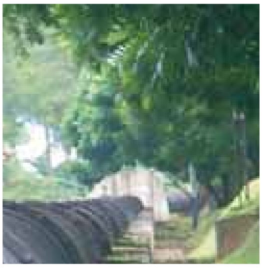
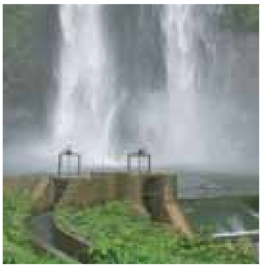
GOOD & BAD
of
Mini Hydro Power







Volume 1

- Site Identification
- Civil Works
- Electro-Mechanical

GOOD & BAD
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Mini Hydro Power

Klaus Jorde
with the resources of Entec AG

Ekart Hartmann, Heinz Unger

Edited by

Roman Ritter
GTZ

ASEAN-German Mini Hydro Project (AGMHP)

Imprint

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Disclaimer:

The publication has been prepared to illustrate good & bad practice examples in micro and mini hydro power planning, implementation, operation & management.
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Foreword

The urgent call for reducing the carbon footprint of our economies combined with the world's ever growing demand for scaling-up access to energy is a priority challenge on the global agenda which defines the role for renewables.

Renewable energies offer climate-friendly, low risk technology options for decentralized power generation. In remote areas, utilizing local renewables to support the development of poor rural communities is often more economically viable than transporting diesel fuel or expanding the national electricity grid over long distances. In locations where however the network infrastructure is already in place, harnessing natural resources for feeding power into the central grid also offers an important source of local income that contributes to macroeconomic stability by gaining independence from price-volatile fossil fuels.

In the light of this, the Association of South East Asian Nations (ASEAN) is emphasizing the need to strengthen the development of renewable energies. Promoting mutual cooperation for the transfer of knowledge and skills in order to narrow development gaps among the ASEAN countries, to empower the region's peoples, and ultimately to alleviate poverty is seen as the way forward.

With this publication, *'GOOD & BAD of Mini Hydro Power',* the ASEAN Centre for Energy (ACE) aims to provide valuable lessons from experiences gained in one member country for the dissemination of good practices throughout the whole region. This is intended to support the capacity development of ASEAN's human resources in the sustainable planning, design, implementation, management, operation and maintenance of mini hydro power (MHP).

The two underlying principles of this book are: "a picture is worth a thousand words" and "the only real mistake is the one from which we learn nothing". Thus – along the sequence 'from water to wire' – contrasting pictures of good & bad examples are provided to illustrate what actually defines the difference. Each picture is complemented by short explanations so that the book can serve as a technical training manual that offers direct and easy-to-understand guidance.

Although MHP is a relatively mature and cost-competitive energy technology, a lot of mistakes are still being made which lead to increased maintenance cost, reduced power output, shortened service life or even physical danger. The good news is that in many cases it is only small changes which need to be made – doing things the right way often requires no more funds than doing them the wrong way. However, what is definitely required is a proper awareness and expertise among hydro practitioners and their principals for whom, quite literally, "knowledge is power".

Nguyen Manh Hung
ACE, Executive Director

Roman Ritter
GTZ, Principal Advisor AGMHP

Acknowledgements

This book draws on countless photographs and experiences which have been collected in practically applying international MHP know-how for the successful improvement of mini hydro power implementation in Indonesia.

Therefore special thanks go to the Indonesian *Directorate General for Electricity and Energy Utilization (DGEEU)* and its Mini Hydro Power Project (MHPP) which has been jointly implemented for more than 10 years by DGEEU and GTZ, the German Technical Cooperation – *Deutsche Gesellschaft für Technische Zusammenarbeit.*

Big thanks also go to the team of authors who made great efforts in bringing together Entec's expertise in MHP development with the didactical concept of using contrasting pictures which require only short explanations to point out the decisive difference.

Last but certainly not least, the *ASEAN Centre for Energy (ACE)* is highly grateful to the German *Federal Ministry for Economic Cooperation and Development (BMZ)* for its continuous support of the ASEAN-German Mini Hydro Project (AGMHP) which provided the necessary resources for compiling this publication.

Nguyen Manh Hung
ACE, Executive Director








1. Site Identification

1.1 GENERAL

Mini hydro power stations (MHP) are installations often referred to as generating less than 1,000 kW electrical energy. The hydraulic sources are:

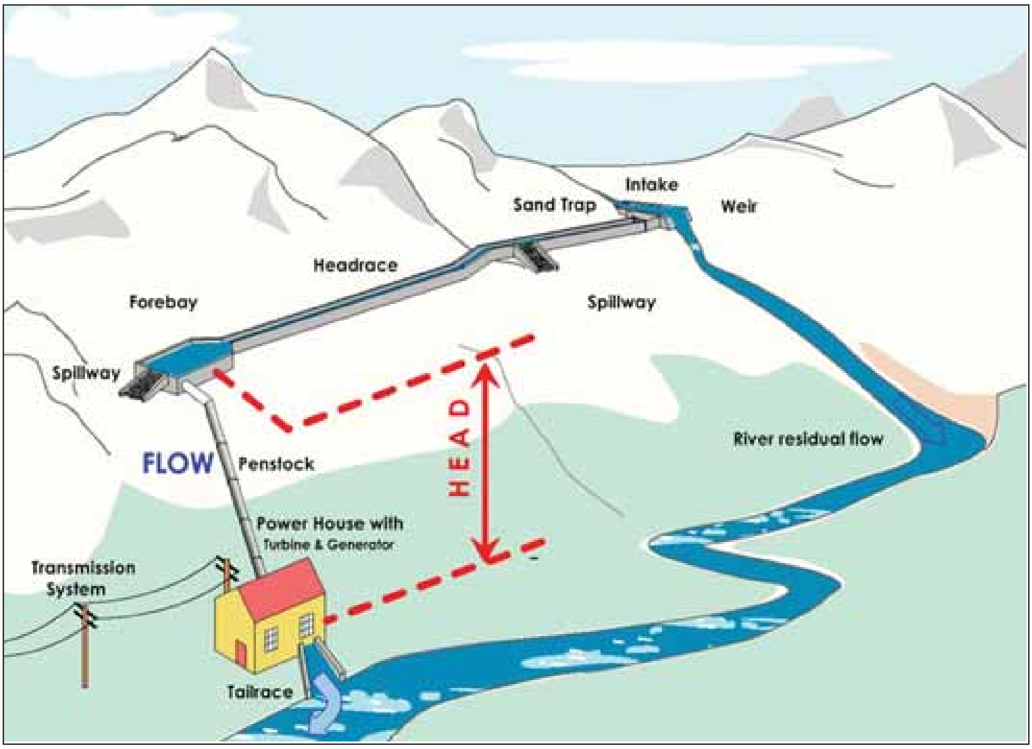
- Rivers and streams
- Water sources
- Water supply mains
- Waste water systems

To create electricity in a small hydro power station the following two questions are essential:

- How much water is available throughout the year for the turbine (flow)?
- What is the possible difference in height (head)?

1.2 RUN OF RIVER HYDRO POWER STATION

Flow and head are the most important parameters for the design of a hydro power plant.



Typical example of a diversion type run-of-river hydropower plant

- A run-of-river hydropower plant is a MHP without any reservoir or storage capacity
- A diversion-type hydropower plant is a MHP where the water is diverted from the river into a channel and/or penstock system

- In general, there are two types of MHP regarding grid connection:
  - Isolated MHP
  - Grid connected MHP
- In some aspects the design of an isolated MHP is different than the one of a grid connected. Most components, such as civil works and hydraulic components are the same
- In some cases, MHP are built as isolated MHP and later are connected to the grid

Note:

CHOOSING INCORRECT PARAMETERS AND DEVELOPING THEREWITH A NON-OPTIMIZED DESIGN RESULTS IN MASSIVE COST INCREASES OR UNSATISFYING PERFORMANCE!

IT IS THEREFORE STRONGLY RECOMMENDED TO CALL AN EXPERIENCED MHP EXPERT FOR THE DESIGN PHASE!

1.3 FEASIBILITY

The most important information which must be available is the general location and topography of the site, the flow which is available in the river throughout the year and the head difference which can be utilized. Additionally it is important to know the distance to the potential electricity consumers and/or the closest power line near by.

1.3.1 Site Identification and Flow Measurement

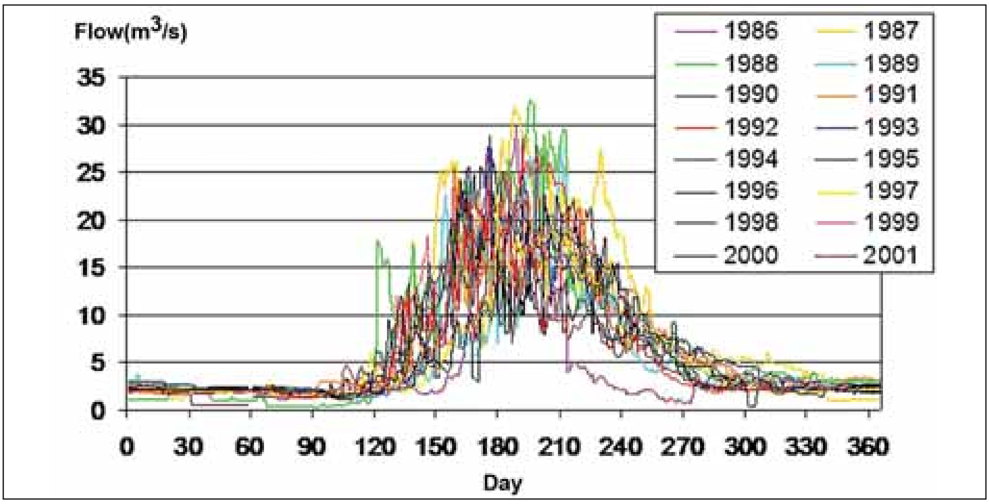
The following information must be gathered:

- The water flow during the whole year with maximum and minimum flow
- The optimal layout of the whole scheme with intake, headrace, sand trap, penstock, powerhouse and tailrace
- Size and length of transmission and distribution line from power house to the users of the electricity
- A demand forecast for households, small industries and social infrastructure facilities for be connected in the future

Collect river/stream flow data

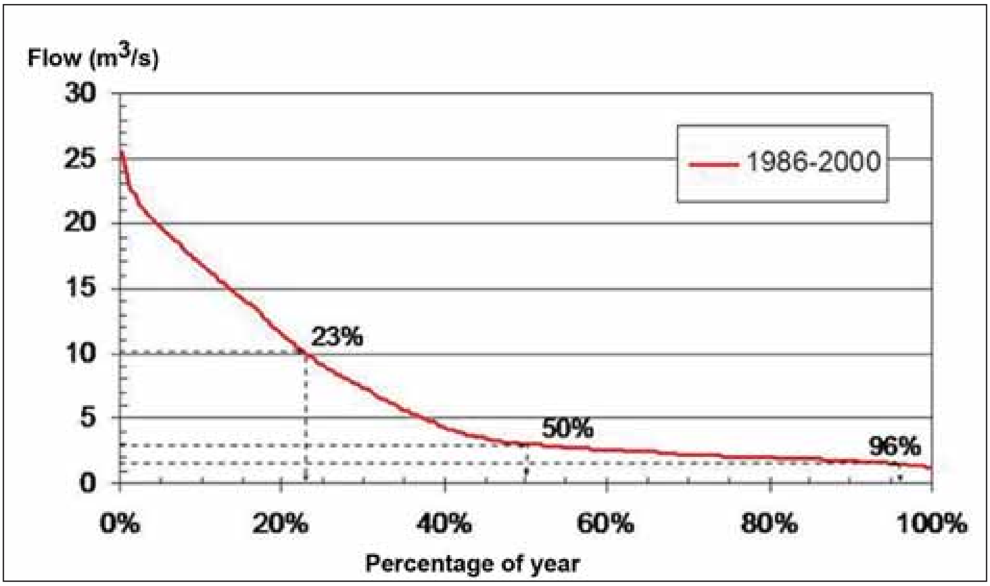
For hydro power design it is very important to have flow data over as many years as possible to be sure how much water (in rainy and dry season) is available to run a turbine. These data give the designer the basic information for the selection of a turbine that works most efficiently.

With this information and the demand of the consumers, the designer can choose the proper turbine and generator as well as he can define size and length of the grid for an isolated MHP.



Hydrographs for a 16 year period

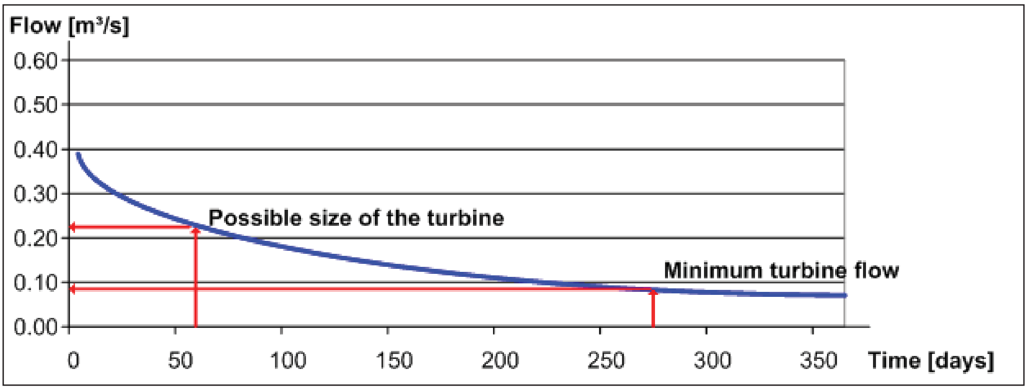
The figure shows daily flows measured over a period of 16 years. This is an ideal data situation. In reality, such good data are often not available.



