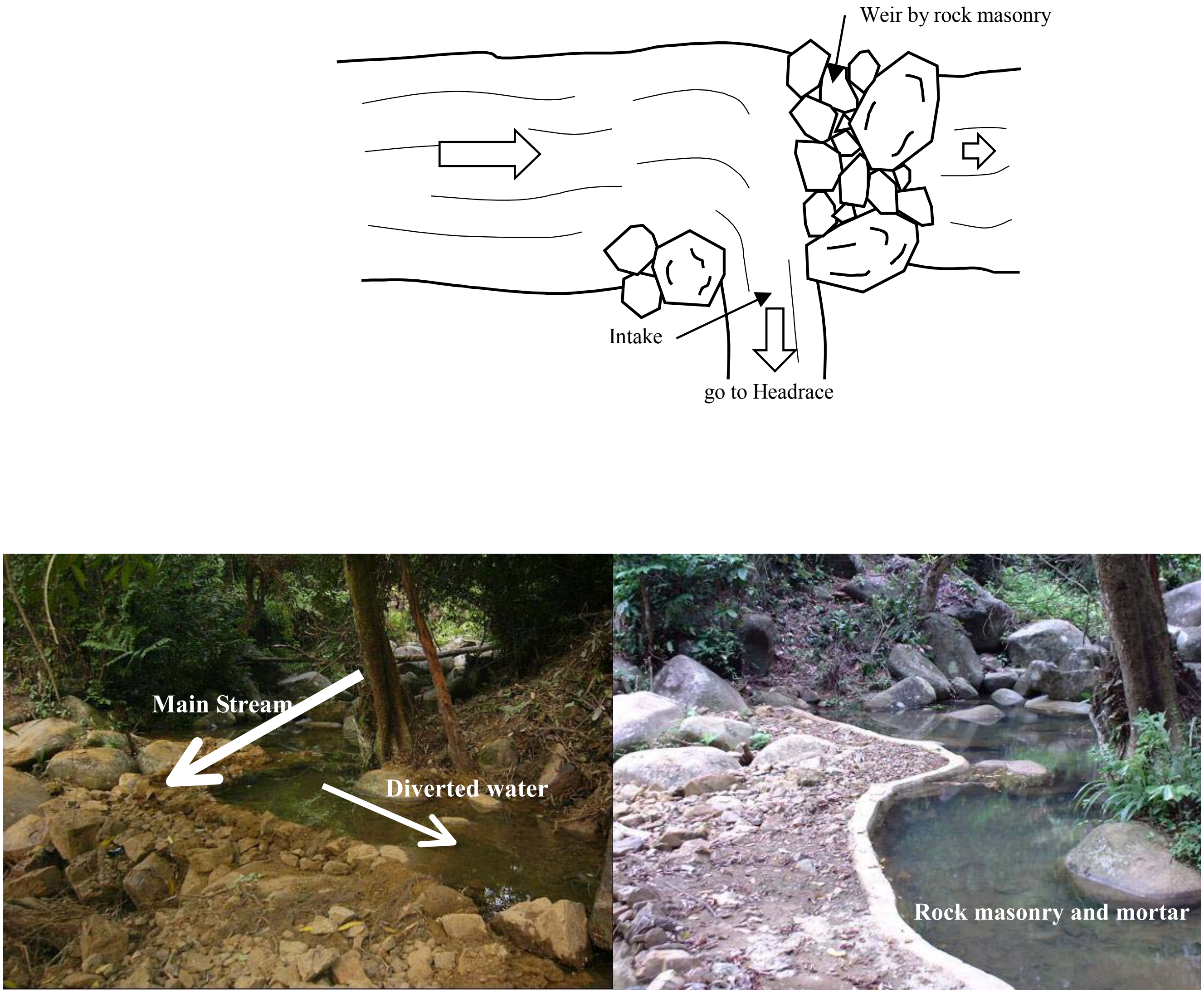


Figure 3-3 A weir and intake constructed by local technology

A weir is a structure built for raising and maintaining the water level of river above the intake mouth. The people of the target village where terraced rice fields spread out are familiar with the construction and maintenance of irrigation facilities. They have skills and experience. If the weir and intake are damaged by flood flows, the villagers will repair them quickly. This is an important point in achieving sustainability of Village Hydro.

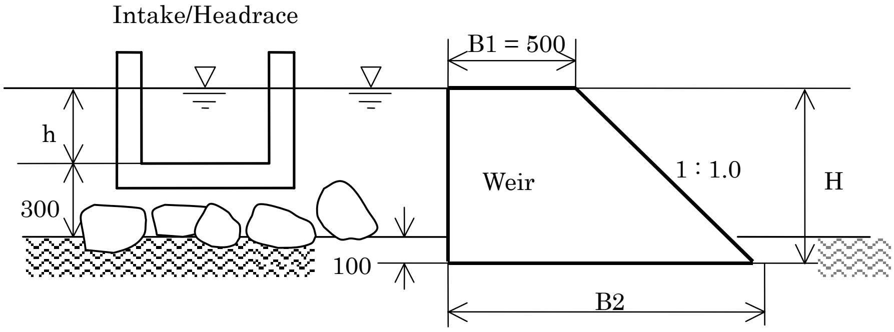


Figure 3-4 An example of weir and intake mouth layuout

Table 3-2 Dimensions of weir

Headrace depth h (m)	Weir height H (m)	Crest width B1 (m)	Width of weir bottom B2 (m)
0.20	0.60	0.50	1.10
0.30	0.70		1.20
0.40	0.80		1.30
0.50	0.90		1.40
0.60	1.00		1.50

An intake has a function of regulating the water inflow to the channel. Moreover, it needs to limit the flow into the channel within a reasonable range when the river in high flow.

Figure 3-5 An orifice at intake to control the water flow

b. Silt basin

The suspended sand in the water flow settles inside the channel and causes damage to the turbine runner. It is necessary to settle out and to remove the sand by building a silt basin.

The water flow must be slowed in silt basins where length and width are large enough. The suspended sand settles on the basin floor. In Village Hydro, it often happens that high silt load water will flow in from the sidewalls of channels in the rainy season. Therefore, it is better to build a silt basin at the end of channel, or at the head tank. If the silt load is high, it is recommended to have another silt basin in the middle of channel to reduce the amount of silt settling in the head tank. It is appropriate to use brick masonry and mortar for silt basin.

To design a silt basin, the length of the basin is calculated by the following equation.

L = （D × V）/Vg = Q/(Vg × W)

Where, L: Required length〔m〕

D: Depth of upper basin〔m〕

Vg: Falling speed of sand〔m/s〕 → 0.05m/sec (assumed)

V: Average flow speed〔m/s〕

W: Width of basin〔m〕

The assumed falling speed of 0.05m/s corresponds to the particle size of 0.5mm. The lower half of the silt basin where the sand settles out needs to be 20 to 30 cm deep.

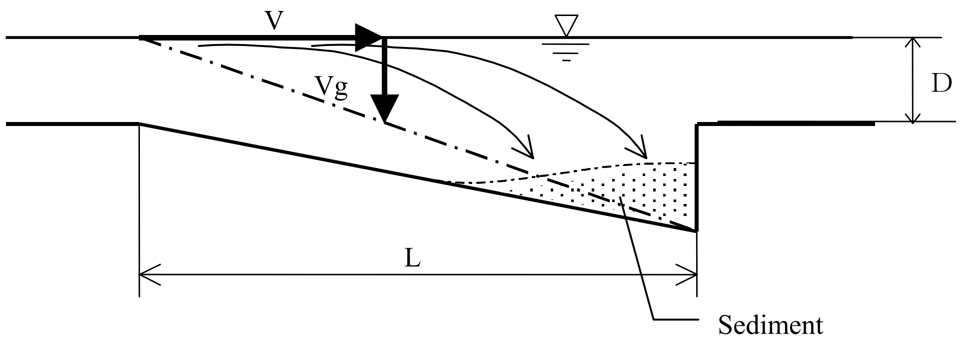


Figure 3-6 Required length of silt basin

Table 3-3 Dimensions of silt basin

Water Flow Q (m^3/s) \ Silt Basin Length (m) / Width (m)	0.80	1.00	1.20	1.40	1.60
0.01					
0.02					
0.03					
0.04	1.00		L (m) > W(m)		
0.05		1.00			
0.06	1.50				
0.07		1.50			
0.08	2.00				
0.09			1.50		
0.10	2.50	2.00		1.50	
0.11					
0.12	3.00	2.50	2.00		
0.13					
0.14				2.00	
0.15		3.00	2.50		
0.16					2.00
0.17				2.50	
0.18			3.00		
0.19					
0.20				3.00	2.50

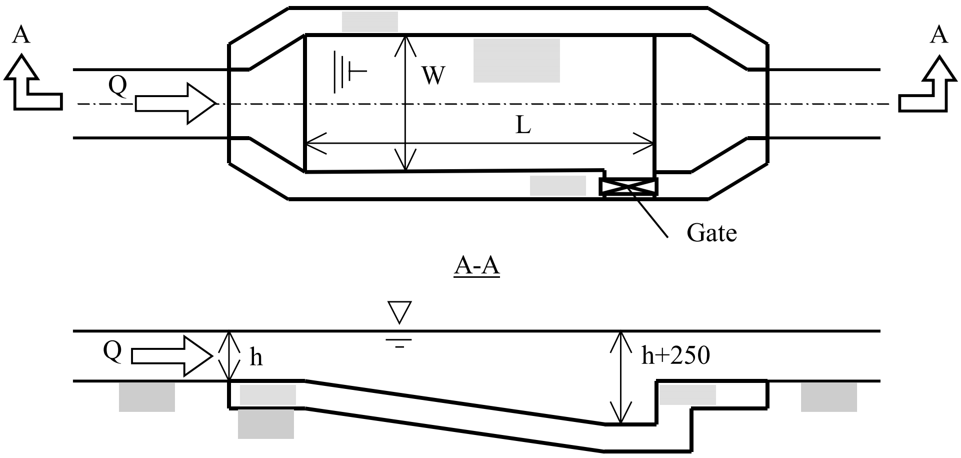


Figure 3-7 Cross section of a silt basin

c. Reservoir

When the water flow is not enough in the dry season, building reservoirs using existing water storage ponds to add more water during peak hours might be effective.

There may be many variations how to use storage ponds in Village Hydro development. (See Figure 3-8) We need to make sure that the use of storage ponds would not interfere with the original purpose of building the ponds, such as irrigation or fish farming.

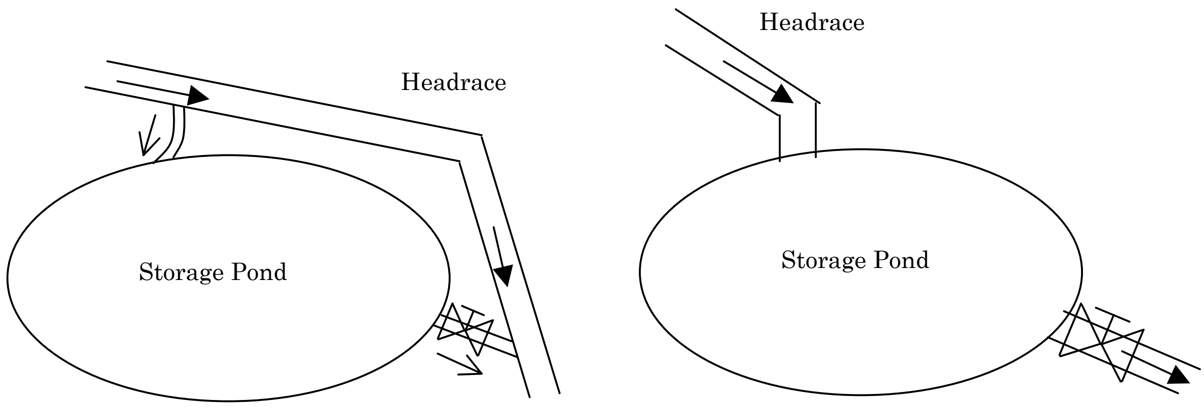


Figure 3-8 Connection of channels with a storage pond

To control the water flow from the reservoir, we need to install a discharging valve or gate. (See Figure 3-9) A common local technology like a sluice valve jointed with steel pipes would be suitable.