Flow duration curve

A so-called flow duration curve is generated by sorting all measured flow data size wise and printing them over 100% of the time covered by the measurements. The diagram says for example that during 23% of the time the discharge is higher than 10 m3/s. This curve is the most important information for the design of the hydropower plant. If it is not based on good data everything else becomes equally speculative as well.

If the required measurements are not available, then the flow should be measured and recorded every day during minimum one year in order to get the following curve:



Example of a flow duration curve for one year

The flow duration curve is generated from the river discharge curve by sorting all the 365 values. Based on the flow duration curve, the designer evaluates the available capacity. The dimensioning of the plant depends on the available flow of water and the estimated future demand of the customers. Ideally the MHP should allow covering the demand all around the year. If the demand is higher than the available capacity, alternative energy resources have to be identified and/or energy efficiency measures have to be taken into consideration.

If you cannot get good measurements over an extended period of time you need the help of an experienced hydrologist for this analysis.

1.3.2 Rough Calculation of Possible Hydro and Electrical Power

By answering the following questions you'll find out, if the scheme is worth to go ahead with the planning:

1. How much flow is available?
Measure and draw a water flow curve (hydrograph) as shown above for minimum one year. Take the minimum flow for your further considerations. This is the flow of water which you have available all year round.

2. How much head is available?
Measure the head from the location of the possible forebay to the place where the turbine is planned to be placed.

When head and discharge (water flow) is known, it is easy to calculate the theoretical hydro power:

$$P[W] = Q\,[l/s] \times H\,[m] \times 9.81$$

P = Power in Watt
Q = Minimum available flow
H = Head, difference in height in meter

This formula shows the hydraulic capacity only and refers to 100% efficiency without losses. Losses in penstock, turbine, gear transmission, generator and electricity transmission reduce the final electrical power. By calculating losses of 20….30%, the final electrical power will approximately be:

$$P[W] = Q\,[l/s] \times H\,[m] \times 7$$

EXAMPLE:

Let's use the flow duration curve for one year on one of the previous pages as an example. The minimum turbine flow which is indicated there is around 90 l/s. This flow is exceeded 275 days per year, the remaining 90 days the flow is slightly smaller so the hydropower plant will generate less power accordingly. Let's assume that we have a head of 30 m available. In this case the power generation will be:

P[W] = 90 [l/s] x 30 [m] x 7 = 18,900 Watt

So this MHP will generate almost 19 kW.

If the designer chooses a larger turbine, let's say with the design charge of 220 l/s, the MHP could generate around 46 kW, but only for about 60 days every year, during high flows. The remainder of the year, around 300 days, the MHP would generate much less power, depending on the discharge which is available.

1.3.3 Estimate Electrical Load

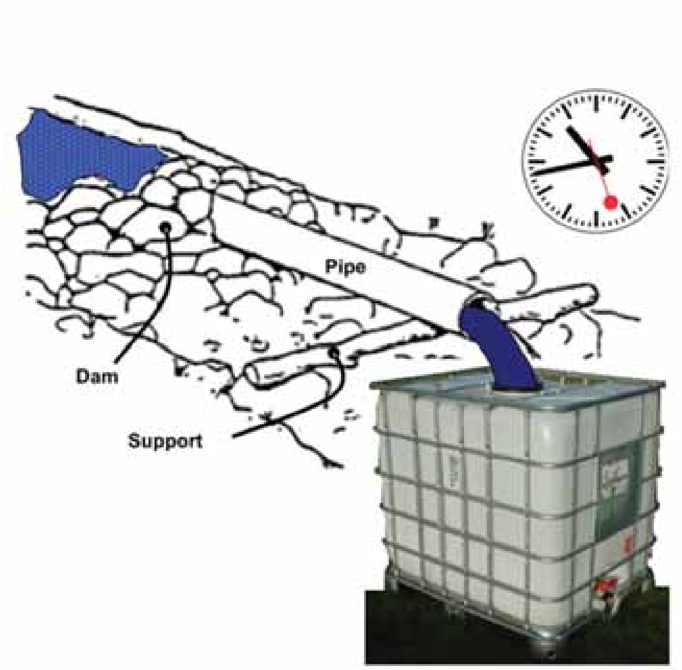
Try to estimate the required electrical power supply needed for all households, public infrastructure facilities (e.g. schools, markets, clinics, community buildings, and street lightings), workshops, etc in the electrical system. For each household calculate around 50…150 W for lighting, radio, TV, fan, refrigerator, etc.
With the flow of the above example around 190 households can be supplied all year round by a possible MHP.

1.3.4 How to Measure the River/Stream Flow

It's not easy to measure an accurate flow of a river or stream!
The flow measurement has to be taken every day during one full year. For this the installation has to be appropriate and robust. Depending on the size of the river or stream there are different methods to measure the flow:

- Bucket Method
- Float Method
- Current Meter Method (Velocity-Area Methods)
- Sharp Crested Weir Method
- Salt Concentration Method

Bucket Method



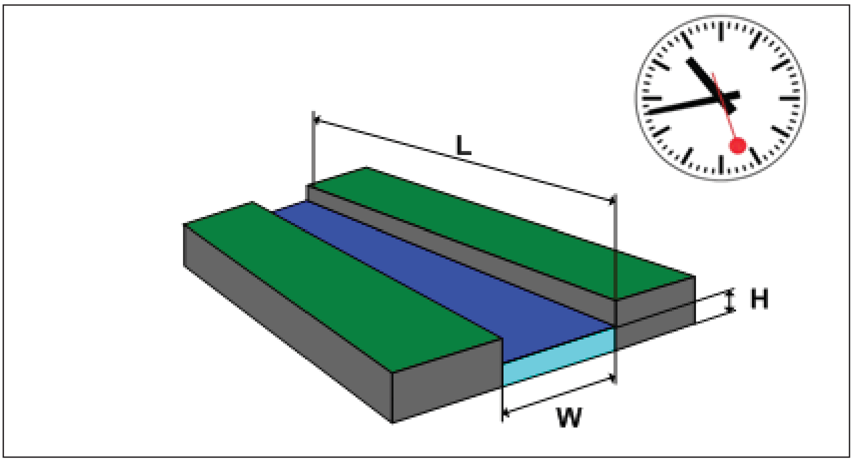
For small flow (around 20 l/s) only

- If you have only a small flow you can do the measurements with this method.
- It's important, to take a big tank (around 1,000 liter) with drain plug at the bottom
- The flow to be measured is diverted into the tank of known volume
- The time it takes to fill the tank must be recorded
- By dividing the volume (in liter) of the tank by the filling time (in seconds) the flow in liter/seconds can be calculated

Note:

THIS METHOD IS VERY ACCURATE IF YOU ARRIVE TO REALIZE SUCH AN INSTALLATION! BUT USE IT FOR SMALL FLOWS ONLY!

Float Method



For flow > 20 l/s

Profile

Define the cross section area first. Normally it's more difficult than in our example (Cross section = H x W). Try to divide the whole cross section into several sections, when the profile is not rectangular, and add the different sections together to define the whole cross section.

Float

For a known length of the stream (L), an average cross section should be available, where a half filled plastic bottle of water has to be timed over a measured length (L = 10…20 m). By multiplying cross section area with average flow velocity, an estimation of flow rate can be made now. For any case a correction factor of +/- 20% must be applied.

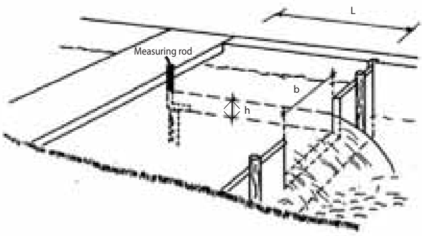
Current Meter Method (Velocity-Area Methods)

- At any point in the river, the velocity is different – faster on the surface and slower on the bottom. The velocity of the flow can be measured at different depths and at any point of the river's cross section by a so called current meter
- The values have to be averaged. The velocity measurement data are then used to calculate the actual flow, based on the area of each segment
- Before starting the velocity measurements, mark the cross section with a horizontally laid out piece of steel or timber to get a reference height. Note the location of the cross section on a map and also note date and time of the flow measurement

Note:

THIS METHOD IS SUITABLE FOR FLOW VELOCITIES RANGING FROM 0.2 - 5 m/s AND WHERE YOU CAN SAFELY WADE THE STREAM!

Sharp Crested Weir Method



Why is this a good example?

- Sharp crested weirs with controlled flow provide good flow measurements

But:

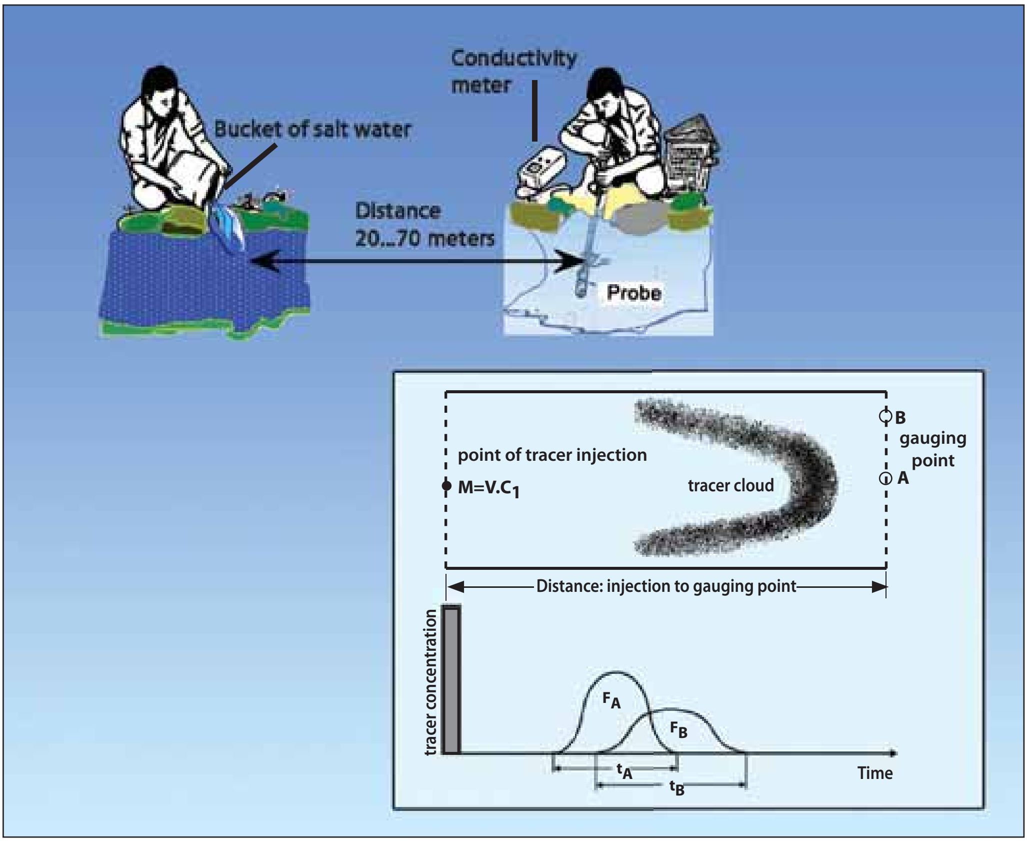
- The installation is not easy and needs a lot of skill and experience
- Reference tables have to indicate relation between height h and flow Q
- The weir on the picture is not quite rectangular

For rectangular weirs with b = 1 m and L is approximately 2 – 3 m, the flow can be read out from following table:

h[m]	Q[l/s]	h[m]	Q[l/s]	h[m]	Q[l/s]	h[m]	Q[l/s]
0.01	1.7	0.22	185	0.58	792	1.15	2210
0.02	5	0.24	210	0.6	833	1.2	2360
0.03	9	0.26	237	0.62	875	1.25	2500
0.04	14	0.28	265	0.64	918	1.3	2660
0.05	20	0.3	294	0.66	961	1.35	2815
0.06	26	0.32	324	0.68	1005	1.4	2970
0.07	33	0.34	355	0.7	1051	1.45	3130
0.08	40	0.36	387	0.72	1095	1.5	3295
0.09	48	0.38	420	0.74	1141		
0.1	56	0.4	453	0.76	1188		
0.11	65	0.42	488	0.78	1235		
0.12	74	0.44	523	0.8	1283		
0.13	84	0.46	558	0.85	1404		
0.14	93	0.48	596	0.9	1530		
0.15	104	0.5	634	0.95	1660		
0.17	125	0.52	672	1	1793		
0.19	148	0.54	711	1.05	1930		
0.2	160	0.56	751	1.1	2069		