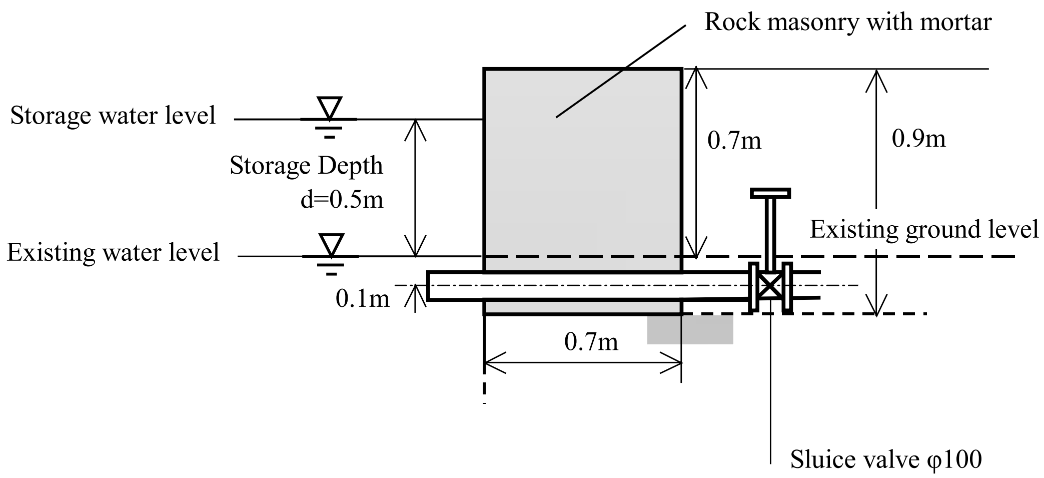


Figure 3-9 An example of discharging equipment

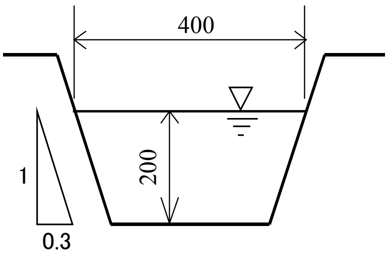
d. Headrace

In Village Hydro development, we use, and often renovate, existing irrigation channels as much as possible.

In case of no-lining open channels, water leakage is a significant problem. If the detected leakage is excessive, some measures such as filling clay as sealant, or building lined channels must be taken. The headrace may be damaged by rock-falls or landslips, but the villagers are used to these problems and they can easily repair it.

When you need to build a new channel, a structure of masonry and mortar would be suitable when the water volume is small. Finishing with mortar improves the coefficient of roughness. The dimensions of channel can be calculated using Table 3-4. This table shows the design data of water depth by a 10cm interval.

Figure 3-10 A no-lining channel (left) and a brick masonry (mortar finish) channel (right)



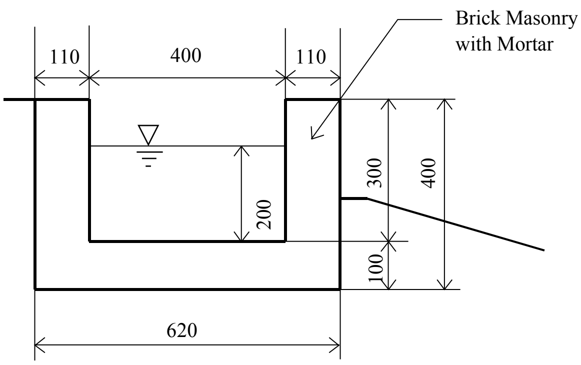


Figure 3-11 Cross section of no-lining channel (left) and brick masonry channel (right)

Table 3-4 Dimensions of channel

① Water slope = 1/250

		No-lining channel										Concrete channel				
Slope: i		1 : 0.6					1 : 0.3					Vertical				
Width of water surface: W (m)		0.40	0.60	0.80	1.00	1.20	0.40	0.60	0.80	1.00	1.20	0.40	0.60	0.80	1.00	1.20
	0.01			Water depth												
	0.02	0.20			H = 0.10 (m)				H = 0.10 (m)					H = 0.10 (m)		
	0.03															
	0.04						0.30									
	0.05		0.30				0.40									
	0.06				0.20		0.50									
	0.07		0.40					0.30		0.20						
	0.08											0.30				
	0.09															
	0.10							0.40						0.20		
	0.11															
	0.12															
Water volume Q (m^3/s)	0.13			0.40	0.30			0.50				0.40				
	0.14									0.30						
	0.15			0.50				0.60								
	0.16															
	0.17			0.60												
	0.18											0.50				
	0.19															
	0.20															
	0.22				0.40				0.50	0.40		0.60	0.40	0.30		
	0.24				0.50											
	0.26								0.60							
	0.28				0.60											
	0.30									0.50			0.50	0.40		

Note: Grey cells indicate that the flow velocity is less than 0.3m/s

② Water slope = 1/500

		No-lining channel										Concrete channel				
Slope: i		1 : 0.6					1 : 0.3					Vertical				
Width of water surface: W (m)		0.40	0.60	0.80	1.00	1.20	0.40	0.60	0.80	1.00	1.20	0.40	0.60	0.80	1.00	1.20
	0.01	0.20		Water depth												
	0.02				H = 0.10 (m)					H = 0.10 (m)				H = 0.10 (m)		
	0.03						0.30									
	0.04		0.30				0.50									
	0.05		0.40		0.20					0.20						
	0.06											0.30		0.20		
	0.07							0.40								
	0.08															
	0.09			0.40	0.30			0.50				0.40				
	0.10									0.30						
	0.11			0.50				0.60	0.40							
Water volume Q (m^3/s)	0.12											0.50				
	0.13				0.40											
	0.14															
	0.15								0.50							
	0.16											0.60	0.40	0.30		
	0.17				0.50											
	0.18					0.40				0.40						
	0.19								0.60							
	0.20				0.60											
	0.22									0.50			0.50			
	0.24					0.50										
	0.26									0.60						
	0.28					0.60					0.50		0.60		0.40	
	0.30													0.50		

Note: Grey cells indicate that the flow velocity is less than 0.3m/s

e. Head tank

<u>A head tank, or a forebay tank, removes sand and rubbish, and allows the water to enter the penstock smoothly. When the turbine is shut down, the head tank lets the water flow into the spillway safely.</u>

Since a typical head tank of Village Hydro is sized more than one-meter deep and needs structural strength, reinforced concrete is suitable. Usually the head tank is combined with a silt basin located before the entrance to the penstock. The length and width the silt basin must be large enough to make the water flow slow. To slow down the water flow is also important to catch floating rubbish securely. The length of head tank should be determined based on the same method for silt basin. The mouth of penstock should be placed below the water level by more than a diameter of penstock, and above the floor by more than 10 cm.

A steel trash rack (bar screen) must be installed to prevent rubbish from flowing into the penstock, and a steel lid must be placed to cover the entry tank.

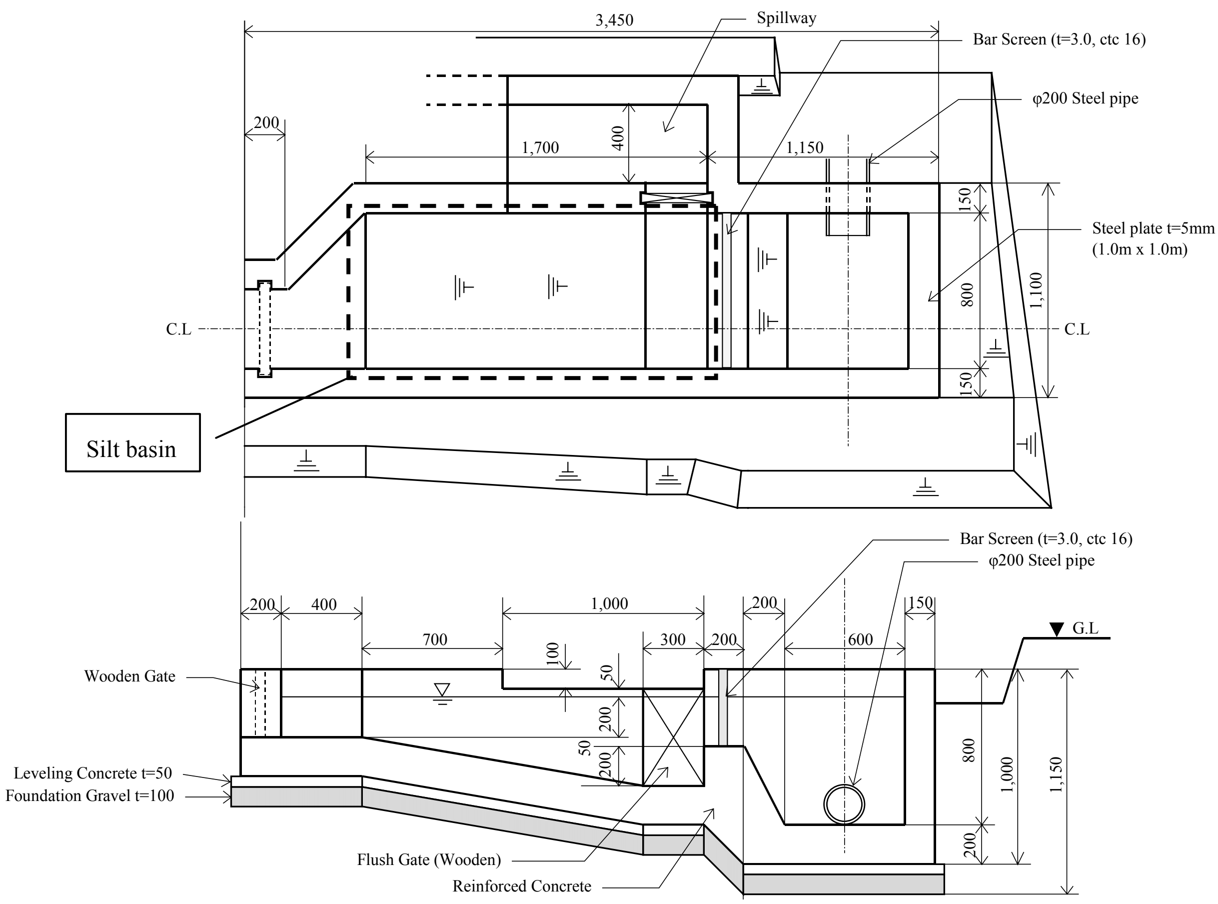


Figure 3-12 Plan and cross section of a head tank

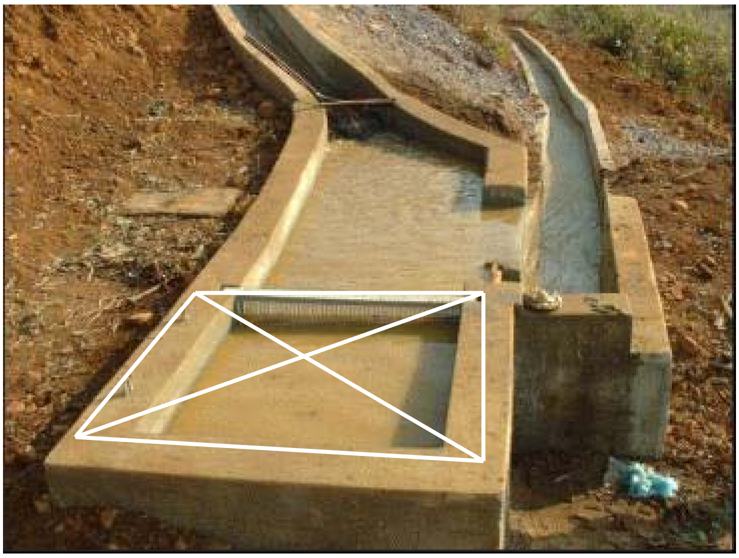


Figure 3-13 A head tank and a spillway (right side)

① Spillway

A spillway drains excess water flow safely back to a stream and protects the channel and head tank from damages caused by overflow. When the turbine is shut down, the spillway needs to drain the entire water flow.

The length of the cut of channel sidewall to spill the excess water is determined based on the water volume for generation. Table 3-5 assumes the overflow depth to be about 10cm, and the spill section should be placed about 15cm lower than the top of sidewall. The spillway can be built with brick masonry and mortar, same as the headrace.

Table 3-5　Dimensions of spill (overflow) section

Water volume Q（m^3/s）	Width of overflow B（m）
0.01	0.50
0.02	
0.03	
0.04	1.00
0.05	
0.06	1.50
0.07	
0.08	
0.09	2.00
0.10	
0.11	2.50
0.12	
0.13	
0.14	3.00
0.15	
0.16	3.50
0.17	
0.18	
0.19	4.00
0.20	

② Trash rack

A trash rack catches floating substance such as leaves, twigs and rubbish. In case of Village Hydro, it is recommended to use a wire mesh with the trash rack to remove tiny particles that may clog at valve nozzles and guide vanes.

Village Hydro uses small control valves because the water volume is small. We often face a problem that tiny particles clog at valves, block the water flow and stop the turbine. This interrupts stable operation. We need to be very careful how to remove small particles. Recommendable ideas are to make the space between the two bars of trash rack small, less than 10mm, and to place a 2mm wire mesh with the trash rack to catch small particles completely.

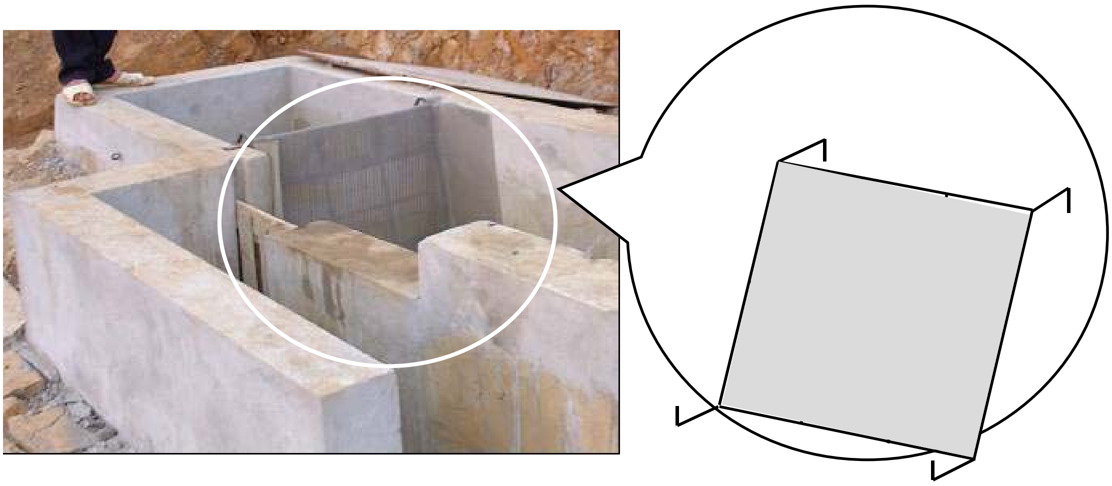


Figure 3-14 Wire mesh to catch small particles

③ Bypass channel

When the headrace is used to supply water for irrigation as well, a bypass channel is necessary at the head tank to divert irrigation water downstream. Design of the bypass channel should be made based on the water volume necessary for irrigation and the water level of head tank.

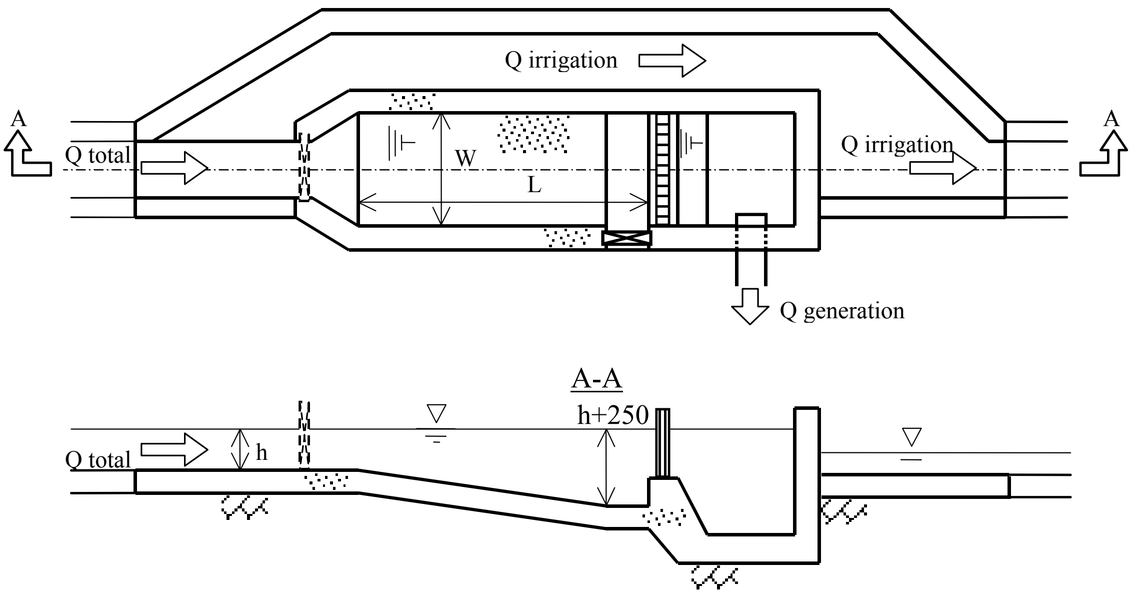


Figure 3-15 Bypass channel

f. Penstock

<u>A penstock connects the head tank and powerhouse. It must be designed to withstand the high pressure.</u>

Pressure resistant pipes are used for penstock. In case of Village Hydro, transporting pipes to the site is often difficult and costly, and therefore we recommend PVC pipes (high-pressure type) that are lightweight, inexpensive and readily available in Vietnam. Since the designed maximum pressure of PVC pipe is 10.0kg/cm^2, it can be used at the site where the head is less than 60m, assuming the surge pressure as 50% of the static pressure. PVC pipes can be connected easily, but must be buried to protect them from sunlight and strong impact. At Village Hydro sites with a high head (more than 60 m), or where burying pipes is difficult, we need to use steel pipes.

The cost of penstock is significant in the total Village Hydro project costs. It is therefore worthwhile to optimize the penstock design to minimize its initial cost. The loss of energy due to friction in the pipe, the friction loss, needs to be assessed carefully when sizing and costing the penstock. Although small diameter pipes are less costly, their friction loss is large. In contrast, big diameter pipes give smaller friction loss, but they are expensive. Choosing the right size of diameter after comparing various options is important. Table 3-6 shows a standard PVC pipe selection, based on the idea to limit the friction loss to less than 10% of the gross head.

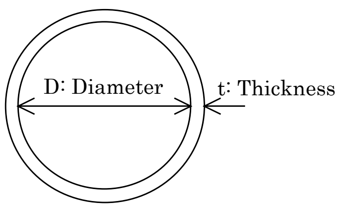
Table 3-6 Sizing of PVC penstock

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">L/H=Penstock length/Head</td></tr>
<tr><td>2.5</td><td>3.0</td><td>3.5</td></tr>
<tr><td colspan="2">Slope</td><td>23.6°</td><td>19.5°</td><td>16.6°</td></tr>
<tr><td rowspan="19">Water volume (m^3/s)</td><td>0.02</td><td colspan="2">125</td><td>150</td></tr>
<tr><td>0.03</td><td>150</td><td colspan="2" rowspan="4">200</td></tr>
<tr><td>0.04</td><td rowspan="4">200</td></tr>
<tr><td>0.05</td></tr>
<tr><td>0.06</td></tr>
<tr><td>0.07</td><td rowspan="6">250</td><td rowspan="5">250</td></tr>
<tr><td>0.08</td><td rowspan="6">250</td></tr>
<tr><td>0.09</td></tr>
<tr><td>0.10</td></tr>
<tr><td>0.11</td></tr>
<tr><td>0.12</td><td rowspan="9">300</td></tr>
<tr><td>0.13</td><td rowspan="8">300</td></tr>
<tr><td>0.14</td><td rowspan="7">300</td></tr>
<tr><td>0.15</td></tr>
<tr><td>0.16</td></tr>
<tr><td>0.17</td></tr>
<tr><td>0.18</td></tr>
<tr><td>0.19</td></tr>
<tr><td>0.20</td></tr>
</table>

Note: Gray cells indicate the friction loss is more than 10% of gross head

Specification and dimensions

Model φ	Diameter Outer (mm)	Diameter Inner:D (mm)	Thickness t (mm)
125	140	126.6	6.7
150	160	144.6	7.7
200	225	203.4	10.8
250	280	253.2	13.4
300	315	285.0	15.0



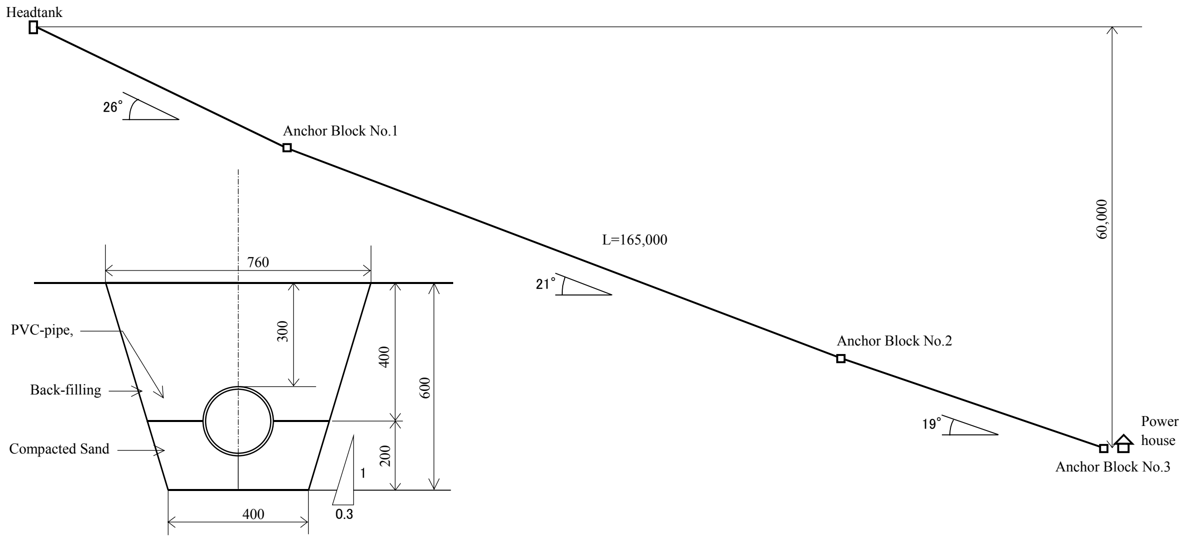


Figure 3-16 An example of PVC penstock layout

Figure 3-17 PVC pipes (pressure resistant type)

An anchor block, a mass of concrete, holds the penstock so that the penstock cannot move in any way relative to the block. An anchor should always be placed at a vertical or horizontal bend in the penstock, and at the entry to powerhouse. At bends, correctly angled steel pipes are connected to PVC pipes at both ends with flange joints.