- Any material can be used for the weir, but the notch should have sharp edges (metal is the best)
- Weirs are always oriented at a right angle to the stream flow
- If b is wider or narrower than 1 m you can simply multiply the Q values in the table by the same ratio. Let's say for a 0.8 m wide weir you multiply the Q values by 0.8 and for a 2 m wide weir you multiply the Q values by 2
- A sharp crested weir is also a good device to generate a flow duration curve (hydrograph) over a longer period of time, e.g. one year. You only need to install a staff gauge 2-3 m upstream of the weir, read the gauge level every day at the same time, calculate the discharge based on the table above, and write this into a table

Salt Concentration Method



The figure shows intensity of conductivity

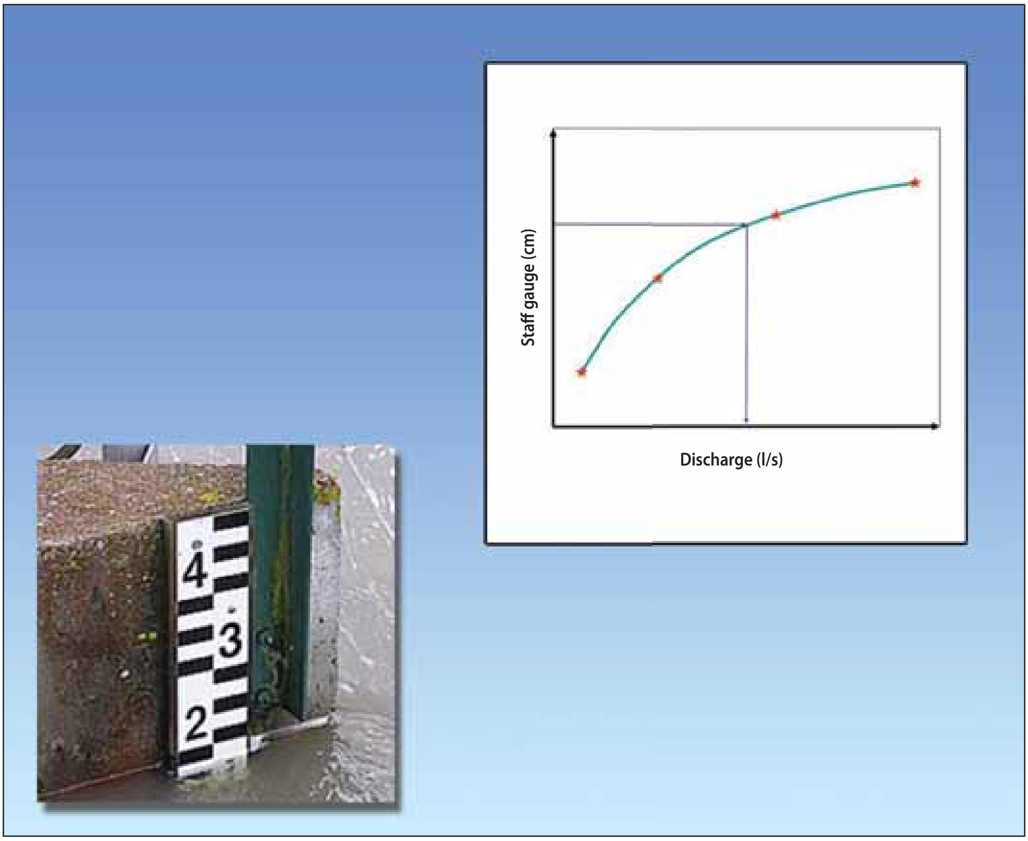
- A bucket with salt water of known concentration is poured into the middle of the stream. The salt concentrate cloud will be spread by the flow of the river
- The probe is inserted at least 20 times the river width downstream to measure the electric conductivity of the stream / salt concentrate mixture. So if the river is 10 m wide, you should measure at least 200 m downstream
- The stream flow will be measured and calculated by the conductivity meter

Note:

THIS METHOD OF MEASUREMENT CAN ONLY BE USED BY A TRAINED PERSON WITH PROPER EQUIPMENT!

1.3.5 Discharge Measurements and Flow Duration Curve

Of course it is a considerable effort to measure the flow, no matter which method you use. So you only want to do this a few times but it must be at different flows, let's say during the lowest flow you can observe, and full river flow and two smaller flows in between. At the same time you always measure the stage of the river at the same location and you must install a permanent staff gauge for this purpose. Then you can develop a relationship between the stage and the discharge, based in your measurements. It is a simple curve, shown green in the figure below.



Staff gauge for quick and easy water level reading

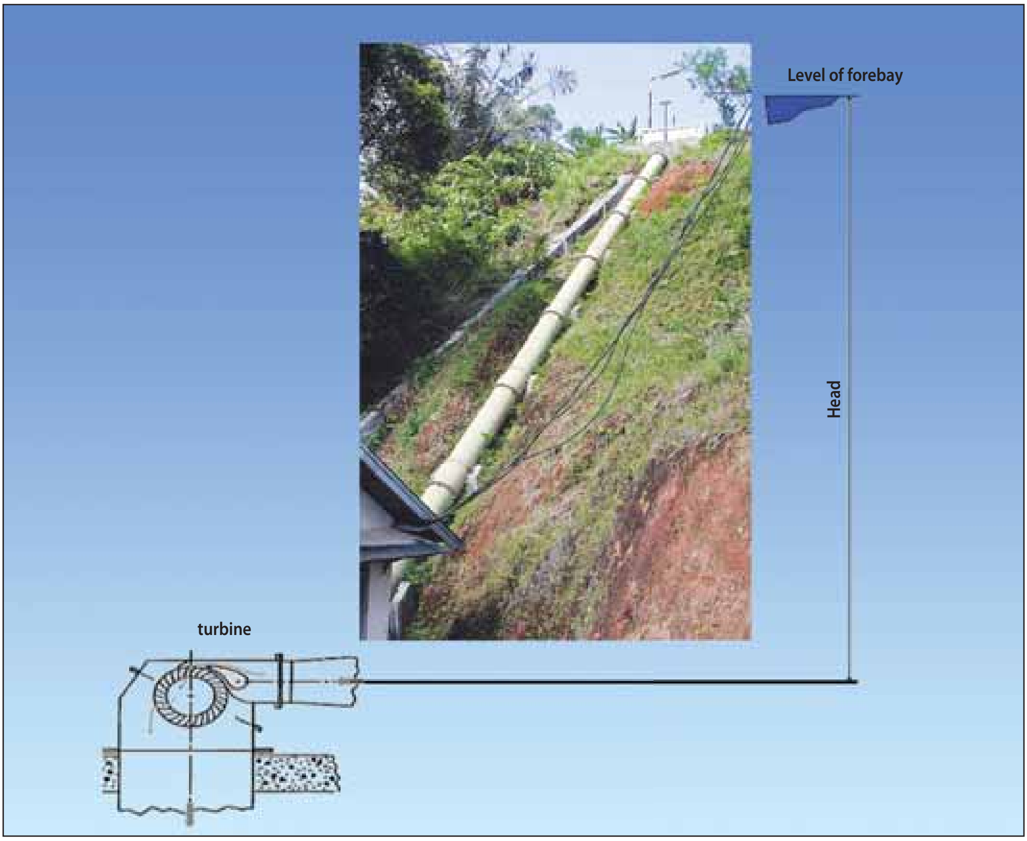
The red stars represent the measurements which you have taken. From then on you must only measure the stage, let's say every day at noon, and your curve will tell you what the discharge is at the same time. The two blue arrows indicate how this works. If you do this for one year you have the perfect data for a flow duration curve.

Note:

IF YOU DO NOT UNDERSTAND THIS PROCEDURE YOU MUST HIRE AN EXPERT TO HELP YOU!

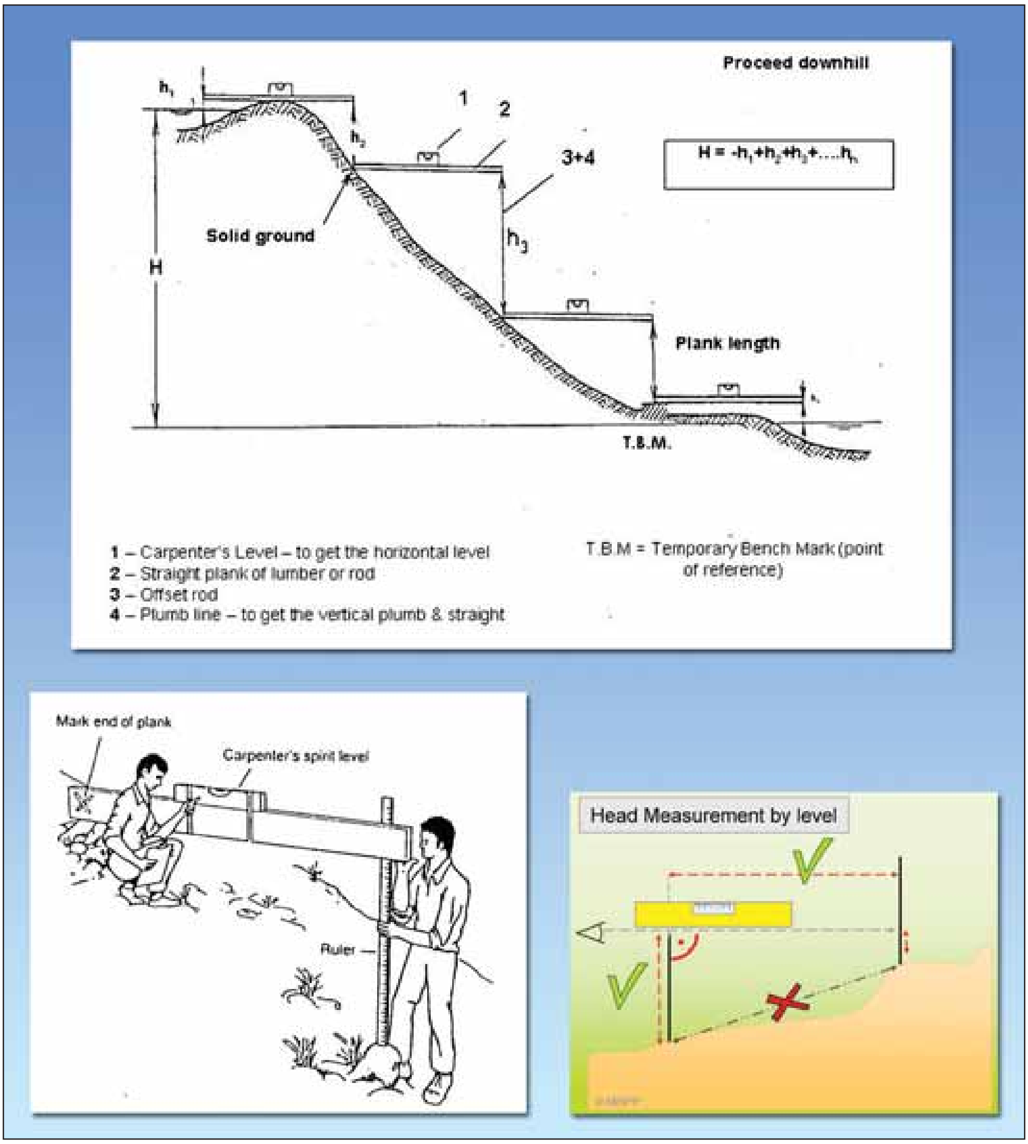
1.3.6 Head Measurement

Head is the difference in height between the water level of the planned forebay and the planned position of the turbine shaft. There are different ways to measure it.