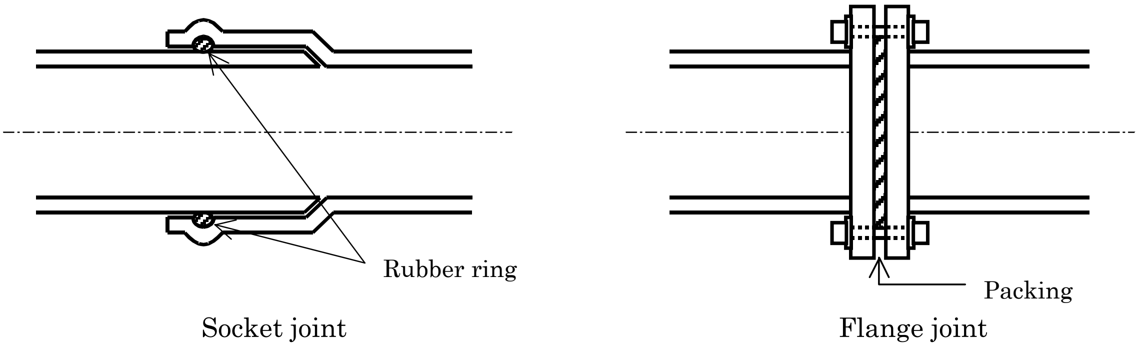


Figure 3-18 Joints

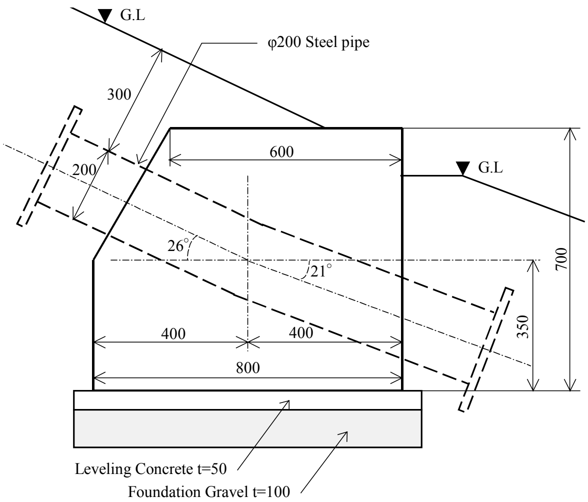


Figure 3-19 An example of an anchor block

Figure 3-20 An anchor block and a steel joint pipe

Figure 3-21 Installation of a PVC penstock

In case of using steel pipes for penstock, flange joints are recommended to be used, because they are easy to install on site. However, flanges can add to the cost of penstock. Welded joints can be used as well to connect steel pipes. Although, welding is cheaper, it needs skilled personnel and carrying welding machine into the site. At some points expansion joints must be used to relieve the thermal expansion forces under hot weather. Slide blocks are placed under the steel penstock to support it.

g. Powerhouse

The foundation of powerhouse should be reinforced concrete to withstand the weight of turbine/generator unit and the vibration of water turbine. When using submersible-type dummy loads, a deep conduit (tail bay) is built underneath the floor to house the dummy loads. A large door must be installed for the ease of bringing and installing the turbine and generator. A typical powerhouse is built with local materials such as bricks and mortar, and fiber cement roofing. The slope of roof should be carefully designed to protect electrical equipment from rainfall.

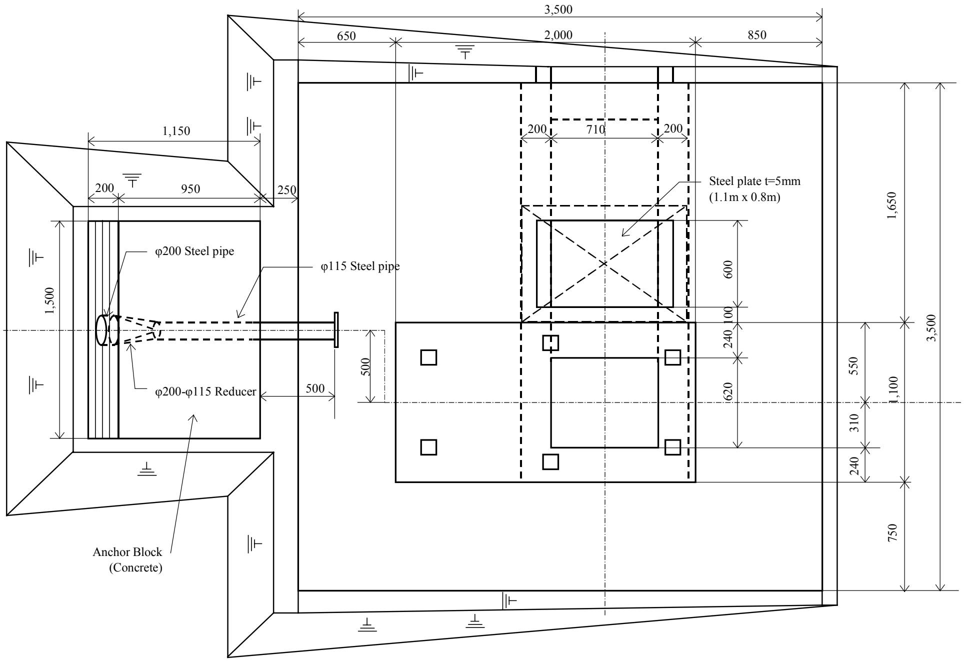


Figure 3-22 An example of powerhouse plan

Figure 3-23 A powerhouse – completed (left) and under construction (right)

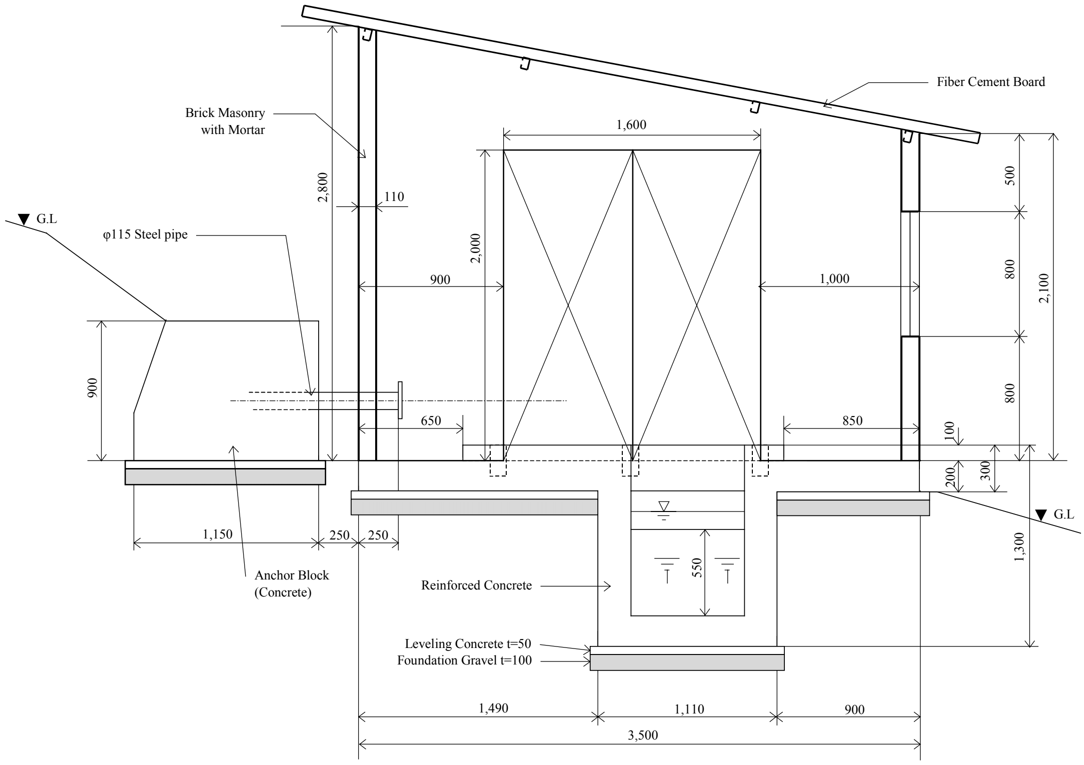


Figure 3-24 An example of powerhouse cross section

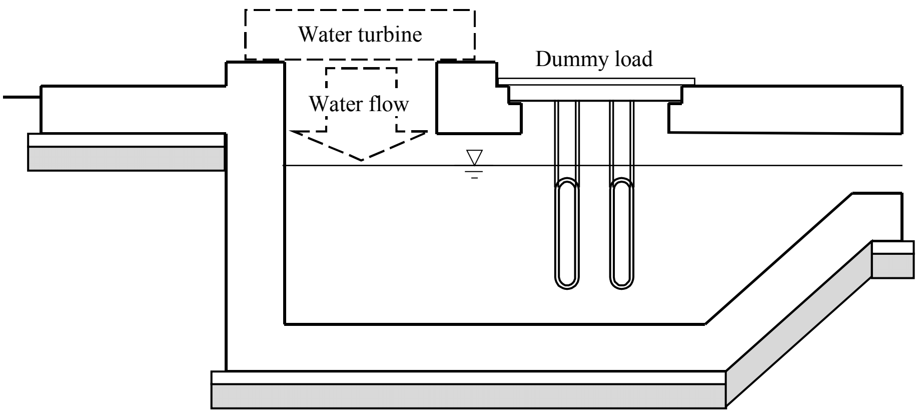


Figure 3-25 Cross section of tail bay

h. Tailrace

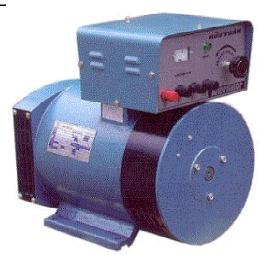
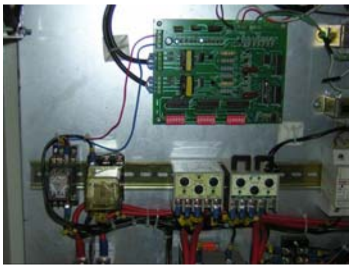
The water used for generation is released to river through tailrace. The tailrace is designed in the same way as the headrace.

Figure 3-26 A powerhouse and tailrace

3-3. Electro-mechanical equipment

The basic components of electro-mechanical equipment of Village Hydro are as follows. We place an order for the equipment to a manufacturer providing the values of head and design water flow, and purchase it after appropriate testing in the workshop.

Table 3-7 Basic components of electro-mechanical equipment

	Item	Photo
a	Inlet valve	
b	Water turbine	
c	Generator	
d	Governor (Load controller)	
e	Switchboard/ Protection devices	

a. Inlet valve

An inlet valve, which is installed before the turbine, completely stops the water flow when the turbine and generator is shut down.