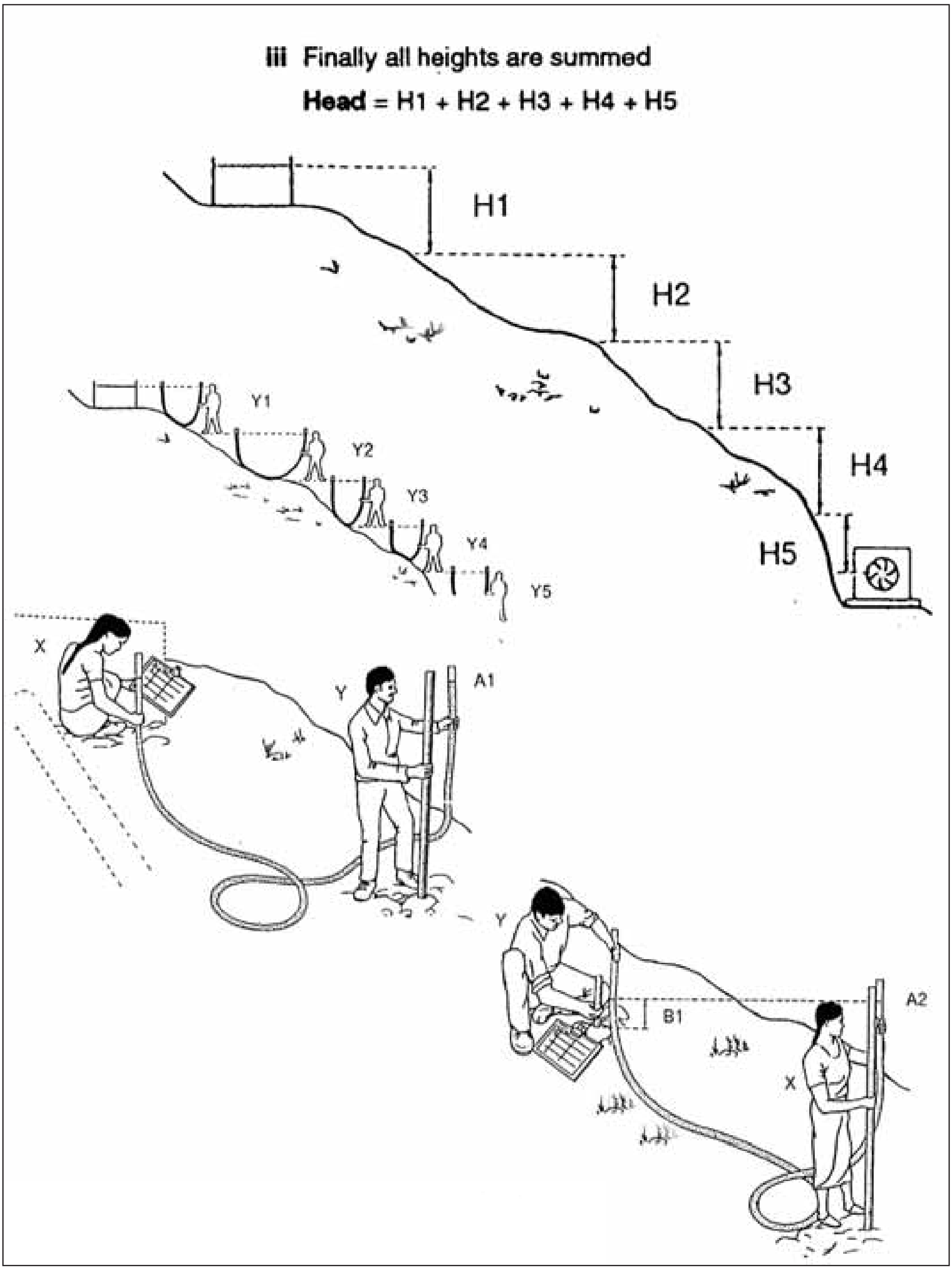
Schematic example of head measurement

Head Measurement by Level



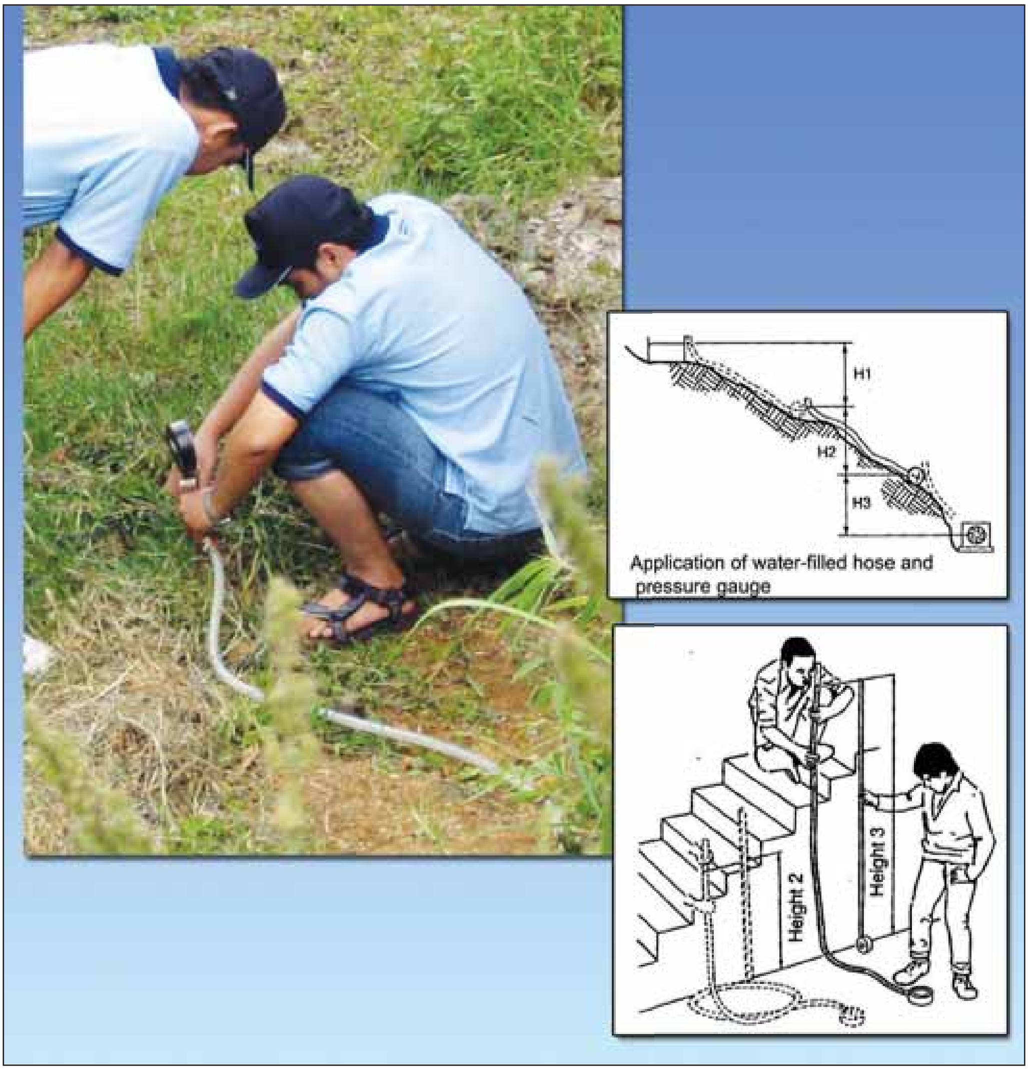
The principles of measurement by the levelling method

Head Measurement by Water Level



This method is similar to the levelling method, except that a water-filled hose is used

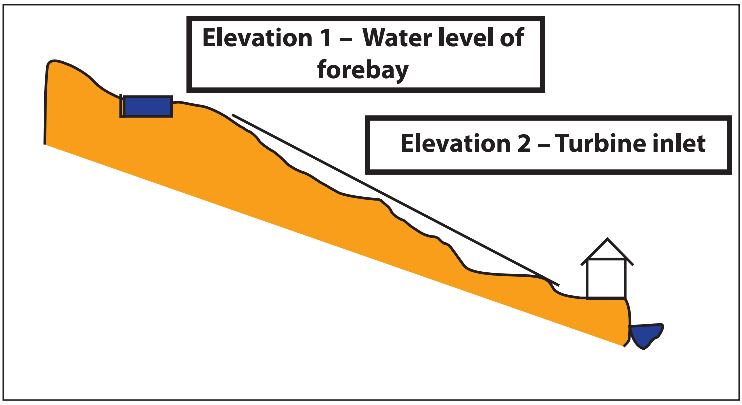
Head Measurement by Pressure Gauge



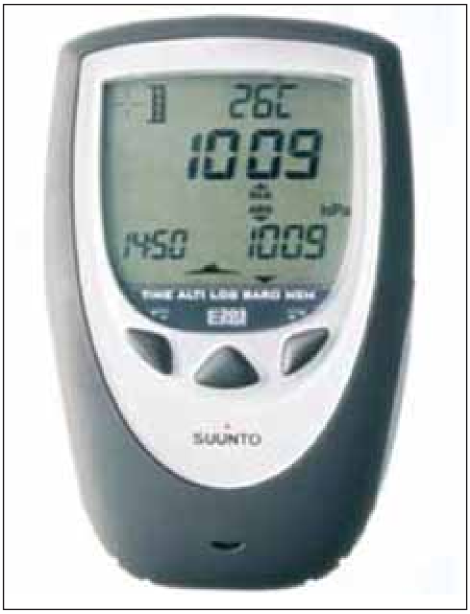
What are the specifics of this simple head measurement method?

- Only a pressure gauge and a clear plastic hose are needed
- Only two main errors can arise:
  - The gauge is not properly calibrated
  - There are air bubbles in the hose
- First calibrate the gauge scale from a low to a high reading; do that 5 times to get reliable results
- Check the size and length of the hose, because the water-filled hose must be carried around the entire length from intake to tailrace
- Record all data on a chart

Head Measurement by Barometer/Altimeter



Head is the difference of elevation 1 and 2

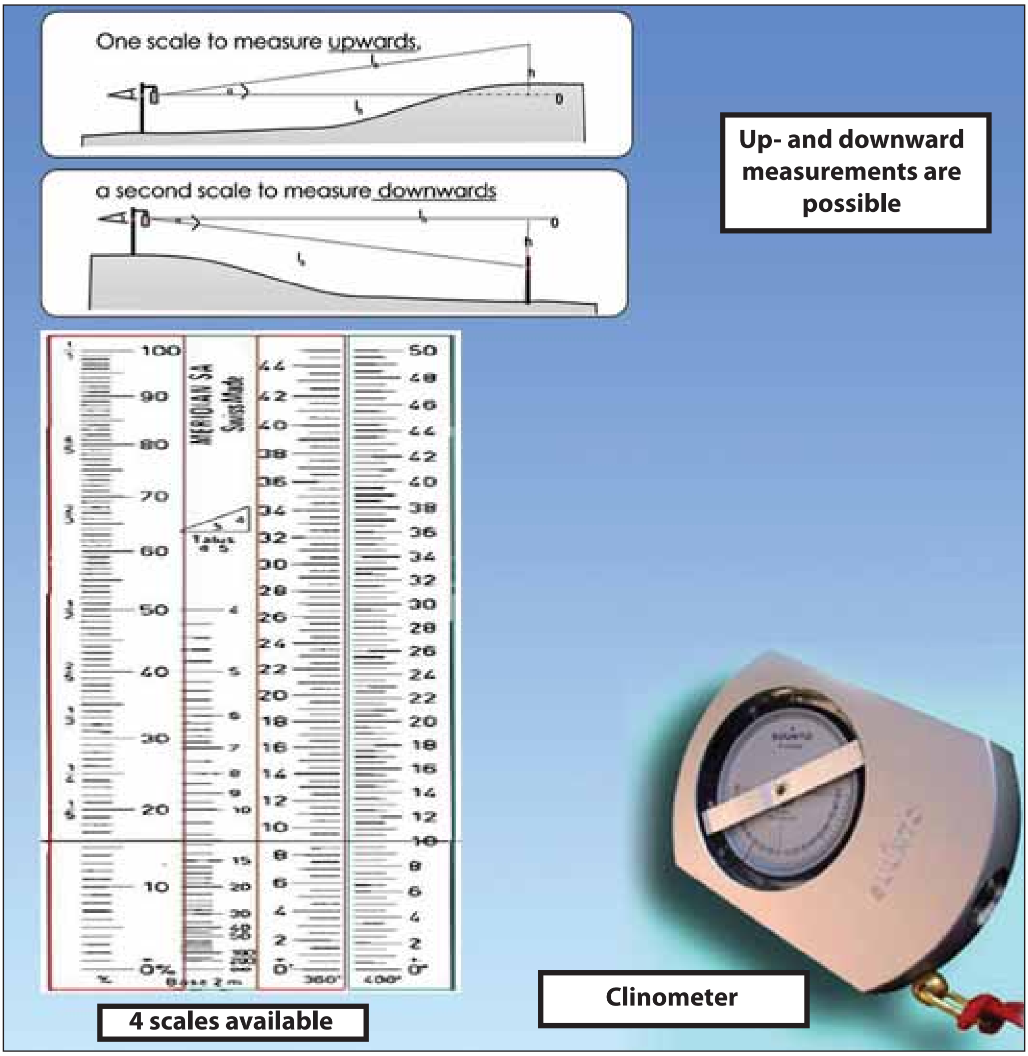


An altimeter is based on atmospheric pressure. The atmospheric pressure is different at different elevations. It decreases with increasing elevation above sea level.

When to use an altimeter?

- Use this method only during stable weather conditions
- Measurements should be carried out in a short time
- Perform this measurement several times and then calculate the average head
- Do not use this method for low heads. Because barometers have considerable uncertainties this method should not be used for heads less than about 50 m
- This method is recommended as a first quick measurement which later must be validated by more accurate measurements

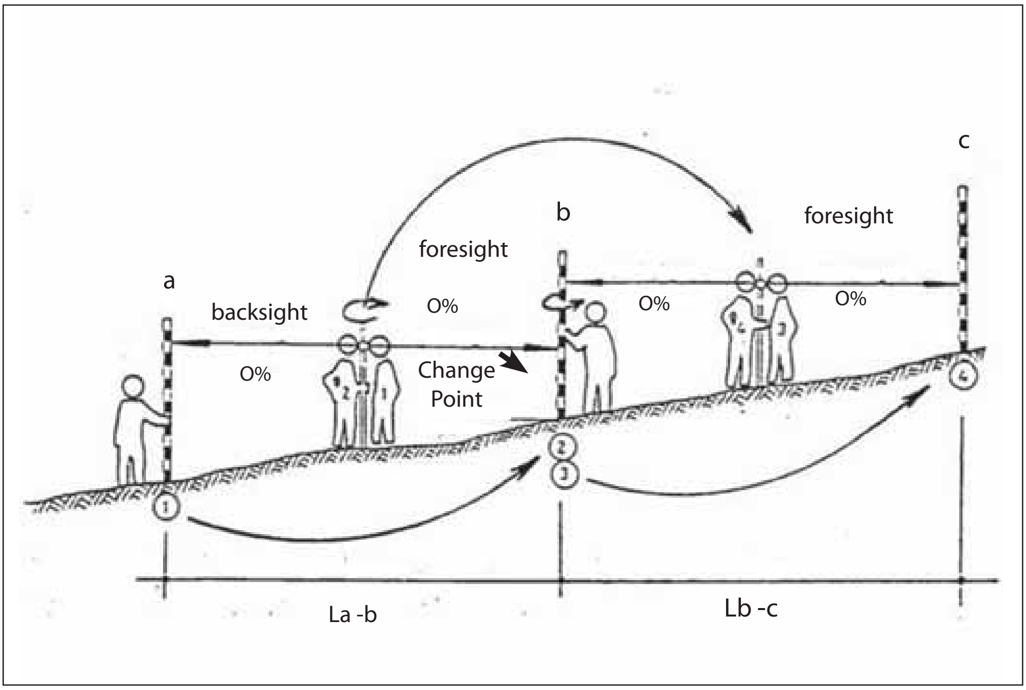
Head Measurement by Clinometer



What is the use of a clinometer?