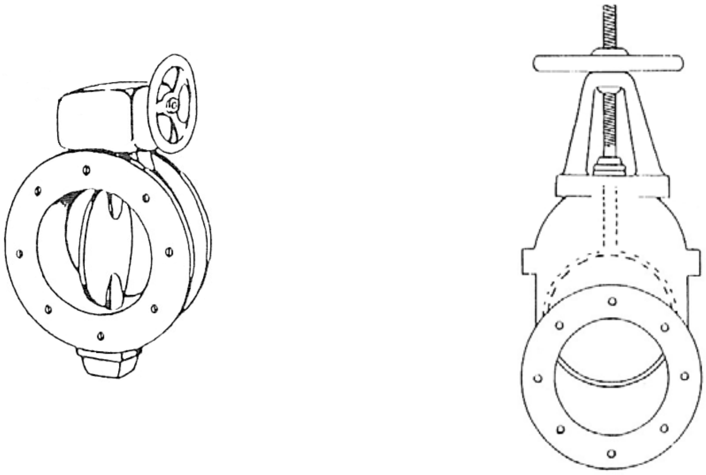
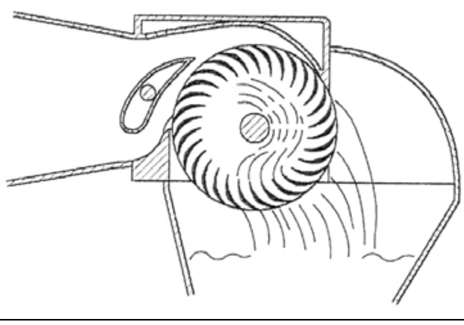
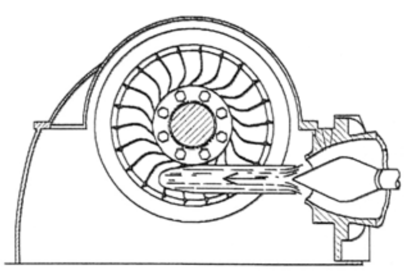


Figure 3-27 Inlet valve - Butterfly valve (left) and Gate valve(right)

b. Water Turbine

A turbine unit consists of a runner connected to a shaft that converts the potential energy in falling water into mechanical power. We need to select an appropriate turbine to utilize the water energy to the fullest extent. Other considerations such as whether the turbine is expected to produce power under part-flow conditions also play an important role in choosing a turbine. Most commonly used turbines in case of Village Hydro are crossflow turbines and Turgo turbines.

Table 3-8 Cross flow turbine and Turgo turbine

Type	Cross flow turbine	Turgo turbine
Feature	・ For low head scheme ・ Easy to manufacture ・ Efficient at part flow ・ Easy to inspect	・ For middle and high head scheme ・ Small in size ・ Efficient at part flow ・ Durable ・ Easy to inspect
Illustration		

Crossflow turbines are suitable for low- and medium-head sites. On the other hand, Turgo turbines are suitable for medium- and high-head sites. Only experienced manufactures can properly design and manufacture Village Hydro turbines. In addition to them, pelton turbines and Pump-as-turbine (PAT) can be used in some cases.

① Pelton turbine

Pelton turbines are used for sites that have low flows and high heads.

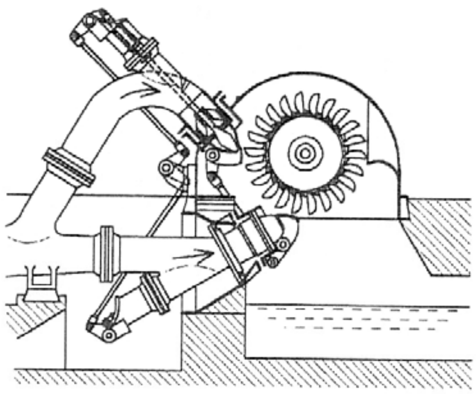


Figure 3-28 Pelton turbine

② Pump as turbine (PAT)

A pump as turbine (PAT) is to use a standard pump and to rotate its runner in reverse by making the water flowing from the outlet of the pump. The runner can work as a turbine. Because the pumps are mass-produced, they are more readily available and less expensive than turbines. In this case, the conditions on the water volume and the head must meet with the specifications of the PAT, because PATs have very poor partial-flow efficiency. PATs are only efficient at the sites that have a fairly constant flow throughout the year.

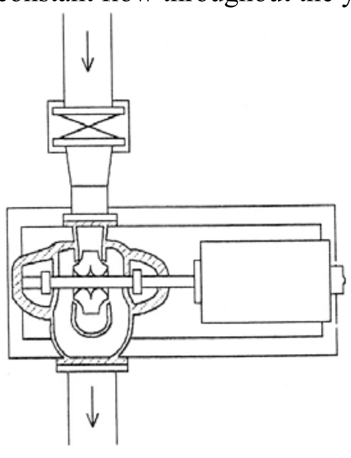


Figure 3-29 Pump as turbine

Table 3-9 shows the suitable head range for each type of turbine.

Table 3-9 Turbine type and suitable head range

Turbine type	Head range
Cross-flow turbine	2m~30m
Turgo turbine	10m~70m
Pelton turbine	50m~200m
Pump as turbine	5m~40m

③ Belt drive

When the rated rotation speed of water turbine differs from the rated generator rotation speed, a belt drive must be installed to adjust the turbine rotation to the required speed of generator.

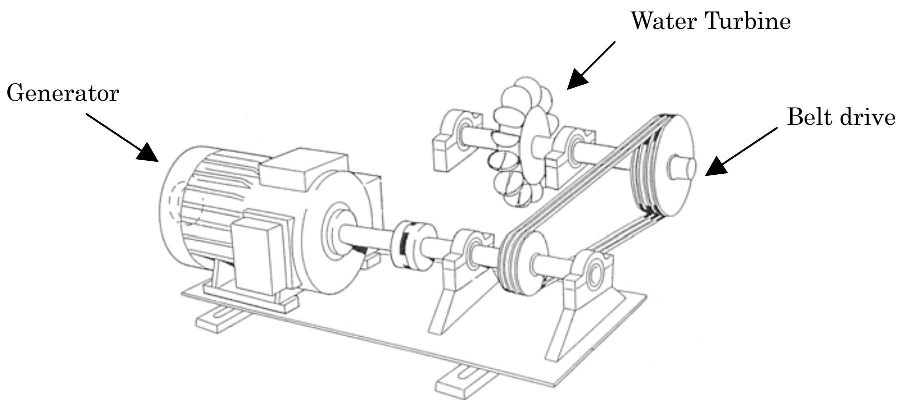


Figure 3-30 Belt drive system

c. Generator

We have to use an appropriate generator that matches the power output and power distribution of Village Hydro.

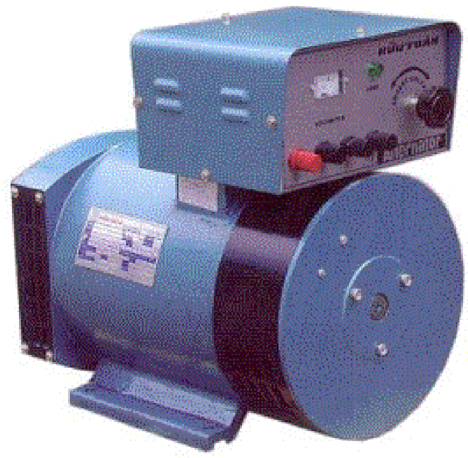
① Types and features of generator

In an off-grid generation system like Village Hydro, a stand-alone generator is necessary. A synchronous generator is most appropriate. When it is difficult to get a synchronous generator, it is also possible to use an induction generator with a set of capacitors for self-excitation.

I. Synchronous generator

In Vietnam, inexpensive small-size synchronous generators, up to 20kW, both three-phase and single-phase, are available in the market. (See Table 3-10) These generators are suitable for Village Hydro.

Table 3-10 Single-phase synchronous generator specifications

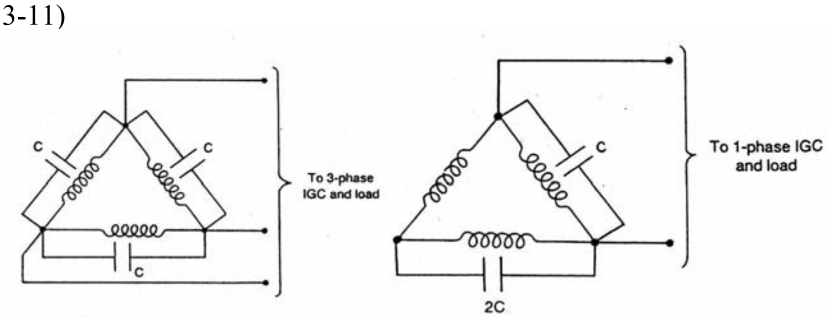


Output (kW)	Rated voltage (V)	Rated current (A)	Weight (kg)
2.0	230	9.0	70
3.0	230	13.6	70
5.0	230	22.7	120
7.5	230	34.0	130
10.0	230	45.0	140
12.0	230	54.5	140
15.0	230	68.0	165
20.0	230	90.0	165

(Note) $\cos\phi = 1.0$
Rotation speed: 1500 (rpm)
(Source): A Vietnamese maker's technical data.

II. Induction generator

Induction generators can be used in Village Hydro if a set of capacitors is equipped for self-excitation. The Figure3-32 illustrates how to connect capacitors. Even motors can be used instead of induction generators. There are many models of induction generators available in the market (See Table 3-11)



For 3-phase: (C-C-C) connection For 1-phase: (C-2C)connection

Figure 3-32 Capacitor connection for self-excitation of induction generators

(I) Selection of excitation capacitor capacity

The appropriate capacity of capacitors for self-excitation is calculated by the formula shown in the following example. When capacitors are not properly sized, induction generators will not generate power or the voltage will go up too high.

<Example of motor selection>

ns: Output 5.0(kW), Turbine rotation speed N=1,000(rpm)

Necessary capacity of induction generator is 5.0x1.2=6.0 (kW)

The induction generator satisfying this from Table 3-11 is

7.5(kW), N=1,000(rpm)

<Example of calculation for excitation capacitor>

Condition for calculation: three-phase induction motor (Capacity P=7.5kW)

Δ connection line (phase voltage:220V),

Frequency f=50Hz, Rated current I=28.0A, Power factor cos ϕ=0.82

Apparent power S=$\sqrt{3}$ x220 x I=10,669.4(VA)

Real power P=S x cos ϕ =8,748.9(W)

Reactive power Q=$\sqrt{(S^2-P^2)}$=6106.8(Var)

Excitation capacitance $C = Q/3/(2\pi fV^2) = Q/(6\pi fV^2)$

C=133.9(μF)

C＝140 (μF/per phase)

Table 3-11 Specifications of three-phase induction generators

Output (kW)	No.of Poles	Rotation speed (rpm)	Voltage (V) Δ/Y	Current (A)	Power factor cos ϕ	Class of non-conductance and heat resistance	Weight (kg)	Excitation capacitance (μF/per phase)
1.1	8	750	220/380	6.1/3.5	0.70	B	35	30
	6	1000	220/380	5.2/3.0	0.76	B	28	
	4	1500	220/380	4.9/2.8	0.81	B	18	
1.5	8	750	220/380	8.2/4.7	0.68	B	43	40
	6	1000	220/380	7.1/4.1	0.74	B	35	
	4	1500	220/380	5.9/3.4	0.85	B	21.5	
2.2	8	750	220/380	10.4/6.2	0.71	B	55.5	50
	6	1000	220/380	9.5/5.5	0.74	B	43	
	4	1500	220/380	8.66/5.0	0.85	B	26.5	
3.0	8	750	220/380	13.5/7.8	0.74	B	69.5	60
	6	1000	220/380	12.8/7.4	0.76	B	58	
	4	1500	220/380	11.6/6.7	0.83	B	36.5	

4.0	8	750	220/380	18.2/10.5	0.70	B	108	85
	6	1000	220/380	16.0/9.2	0.81	B	72	
	4	1500	220/380	14.9/8.6	0.84	B	41	
5.5	8	750	220/380	23.6/13.6	0.74	B	116	105
	6	1000	220/380	21.3/12.3	0.80	B	81	
	4	1500	220/380	19.8/11.4	0.86	B	62	
7.5	8	750	220/380	30.7/17.7	0.75	B	170	140
	6	1000	220/380	28.0/16.2	0.82	B	116	
	4	1500	220/380	26.2/15.1	0.86	B	72	
11	8	750	220/380	45.0/26.0	0.76	B	225	190
	6	1000	220/380	39.2/22.6	0.86	B	146	
	4	1500	220/380	38.0/22.0	0.87	B	106	

(Source) Technical data from a Vietnamese manufacturer

d. Governor

With a constant water flow, the rotation speed of turbine fluctuates with changing loads, and the voltage and frequency also go up and down. Users will suffer from unstable voltage and frequency. In addition, over-speed of turbine and generator, caused by sudden removal of load for example, may cause severe damage to the generator coils. To prevent these problems, a load controller that regulates the rotation speed of turbine constant regardless of fluctuating loads is required. For Village Hydro, a simple, inexpensive and reliable “dummy load governor” is suitable. This is an electronic device already manufactured in Vietnam.