- Different measurements can be performed with a clinometer:
- For angle measurements the clinometer must hang vertically
- For slope (%) measurements the clinometer must be held and pointed with the "0%" at the bottom/top of the point to be measured
- For distance measurement the clinometer must be held and pointed with the "00" at the bottom/top of the point
- Best and most accurate results are obtained by either steadying the hand on the forehead or on a pole
- From the measurement the difference in height between the two points can be calculated

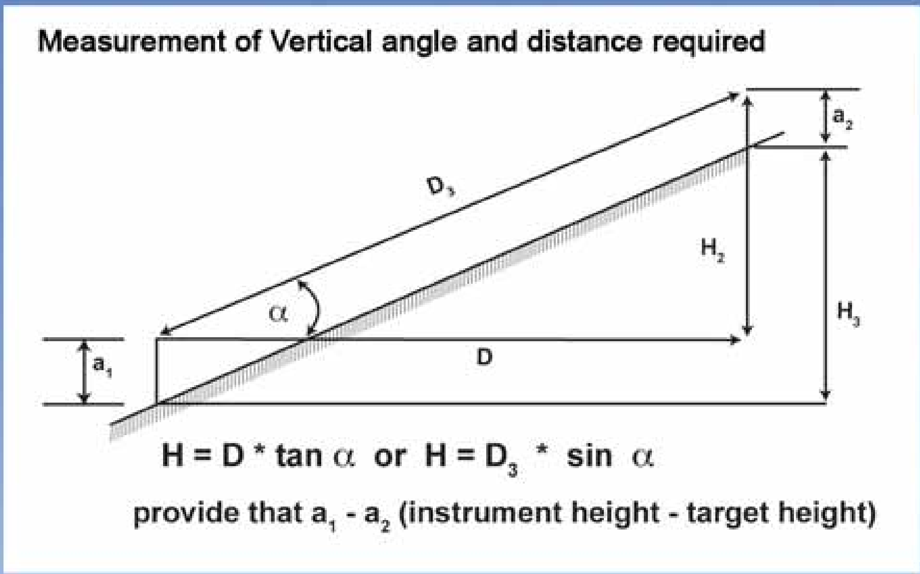
Head Measuring by Level Instrument



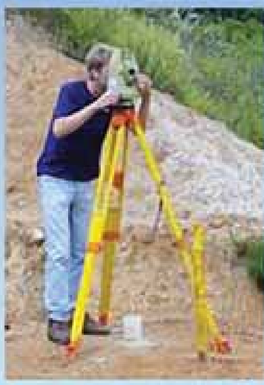
Why to use an automatic level instrument?

- Measurements are fast and also work for longer distances, such as in flat terrain; in steep terrain, the instrument has to be set up more often
- The accuracy of measurements is very high, if they are done correctly
- Make sure that level instrument is set up horizontally on the tripod
- Level instruments can measure only in a horizontal line – no deflection is possible
- The result of measurement is the difference in height and distance between the two points where the rod is set up
- By recording all measurements and adding them up, the distance and the height (which is the available head) can be calculated
- This method is similar to the one used with a clinometer but more accurate

Land Survey Instruments (Theodolite or Total Station)



Theodolite



On site

Total Station

Specifics of the high tech instruments:

- A theodolite can measure distances, heights and angles, data are recorded manually
- A "Total Station" does the same, but the survey data are stored automatically on a memory chip
- These instruments are used by professional land surveyors
- For head calculation only, such instruments are not really necessary, but they can be very useful if larger areas have to be surveyed

Head Measurement with High-Tech Instruments

These instruments should be used by people who are trained to handle them as well as to analyze the data of the measurements

1.3.7 General Project Data

Try to get an answer to the following questions:

- Where is the project area located? – define coordinates by GPS
- Who will be the developer of the project, means which organization(s) support(s) the project?
- Find a person within the village for communication any time
- Find a person within the developer organization for communication any time
- How is the electrical infrastructure of the village developed? Assess existing grid with voltage and transformers/medium voltage lines with length and number of wires/low voltage lines with length and number of wires
- Is there good accessibility to the next village/town, market and suppliers, etc? – distance in km and time should be recorded
- Is transportation available? - type and cost of transportation
- Are the roads accessible all the year?
- Are neighboring villages or hamlets already connected to the electric grid?
- Draw an approximate map of the village and its location and context

Demographic and Socio-Economic Parameters

- How many households live in the main village and in its surrounding area?
- How many persons live in an average household?
- What is the population's growth rate in this area?
- Who has electricity already, and how many want to be connected to a mini hydro power system?
- Rate people's interest and understanding about the way to become "electrified"
- Find out the various sources of income – agriculture, trading, supply of labor, remittances, etc.
- Estimate the average monthly income of an average household
- How many persons are not employed and have no income or receive support from others?
- Are the villagers willing to pay for the use of electricity and how much can they afford monthly?
- Are there any public support systems for persons with low income?
- Which ethnic groups live in the area?

1.3.8 Synergies, Ownership and Management

Try to consider following points:

- Make note of any recent, ongoing and future (infrastructure) development projects
- Check out other involvements in the village, like NGO's, government or aid agencies
- Gauge the anticipated level of community participation
- Make sure there is enough involvement in tariff setting, making policy decisions such as how to handle payment defaulters etc
- What is the availability of local people with management / business skill as well as with civil, electrical and mechanical background?
- For the hydro power enterprise, explore and propose different ownership models (e.g. community-based, private, company-driven)

1.3.9 Energy Supply and Demand

- Is there any electric grid near the village for connection? If so, check out what is the least-cost option (electricity supply from the existing grid vs. setting up a stand-alone MHP scheme vs. selling surplus energy from the MHP to the grid)
- Lump sum payment or metered service?
- Clustering or separate installations?
- What is the domestic demand of each household? - lighting, radio, TV, fan, refrigerator, etc – ask all households
- Check the demand of public facilities, like: schools, market, clinic, community buildings, street lighting, place of worship etc.
- Are there any existing (or proposed) productive applications in the village: mill of any type, kiosk, manufacturing, cottage industry, etc.?
- Find out at what time and how long the various demand is needed, and when and how long are the peaks of usage
- Make a summary of all demand and calculate the daily, the annual and the peak demand for the village
- For the design add 15% or some other percentage for future extensions to the summary demand

Example: see following page!

Mini Hydropower Scheme xy

Load Estimate Established by: …….

Current and future (20 years from now)

Class: **Domestic**		Appliances (Wattage per unit)						
Quantity	Description	Lights	Fan (ceiling)	Radio	Fridge	Others (Iron, video, etc.)	Total per house	**Total [W]**
80	Currently connected households	150	30	50	100	0	330	26'400
	Future connections:						**Total domestic (current)**	**26'400**
90	xy village	150	30	50	100	0	330	29'700
40	yz village	150	30	50	100	0	330	13'200
30	zy village	150	30	50	100	0	330	9'900
100	New houses and appliances for 20-year period	150	30	50	100	200	530	53'000
							Total domestic (future)	**132'200**

Class: **Commercial**		Appliances (Wattage per unit)						
Quantity	Description	Lights	Fan (ceiling)	Radio cassette	Fridge	Freezer, Aircon, etc.	Total (premises)	**Total [W]**
5	Currently connected shops	150	30	150	100	2000	2430	12'150
2	Rest-house (Prov., Mothers' Union)	500	150	0	100	0	750	1'500
1	Diocese (rest-house, church HQ)	600	180	100	200	2000	3080	3'080
3	Butchery, Bakery, Fisheries Centre	150	30	0	0	3000	3180	9'540
2	Workshops	100	30	0	0	3000	3130	6'260
1	CEMA warehouse / office	150	30	0	100	0	280	280
2	Commercial banks	150	30	0	0	300	480	960
	Future connections:						**Total commercial (current)**	**33'770**
5	Trade stores	150	60	150	150	2500	3010	15'050
1	Rest-house	500	200	100	150	3000	3950	3'950
5	Workshops	100	60	50	100	5000	5310	26'550
	Other business expansions							20'000
							Total commercial (future)	**99'320**

Class: **Government**		Appliances (Wattage per unit)						
Quantity	Description	Lights	Fan (ceiling)	Fridge	Other appl.	Photo copier, computer	Total (premises)	**Total [W]**
10	Government Offices (incl. Telekom)	100	30	0	0	500	630	6'300
1	Hospital	2500	500	1000	10000	4000	18'000	18'000
1	School	2000	0	0	250	250	2500	2'500
	Future connections:						**Total government (current)**	**26'800**
	General expansions							20'000
							Total government (future)	**46'800**

Class: **Others**		Appliances (Wattage per unit)						
Quantity	Description	Lights	Fan (ceiling)	Fridge	Other appl.	Audio / Video	Total (premises)	**Total [W]**
2	Churches	400	0	0	0	200	600	1'200
10	Street lights	120	0	0	0	0	120	1'200
	Future connections:						**Total others (current)**	**2'400**
2	Churches	400	200	100	0	400	1100	2'200
20	Street lights	120	0	0	0	400	520	10'400
							Total others (future)	**15'000**

Grand total (current)	89'370	Watts
Coincidence factor	0.45	
Peak dem. Current	**40'217**	**Watts**
Grand total (future)	293'320	Watts
Coincidence factor	0.50	
Peak dem. Future	**146'660**	**Watts**

1.3.10 Consultants

MANY FACTS HAVE TO BE CONSIDERED BEFORE STARTING WITH HYDRO POWER STATION DESIGN!

When to look for consultants?

If communities intend to implement an electrical system they are well advised to ask a consultant for support:

- A hydro power station including an electrical system is a complex subject and the help of a reliable professional is very important. Only with such a professional you prevent mistakes in calculation, design, construction and operation
- If an electrical system should be installed the source for the energy has to be selected very carefully. Hydro, wind or solar potential will be checked in detail. The professional consultant will recommend the most appropriate energy system

Note:

SUCH SYSTEMS SHOULD NOT HARM THE ENVIRONMENT!

THIS FACT BECOMES MORE AND MORE IMPORTANT – EVEN MHP IF NOT DESIGNED, BUILD AND OPERATED PROPERLY, CAN HARM THE ENVIRONMENT IN CERTAIN CASES!

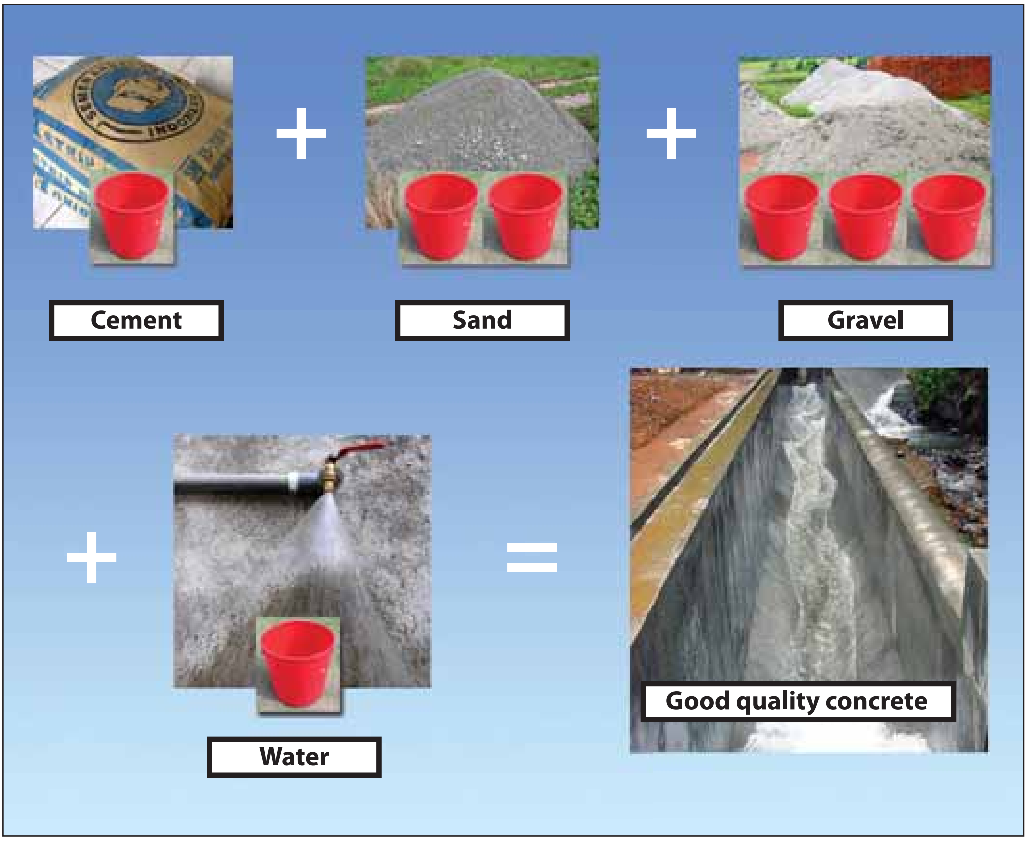





2. Civil Works

2.1 CONSTRUCTION BASICS

This chapter will provide general advice for construction and show a number of good and bad examples to illustrate what makes the important difference.



How to make concrete

What has to be considered for good workmanship?

- The quality of concrete depends on the correct proportions of all the ingredients, i.e. cement, sand, gravel and water
- Not enough cement in the mix makes weak, low strength concrete
- Too much water also makes poor quality concrete
- It is important to measure and add aggregates plus sand separately for making dense concrete of good quality
- Use only clean aggregates

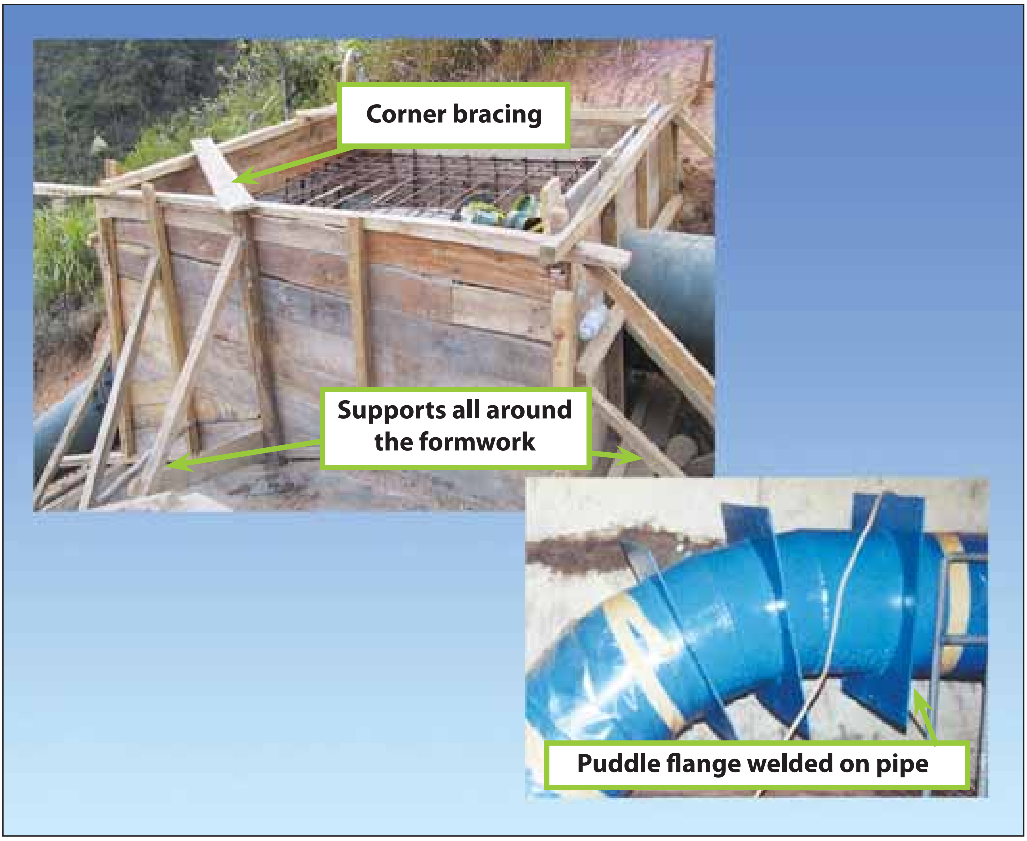
Note:

THERE IS NEVER AN ALTERNATIVE TO GOOD QUALITY WORKMANSHIP!

Construction of anchor block

What has to be considered for good workmanship?

- Good preparation is essential for good concrete
- Do not drop the concrete into the formwork from any height, but let it slip
- Maximum drop of concrete is 5 m, otherwise the aggregates get separated
- Avoid cold joints during concreting - do one section in one lift
- Make sure concrete fills all voids, use a vibrator, stir during pouring, knock on formwork from outside etc



Anchor block ready for concreting

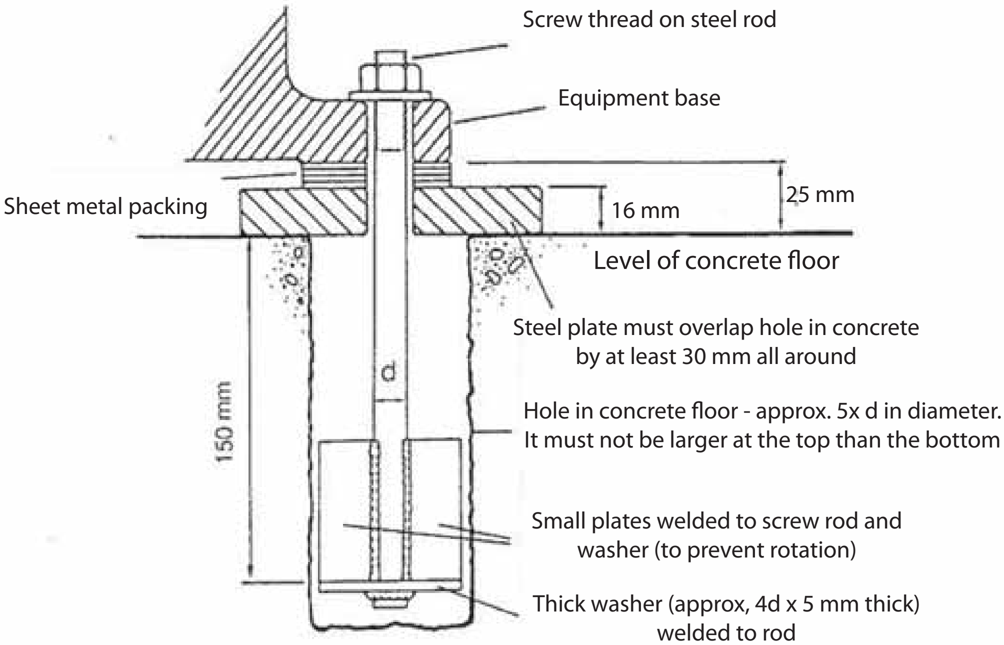
What has to be considered for good workmanship?

- The boards of the formwork are of good quality
- The supports are fastened to the formwork and braced against the ground to avoid movements during placing the concrete
- Puddle flanges are welded to the penstock pipe to better anchor it
- Reinforcement is in place and ready for concreting
- Formwork must be well fixed because it is impossible to hold it up when the concrete is being "poured" into the formwork
- Before pouring, clearly mark the necessary top of concrete surface to get enough coverage of reinforcement, at least 3 cm
- Vibrate concrete well – this will give concrete the density and fill all voids so it has the strength and quality to fulfill the task of an anchor block

Construction details of equipment foundation

What has to be considered for good workmanship?

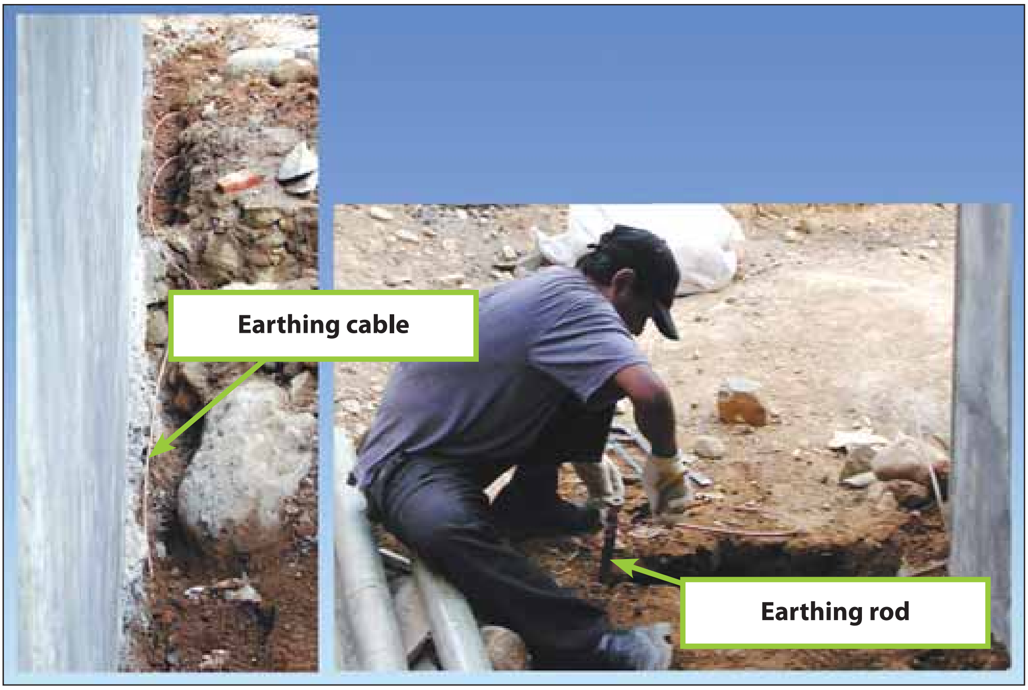
- The foundations of turbine and generator must be built with care
- A stable foundation avoids movements of the equipment which is absolutely necessary for a trouble-free operation of the plant
- The generator shown in the picture is properly fastened and adjusted by turnbuckles to keep the equipment stable and horizontal while the concrete is being placed
- An absolutely horizontal base is essential for a smooth transmission
- The earthing cable is connected to the reinforcement of the base and will be later also connected to the equipment itself. This is very important to avoid short circuits during operation
- In order to get good quality concrete, the concrete must be vibrated after being poured



Fastening of equipment to concrete floor without building a foundation

What has to be considered for good workmanship?

- If no new foundation is to be built, equipment can also be fixed to the concrete as shown above and described below
- This method is also applicable when a fastening bolt becomes loose and must be repaired
- Drill a vertical hole in the concrete floor and make sure that the top diameter is not larger than the diameter of the bottom of the hole
- For grouting use only high density mortar, non-shrink, and slow setting
- Pour mortar first and than insert bolt vertically; set equipment on top – during this operation the mortar is still soft and all parts are adjustable



Earthing must be done properly for the sake of safety

What has to be considered for good workmanship?

- Earthing is a safeguard system for people and machines
- Earthing cable must have a good connection to the earthing rod
- Use ONLY approved earthing clamps
- Length of earthing pole depends on the conductivity of the ground but must be at least 3 m long
- Earthing should be laid around the power house at the foundation level
- Connect all reinforced concrete foundations (power house and power equipment) and any other electrical equipment to the earthing ring
- Lightning conductor to be connected to earthing ring → 1 m above ground
- This connection will be used to measure the resistance for finding out if the earthing is still functioning as it should be

Note:

EARTHING IS A SAFEGUARD FOR PEOPLE AND MACHINES!

NO EARTHING → DEADLY DANGER!

Dealing with surface water; here: uncontrolled water flow

What has to be considered for good workmanship?

- Proper drainage of all structures is necessary for longer life expectancy
- The base of structures, e.g. foundation of power house, penstock supports etc, can be easily destroyed by water, unless they have a stable concrete foundation
- Flowing surface water will wash out soil and cause erosion underneath structures and foundations - keep an eye on surface water – where it comes from and where it goes
- Water discharge is an important subject of construction – do not neglect it

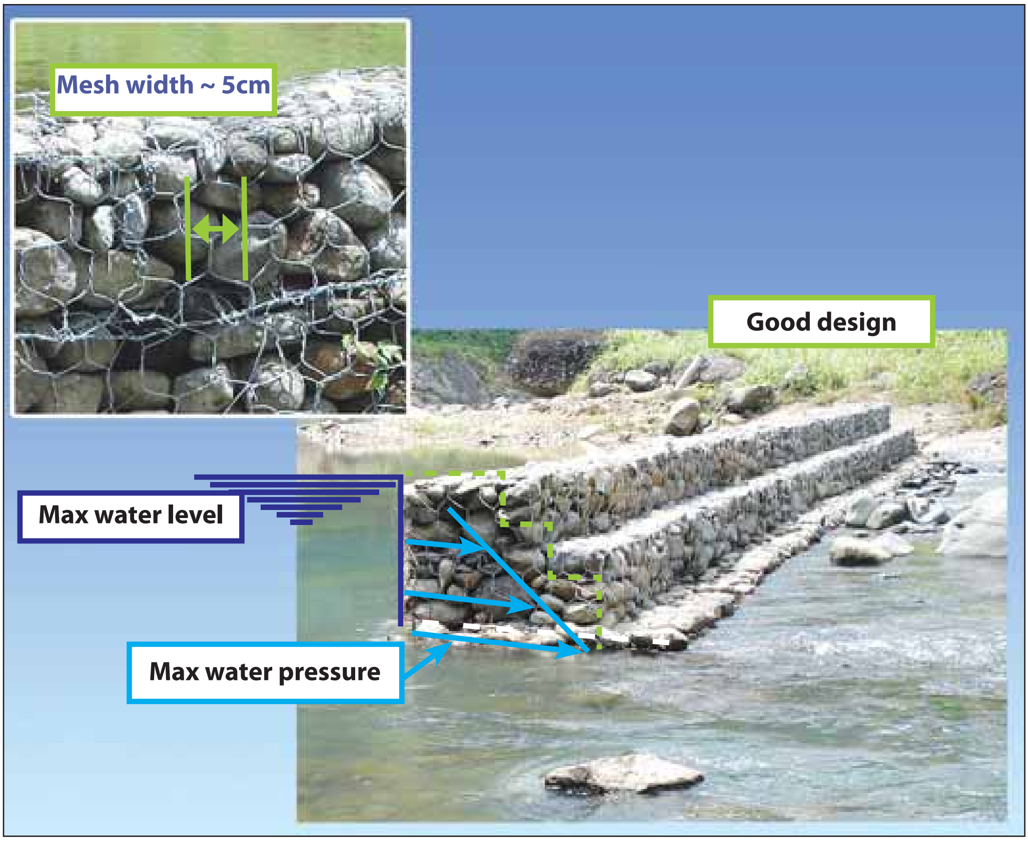
Note:

WATER CAN BE A HAZARD TO STRUCTURES!