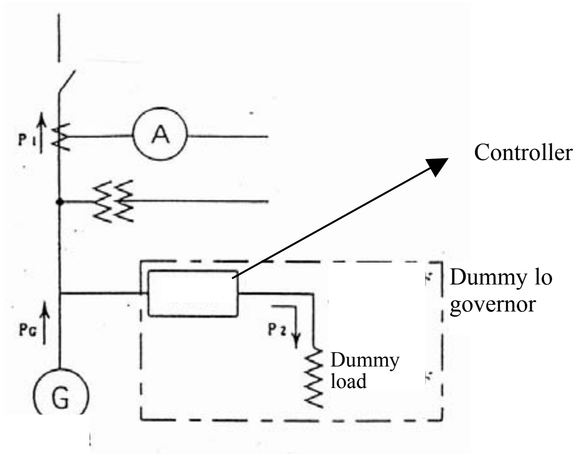


Figure 3-33 Dummy load governor

① How it works

The dummy load governor senses the voltage or frequency of the generator output, and changes the power diverted into a dummy load in such a way that the total load, user load and dummy load, is held constant. As a result, the full power generated by the turbine is always used, by the combination of user load and dummy load, and hence the voltage and frequency are kept stable. (See Figure 3-34)

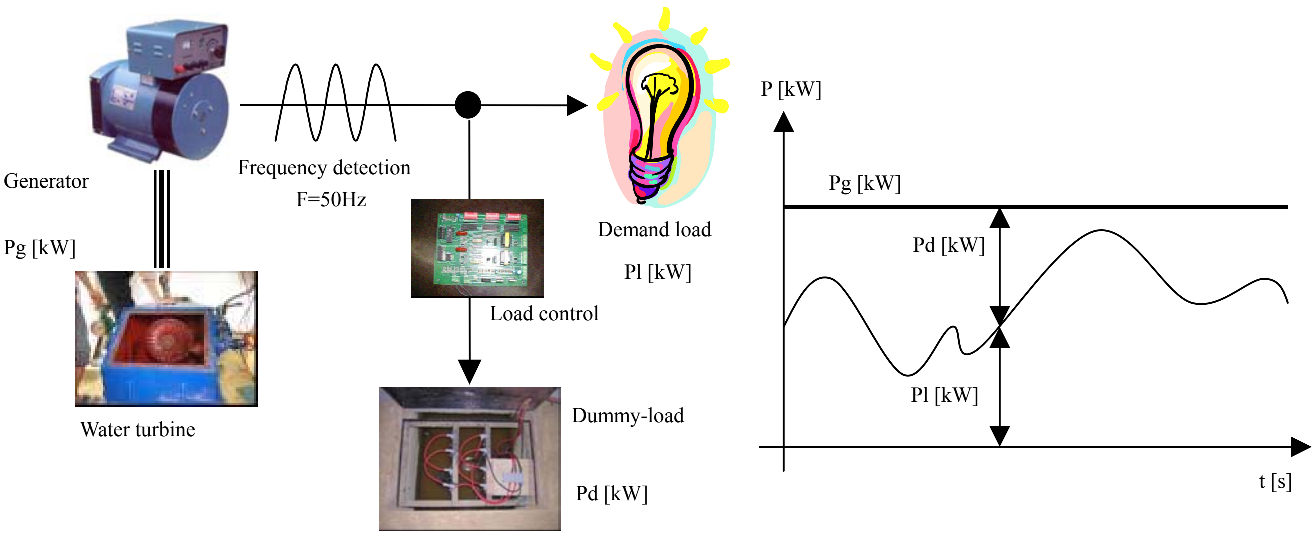
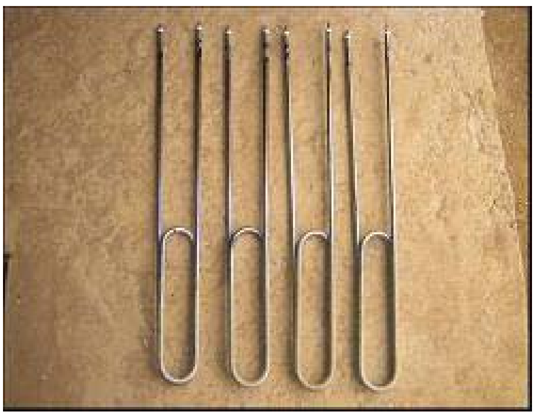


Figure 3-34 Function of dummy load controller

② Dummy load

A dummy load consists of several heater elements working as resistance. The water-cooled dummy load is the most common type in Village Hydro. Its capacity should be 110% to 120% of the generator output. It can be installed either in the tailrace, on in a separate water tank.



Heater elements

Setting dummy load in tailrace

Figure 3-35 Water-cooled dummy load

③ Back-up dummy load

If the dummy load controller fails, there emerges a risk of damaging the generator by over speed. To protect the generator from this potential problem, it is recommended to install a back-up system of dummy load controller that can limit the speed of the turbine/generator independently.

e. Operation control & protection equipment

An operation control system is installed to start and stop the power plant safely. Also, it has safety devices that minimize the damages to the power plant in case of faults. In Village Hydro, it is recommended to install three kinds of protection: over-current relay, over-voltage relay and frequency relay.

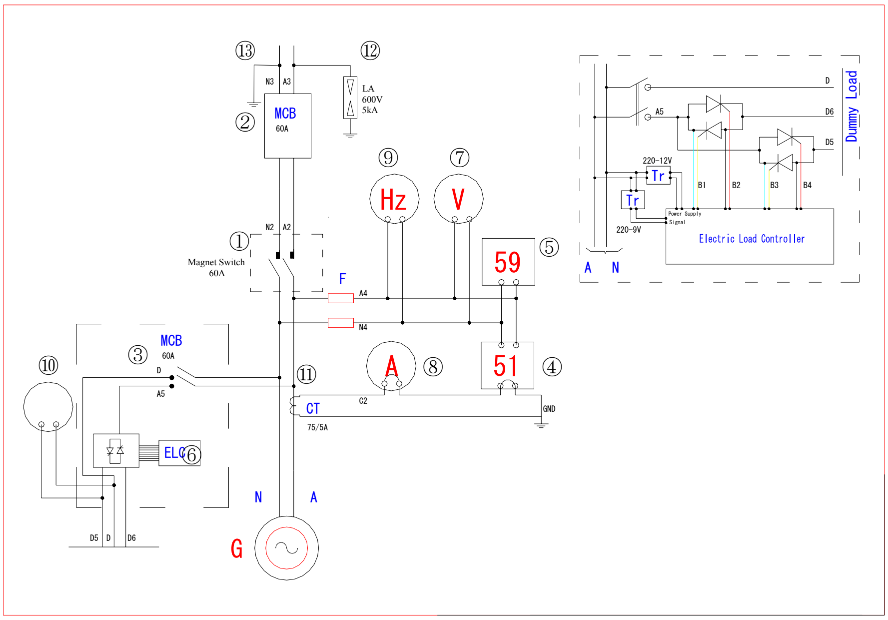


Figure 3-36 An example of schematic diagram (single phase system)

Table 3-12 An example of safety devices

Classification	No.	Device	Specification	Function
Switch	①	Contactor	100A (> 60A)	For system connection and separation
	②	MCB for transmission	60A	Over-load and short-circuit protection
		It is also possible to install ELCB for earth leakage protection.		
	③	MCB for Dummy Load	60A	Dummy load short-circuit protection
Protective Relay	④	Over Current Relay (51)	7.5-97.5A (0.5-6.5A) On Time 0-10s Delay Time 0-30s	Over-load and short-circuit protection
	⑤	Over Voltage Relay (59)	220-300V On Time 0-30s Delay Time 0-30s	Over-voltage protection
	⑥	Over & Under Frequency Relay (OF, UF)	OF 55Hz UF 45Hz On Time 5s Type : Set in ELC	Over- and under- frequency protection
Instrument	⑦	Potential meter	0-300V	Measurement of voltage
	⑧	Current meter	0-150A	Measurement of current
	⑨	Frequency meter	45-65Hz	Measurement of frequency
	⑩	Potential meter for DL	0-300V	Measurement of dummy load
Transformer	⑪	Current Transformer	75 / 5 A	For meters and relays
Lightning Protection	⑫	Lightning Arrester (LA)	600V 5000A	Apparatus protection from lightning
	⑬	Earthing (One line multiple grounding system)	< 4 Ω	

3-4. Power distribution system

a. Technical standards

Village Hydro's low-voltage (220V) distribution line systems are designed and constructed by applying the technical standards of Vietnam. It is important to note that the distribution line can be used even after the grid reaches the village. See the following documents for reference.

Table 3-13 Reference books and technical standards

Document name	Chapters	Publishing organization
Vietnam electricity equipment standards	Part 1:General Provisions (11TCN-18-84) Part 2:System of power transmission (11TCN-19-84) Part 3:Protection and automation (11TCN-20-84) Part 4:Distribution equipment and substation (11TCN-21-84)	Ministry of Electricity, 1984
District electrification technical guidebook		EVN, 2003

b. Power distribution system

In a village-scale scheme, low-voltage lines are more economic than high-voltage lines. Furthermore, the greater simplicity of low-voltage lines is much preferable in remote areas. These are the reasons for selecting a 220V low-voltage line system in case of Village Hydro. The power supply system can be either single-phase or three-phase. In Village Hydro, a single-phase system is usually used. But when a special load such as three-phase motor is used, a three-phase system must be built.

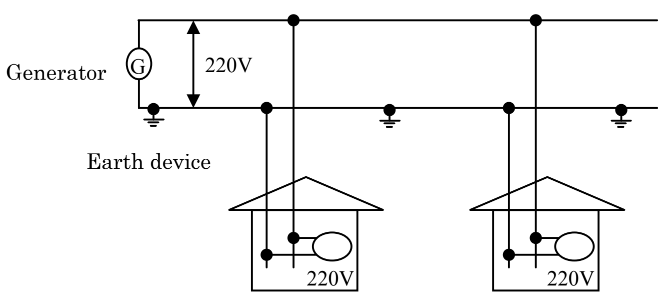


Figure 3-37 Single-phase 2 line power distribution system (220V)

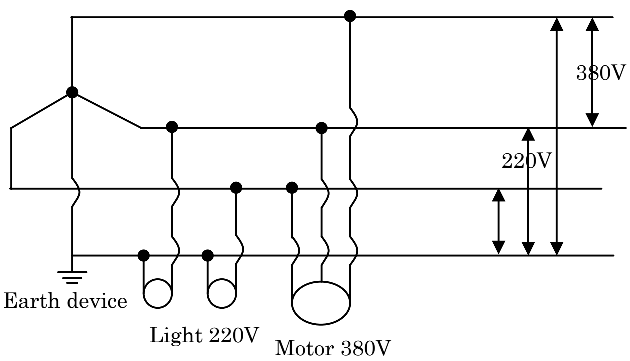


Figure 3-38 Three-phase 4 line power distribution system (220/380V)

c. Routing

The route of distribution lines, connecting the powerhouse and hamlets, is decided based on the economics after examining various patterns. The position of each pole is set taking the length of cable span and lead-in wires into account.

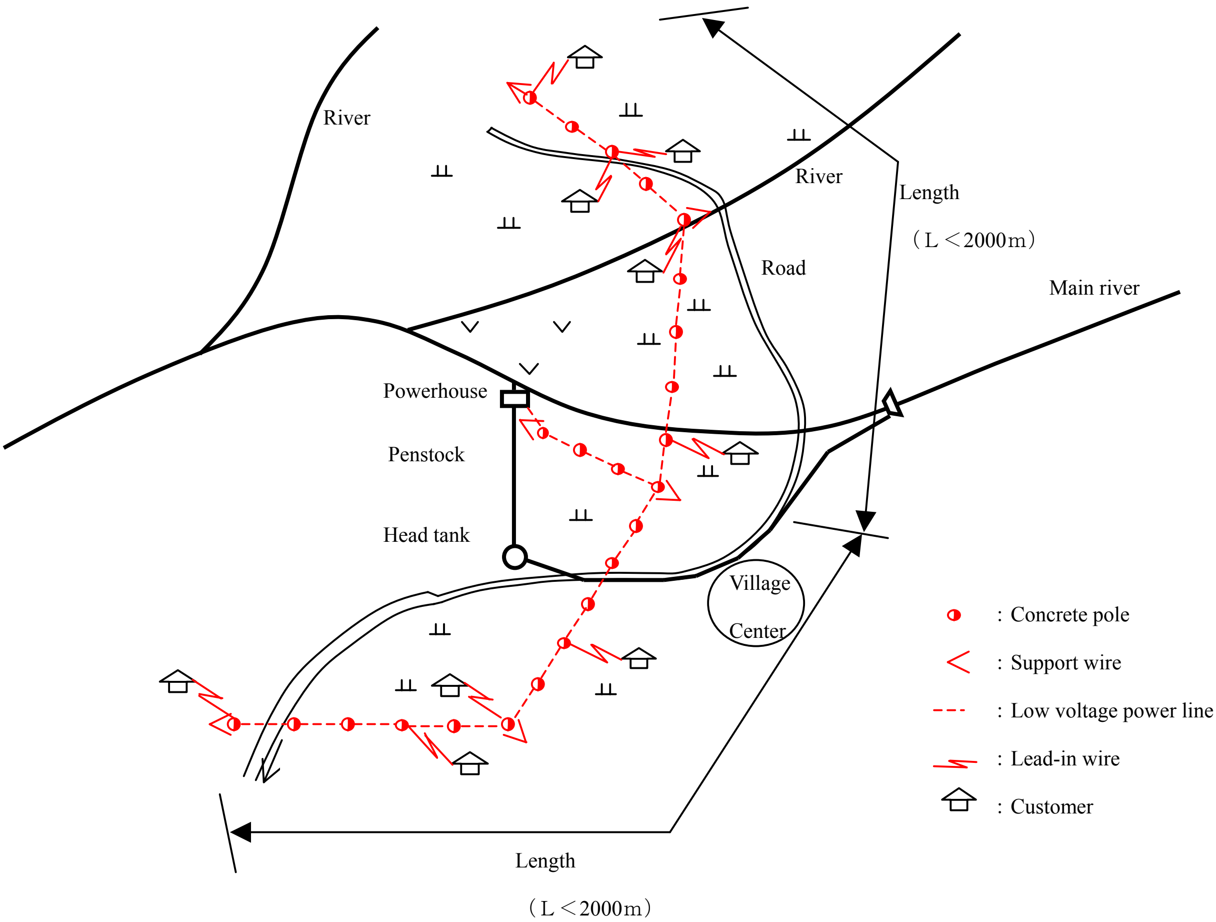


Figure 3-39 An example of distribution line route

d. Specifications and design

① Allowable voltage

We need to make sure that delivered voltage is within the allowable voltage range. In Village Hydro, it is recommended to set the minimum voltage at 200V. To achieve this, appropriate size of cables must be selected. If we use a larger cable, we can reduce the voltage drop but the cable cost goes up. We need to calculate the figure of voltage drop by changing the size of cables. In order to save the cable cost, which is significant in the total project cost, it is a good idea to raise the generated voltage in the powerhouse slightly to 230V.

② Selection of equipment

In principle, we need to use standard equipment and materials, which are usually low cost and highly available, in the distribution line system, so that the villagers can use the distribution line system even after the grid extension.

Table 3-14 Selection of distribution equipment

Distribution equipment	Recommendation	Expected benefits
Pole	Reinforced concrete pole	• Strong and long life. • Compatible with the grid system
Cable	Insulated aluminum cable	• Low cost • High availability • Safety for villagers
Mounting	Horizontal	• Standard method

③ Cable span and sagging

The pole spacing must be less than 40m except for the poles with support wires, and the sagging of cables should be limited to 1% to 3 % of the cable span.

④ Pole height and load

The height and load of poles are decided based on the data of cables, their number, diameter and weight, and site conditions. The standard pole of Village Hydro is the H7.5 pole. At some places where the support structures are required, high-load type (C-type) should be selected. In other cases, standard type (B-type) can be used. The base of poles should be 1.5m deep when the H7.5 poles are used, but can be reduced to 1m if concrete structures are selected.

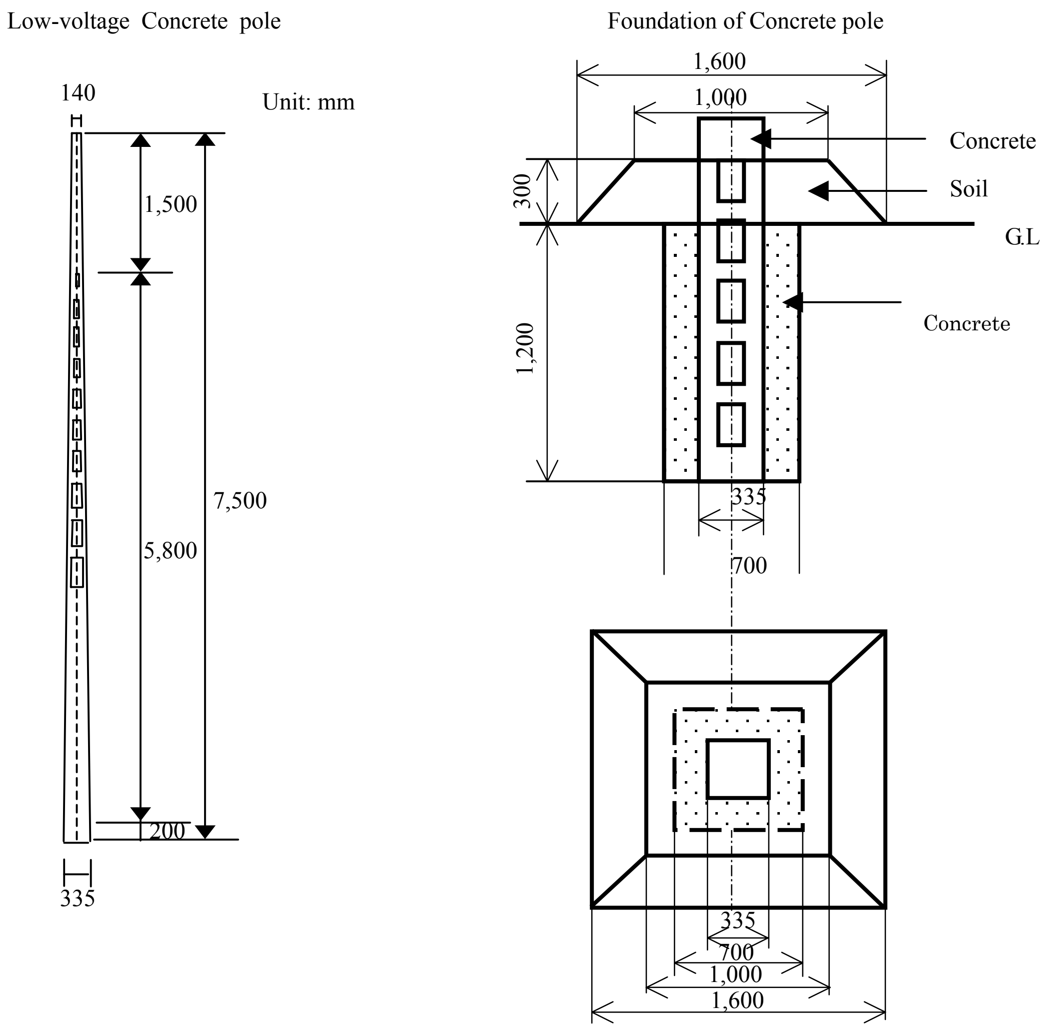


Figure 3-40 Dimensions of H7.5 concrete pole

⑤ Making poles on site

Sometimes, it is difficult to transport concrete poles to the village due to bad road conditions. If so, we need to make poles on site by bringing frames, steel bars, and sacks of cement.

⑥ Support wire

At some poles with high loads, support wires are built to share the loads. The design and construction of support wires must meet the conditions of the technical standards.

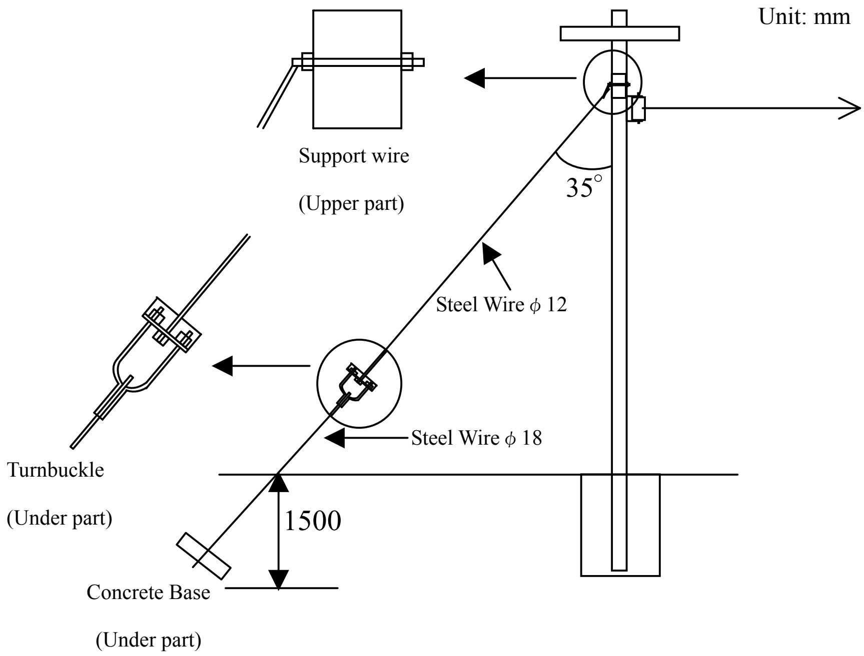


Figure 3-41 An example of pole and its support wire

⑦ Selection of cable size

In Village Hydro, insulated aluminum (Al-PVC) electric cables that are common, inexpensive and widely used in Vietnam are recommended. There are many different sizes. After conducting a voltage drop simulation, the most appropriate cables are to be selected.