Big structure without static design

What has to be considered for good workmanship?

- For all structures, especially for big ones, it is essential to have a static / structural design before construction works starts
- Choose material according to design and required strength
- Carry out works very carefully and follow the advice of the engineer
- Weak and unstable wall constructions can be a hazard to people when collapsing
- The flood following a broken retaining wall is very dangerous to people who live downstream



Gabion used for weir construction

What has to be considered for good workmanship?

- The dimension of the lowest row of gabions must be larger than the max. water pressure, e.g. if the water is 1 m deep, the lowest gabion should be 1.2 m
- All steps of the gabion weir must be above water pressure line
- To reach better stability of the construction, dig the lowest gabion into the river bottom
- Tie the gabion ends into the river banks or into wing walls
- As alternative to a straight alignment set the gabions in an upstream curve
- For better friction, the length of the upper gabion should be 2/3 of the length of the lower one
- Make sure that the maximum size of the wire mesh is 5 cm, definitely smaller than the smallest cobbles in the gabions
- Connect all gabions to each other
- Use only wire material that does not rust, such as galvanized or epoxy-coated

Headrace channel too close to a steep slope

What has to be considered for good workmanship?

- The side walls of a channel must be able to withstand the water pressure
- The water pressure is at the highest at the bottom of the channel
- Build the channel as a rigid box and/or dig the channel in deeper with enough undisturbed material remaining on the down slope side
- If there is no other alignment possible, use material which can withstand the water pressure → use concrete on a good base foundation
- The area around the channel should be well drained to lighten any water pressure and keep the slope from sliding

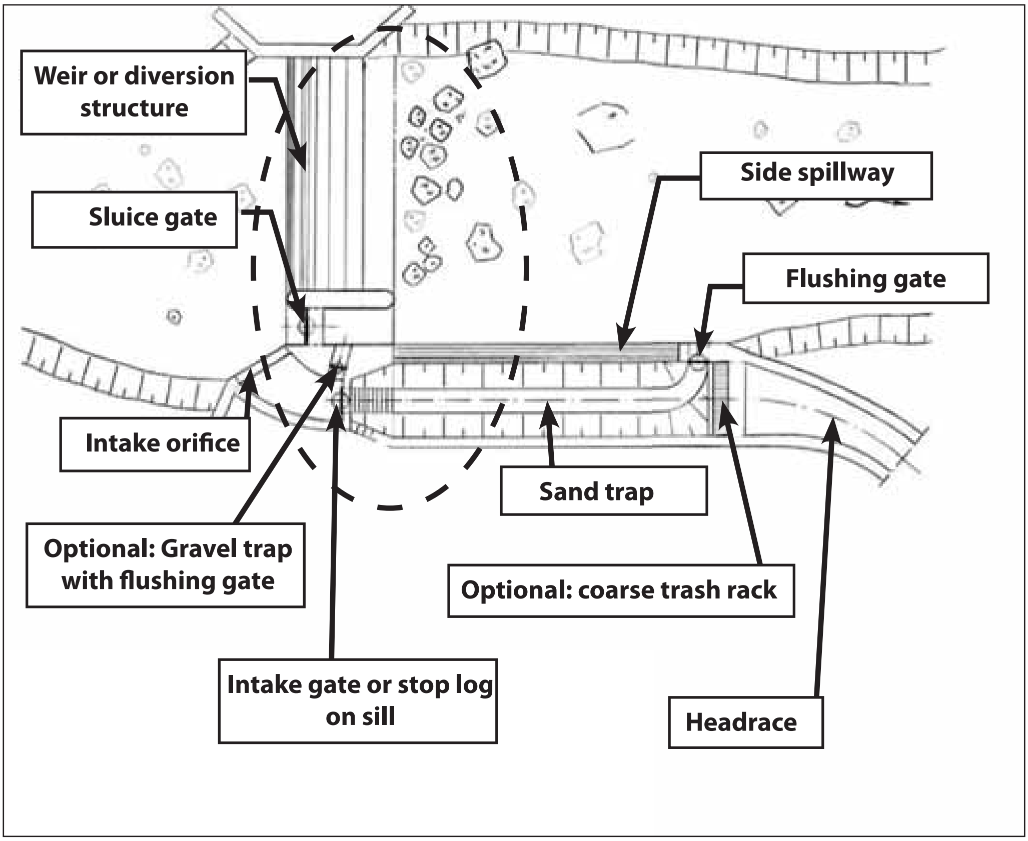
Broken channel invert caused by erosion and sliding

What has to be considered for good workmanship?

- A channel usually consists of two side walls and an invert (bed)
- If a channel has no upslope retaining wall, water will seep through underneath the channel and erode and damage the bed
- The money saved by not building an upslope wall will have to be spent for repairs of the channel – this becomes more expensive because the channel invert must be repaired too
- It is a good investment to build a retaining wall on the upslope side unless there is a stable rock face where only a thin liner is needed
- Upslope retaining walls also help to prevent that eroded material drops into the channel
- Make sure that the slope around the channel is well drained to keep the slope from sliding, place drainpipes underneath the channel

2.2 INDIVIDUAL COMPONENTS

2.2.1 Weir and Intake



Main elements of a weir and intake structure

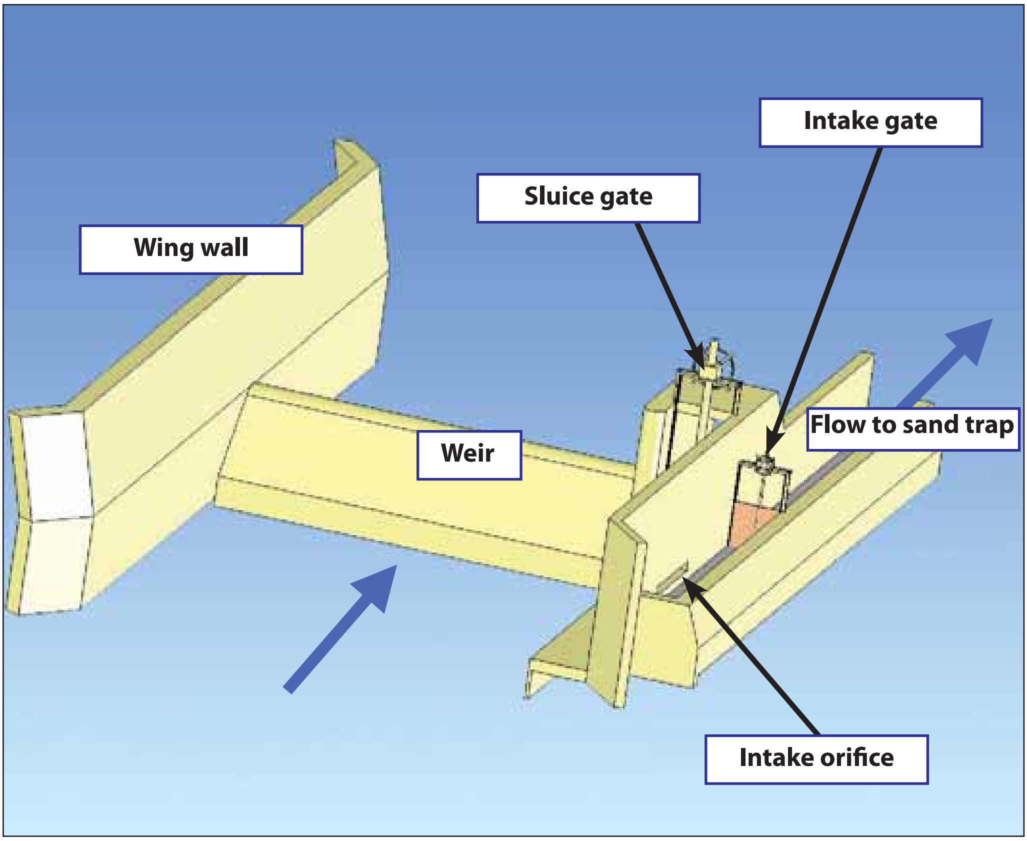
Main functions and design principles of weir & intake structure:

Intake must divert the required stream flow into the headrace channel at all times and all water levels in the river

Intakes should – if possible – be located on the outer side of a river bend to minimize sediment in headrace

Provisions should be made to exclude large floating debris (floating bar or submerged intake orifice) and coarse gravel (bottom sill) from the flow diverted into the headrace

The sluice gate must be installed close to the intake orifice in order to allow flushing of sediments depositing in front of the intake orifice



3D sketch of weir and intake

Main elements of an intake:

This drawing shows a typical combination of weir and intake including a sluice gate which can be used to remove deposited sand and gravel from the intake. The main function of the intake is to allow a certain amount of water into the sand trap and headrace and to keep sediments and floating debris away from the headrace system. Excess water must be returned into the river.

Most elements of a proper weir and intake structure are missing

How can I improve it?

- Build a weir equipped with overflow spillway, sluice gate and intake gate to the headrace or a properly dimensioned intake opening with stop log grooves
- The headrace should be built of concrete, masonry or similar material
- Side and wing walls up- and downstream of the weir are essential

Why?

- The river bed upstream of the weir must be flushed regularly to prevent sediments from entering the headrace
- An elevated intake gate or intake opening is needed to control the flow into the headrace and prevent sediments from entering
- If there is no gate, stop logs can be used to close the opening for O&M
- Without proper spillway the weir structure may be eroded and damaged during floods
- Without wing walls and sidewalls the river banks will be eroded

Main elements of a weir and intake structure

Why is this a good example?

- All elements necessary for a well functioning intake are included in this structure
- The main elements are well arranged
- The quality of construction is good
- The structure is well maintained
- Gates and access to the gates is covered by a roof

Examples of unsuitable dam materials

Concrete weirs can last for a long time

Why are these good examples?

- Concrete / concrete masonry is the preferred material for building weirs
- Mass concrete will withstand the high hydraulic loads during floods
- Concrete is a strong, durable material, also resistant to chemicals
- Concrete can be used for any type of weir

An unstable construction

How can I improve it?

- Build concrete columns on both sides
- Support the frame (yoke) of the gate solidly

Why?

- The gate slides inside the frame
- If the frame gets bent or twisted, the gate will not move anymore • flow cannot be controlled
- The frame could also get bent or twisted by a flood in the river or some other incident such as floating debris

The columns are good supports for the gate

Why is this a good example?