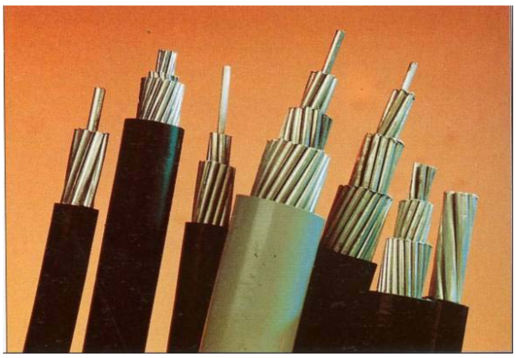


Figure 3-42 Insulated aluminum cables

Table 3-15　LV (Al-PVC) electric cable technical specifications

Item	Unit	Value			
Nominal Area	(mm^2)	35	50	70	95
Diameter Core	(mm)	8.4	9.6	11.4	13.5
Overall diameter	(mm)	12.0	13.2	15.4	17.5
Resistance of Conductor	(Ω/ km)	0.78	0.60	0.42	0.30
Reactance of Conductor	(Ω/ km)	0.28	0.27	0.26	0.26
Weight	(kg/km)	231	287	396	534

(Source) A Vietnamese maker's catalog

⑧ Calculation of voltage drop

Voltage drop is calculated by the following formula.

$\Delta V = K \times I \times Ze \times L$（V）

Where,

K：Transmission system coefficient

（K＝2 for 1 phase, K＝$\sqrt{3}$ for 3 phase）

I：Load current（A）

Ze：Equivalent resistance per unit length of electric cable

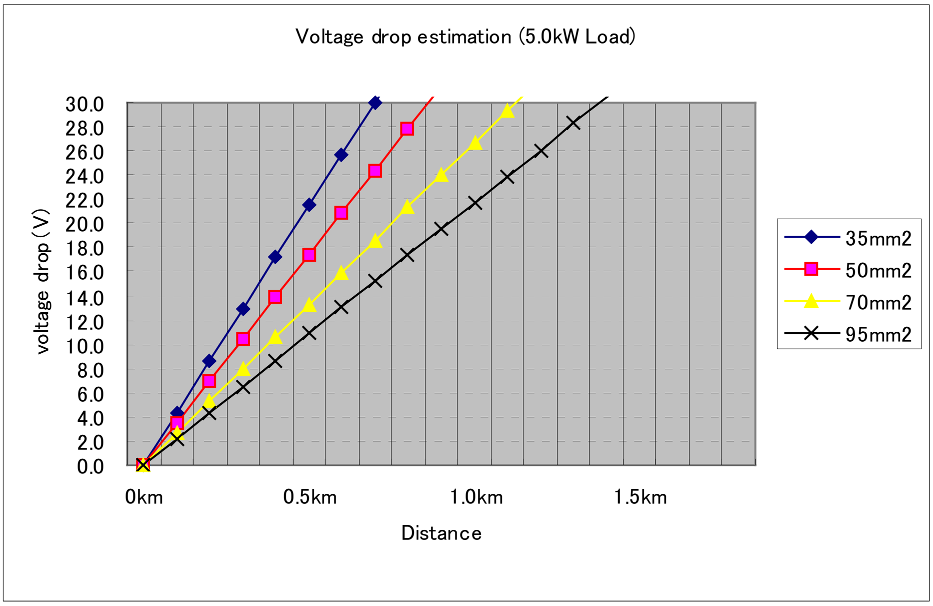
$Ze = R\cos\varphi + X\sin\varphi$（Ω/km）

cosφ：Power factor

Example 1 : Voltage drop with a 5kW load　(Power Factor cosφ=0.8)

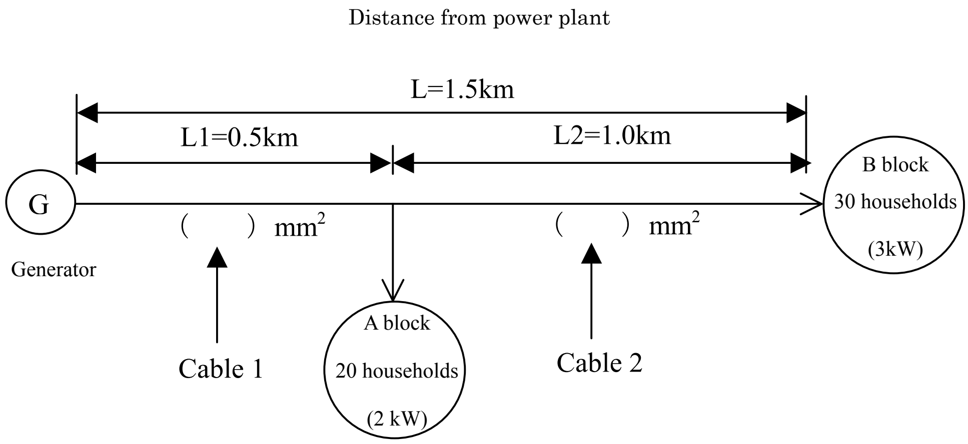
The results of calculation based on Table 3-15 are shown below.

Distance	Voltage Drop (ΔV)			
	$35mm^2$	$50mm^2$	$70mm^2$	$95mm^2$
0.1km	4.3	3.5	2.7	2.2
0.2km	8.6	7.0	5.3	4.3
0.3km	12.9	10.4	8.0	6.5
0.4km	17.2	13.9	10.7	8.7
0.5km	21.5	17.4	13.3	10.9
0.6km	25.8	20.9	16.0	13.0
0.7km	30.1	24.3	18.6	15.2
0.8km	34.3	27.8	21.3	17.4
0.9km	38.6	31.3	24.0	19.6
1.0km	42.9	34.8	26.6	21.7
1.1km	47.2	38.3	29.3	23.9
1.2km	51.5	41.7	32.0	26.1
1.3km	55.8	45.2	34.6	28.3
1.4km	60.1	48.7	37.3	30.4
1.5km	64.4	52.2	39.9	32.6



Example 2 : Voltage drop simulation and cable sizing

Suppose a distribution line with two load points as shown below. We need to calculate the voltage drop changing the size of cables, and select appropriate cables. We allow a voltage drop of 20V.



< Data and equation>

K: transmission system coefficient (single phase K=2, three phase K=√3)

Ze: Equivalent resistance per unit length of electric cable, Ze=Rcosφ+Xsinφ (Ω/km)

cosφ: Power factor (assuming cosφ=0.8)

Al-PVC(95mm^2) Ze=0.40 (Ω/km)

Al-PVC(70mm^2) Ze=0.49 (Ω/km)

Al-PVC(50mm^2) Ze=0.64 (Ω/km)

Al-PVC(35mm^2) Ze=0.79 (Ω/km)

<Simulation results>

Section L1 (5 k W load)					Section L2 (3 k W load)				
Size	Voltage Es (V)	Load current I (A)	Voltage drop ΔV (V)	Voltage Er (V)	Size	Voltage Es (V)	Load current I (A)	Voltage drop ΔV (V)	Voltage Er (V)
35mm^2	230.0	27.2	21.5	208.5	35mm^2	208.5	18.0	28.4	180.1
					50mm^2	208.5	18.0	23.0	185.5
					70mm^2	208.5	18.0	17.6	190.9
					95mm^2	208.5	18.0	14.4	194.1
50mm^2	230.0	27.2	17.4	212.6	35mm^2	212.6	17.6	27.8	184.8
					50mm^2	212.6	17.6	22.5	190.1
					70mm^2	212.6	17.6	17.2	195.4
					95mm^2	212.6	17.6	14.0	198.6
70mm^2	230.0	27.2	13.3	216.7	35mm^2	216.7	17.3	27.3	189.4
					50mm^2	216.7	17.3	22.1	194.6
					70mm^2	216.7	17.3	17.0	199.7
					95mm^2	216.7	17.3	13.8	202.9
95mm^2	230.0	27.2	10.9	219.1	35mm^2	219.1	17.1	27.0	192.1
					50mm^2	219.1	17.1	21.9	197.2
					70mm^2	219.1	17.1	16.8	202.3
					95mm^2	219.1	17.1	13.7	205.4

<Conclusion>

In order to secure 200V at the end of distribution line, we need to use a combination of 70mm^2 and 95mm^2 cables. In this example, we choose 95mm^2 cable for L1 and 70mm^2 cable for L2 after comparing the total costs.

Section number	Distance (km)	Cable size combination pattern		
		Case1	Case2	Case 3
L1	0.5	70mm^2	95mm^2	95mm^2
L2	1.0	95mm^2	70mm^2	95mm^2
Cost comparison		-	Minimum	-

⑨ Power cut-off switch

It is recommended to install cut-off switches at some points of the distribution lines to enable planned power outages at some areas when the power output is decreased and the power supply to all users becomes difficult.

⑩ Grounding

The standard grounding system is one line grounding system, which connects one distribution line to the ground at many points. With this grounding system, we need to be aware of the risk of electric shock. (See Figure 3-43)

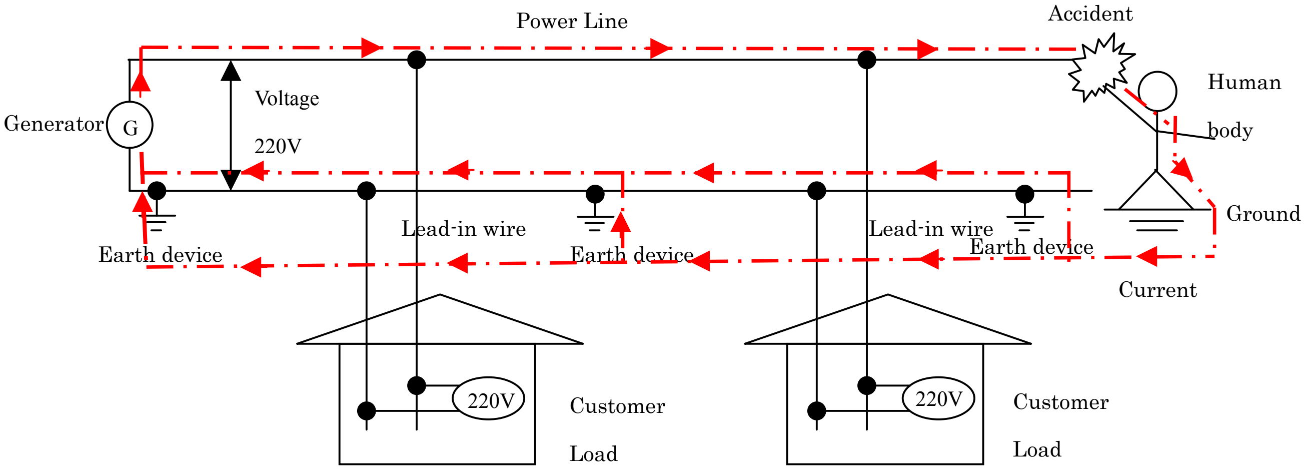


Figure 3-43 Electric shock accident

⑪ Battery Charging

Sometimes, it is necessary to install a battery charging unit to serve customers who live outside of the supply area. In this case, they can use appliances that are driven by 12V DC.

Figure 3-44 Battery charging system

3-5. Cost estimation

After the Village Hydro development planning is completed, it is necessary to obtain an official approval for the project from the Provincial People's Committee or donor organizations. This process is required to mobilize support and to get funding for the project, in which we need to show a project cost estimate.

The cost estimation of civil works and distribution facilities are relatively easy, because there are many similar facilities built before in the same region. We can use the data of such facilities as a good reference. On the other hand, the cost estimation of electro-mechanical equipment is difficult, because the equipment is custom-made and there are not many examples. We need to quote the price of manufacturers. In case of Village Hydro, we need to pay special attention to transportation cost, because trucks often cannot reach the target village due to bad road conditions.

Table 3-16 Items of construction cost estimation

Item		Material costs	Transportation costs	Labor costs
Generation	Civil works			
	Electro- mechanical facilities			
Distribution				
Overhead costs, tax, others				

The target of total construction cost is less than \$3,000 per kW, and that of generation facility, civil works and electro-mechanical equipment, is around \$1,000 per kW. The construction cost of low-voltage distribution line is around \$5,000 per km under normal conditions.

Table 3-17   An example of construction timetable