- The frame of the gate should be built as a solid wall or in strong columns
- The steel frame must be kept straight all the time to let the gate slide in the rails
- The gate must be able to be moved to control the flow to the sand trap and further on to the headrace and forebay

Points for operation and maintenance

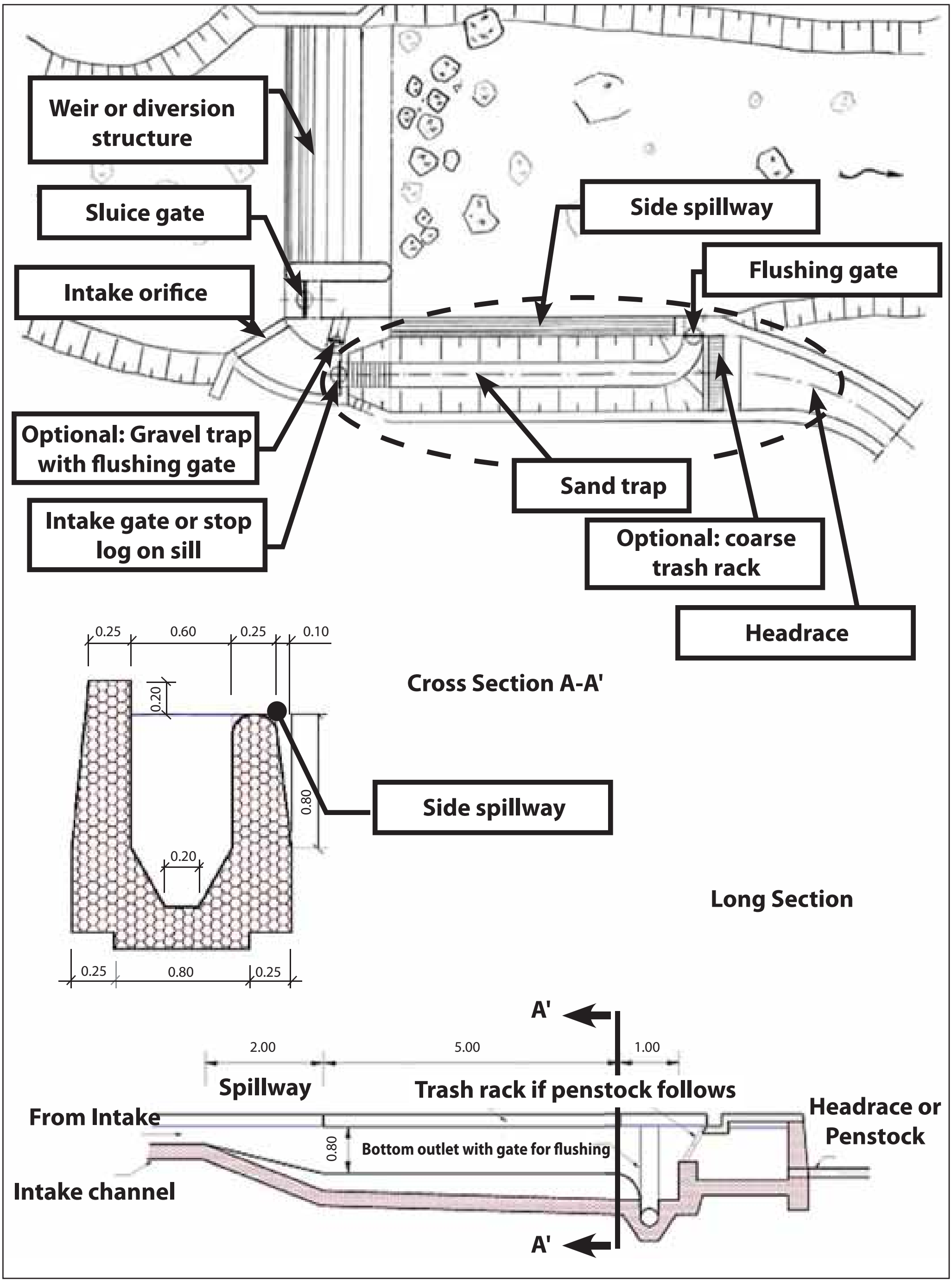
What must I do to keep system running well?

1	Daily	:	Keep the intake orifice clean
2	Weekly	:	Check for deposits, if there are any, flush at intake gate
3	Monthly	:	Flush through sluice gate to clean upstream basin
4	As needed	:	Apply grease on wheels and threads of the gates
5	During/after flood	:	Check for bank erosion behind wing walls
6	During/after flood	:	Check for erosion and damage in stilling basin and on downstream banks

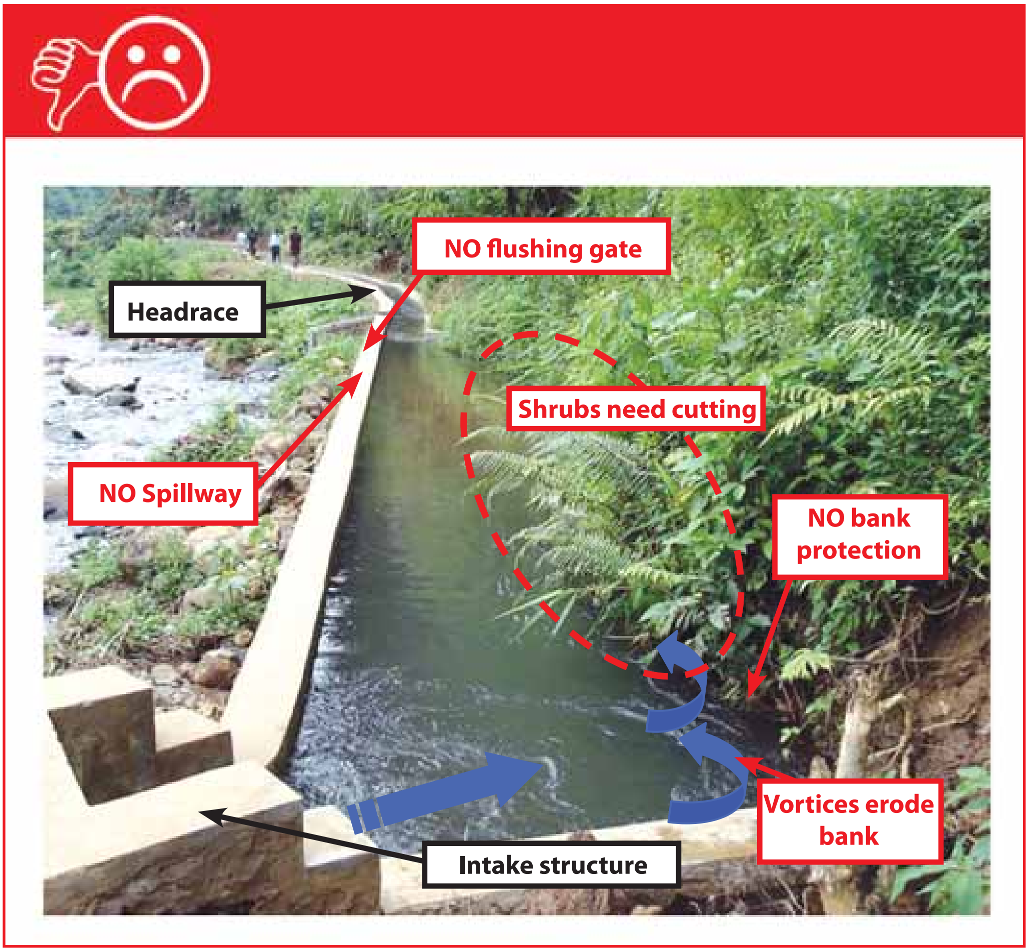
Note:

IF ANY PROBLEMS ARE FOUND, REPAIRS MUST BE MADE IMMEDIATELY!

2.2.2 Sand Trap - Settling Basin



Main construction details of a sand trap/settling basing



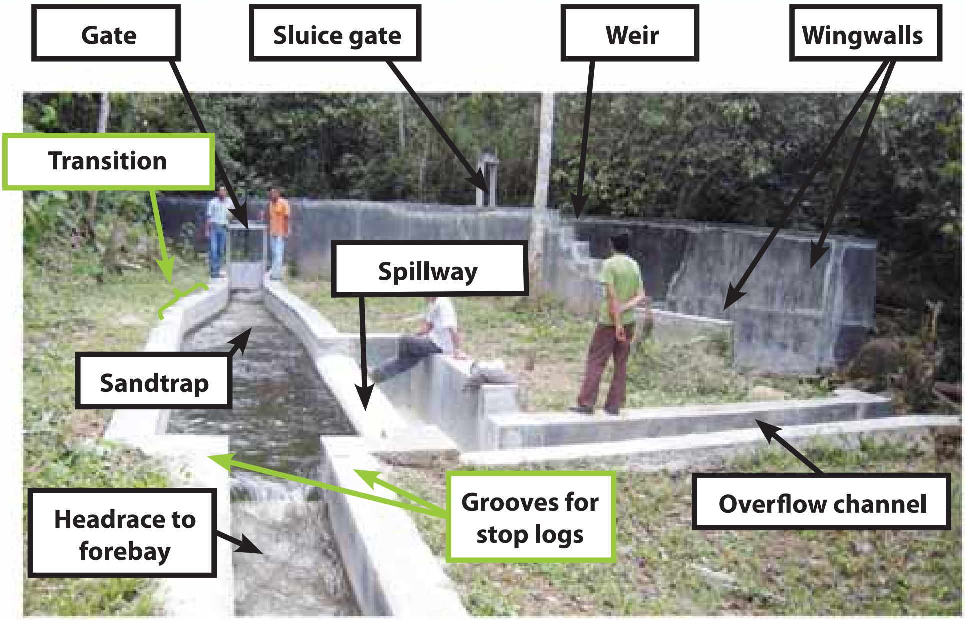
There are a number of problems with this intake

How can I improve it?

- Build a concrete wall further back on the hillside bank
- Cut back all shrubs and maintain regularly
- Spillway should be located at the end of the sand trap, NOT in the headrace trap

Why?

- Ongoing scouring by water will cause the bank to erode
- Settling out of sediment will be less effective if flow is not linear
- Sediments from bank erosion will silt up the headrace and will have to be manually removed because there is no flushing gate



This picture shows all main elements of a well designed water intake with sandtrap

Why is this a good example?

- The transition is important to calm and slow down the flow velocity
- Sediments settle out more easily when the velocity is low and the flow is linear
- The spillway controls the maximum volume of flow into the headrace
- Stop log grooves allow the insertion of boards to block the flow for cleaning and repairing the headrace

But:

- For a sand trap, the basin is too short, the flow velocity is too high and the sand may not settle down
- If the sand settles down, there is no flushing gate and the sand must be removed manually

Issues for operation and maintenace of a sandtrap

What must I do to keep the system running well?

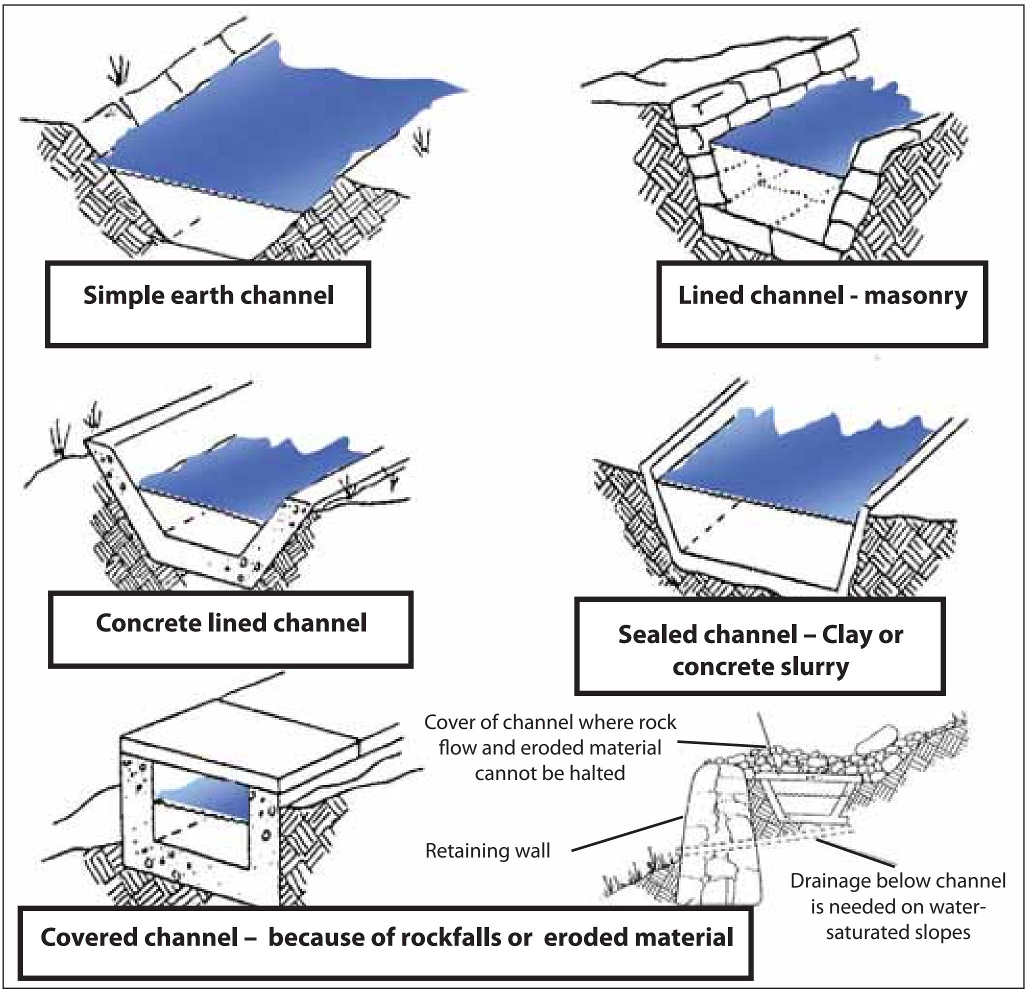
1. Remove any remaining sediment manually after flushing the sandtrap
2. Clean concrete surface from vegetation
3. Repair broken parts of the sandtrap
4. Check gates and/or stop logs to be ready for use (not shown in the picture)
5. Remove all grass, shrubs, debris and dirt – and do it regularly

Note:

SEDIMENT PARTICLES MAY DAMAGE PENSTOCK AND TURBINE!

CHECK AT LEAST ONCE A MONTH!

2.2.3 Headrace Channel



Examples of headrace channels

What do I have to consider regarding headrace channels?

- Avoid earth channels if possible at all → higher maintenance and higher risk of erosion material which could reach the turbine
- Cut slopes back from channel to avoid eroded material or rocks from dropping into the headrace channel
- Retaining walls must always be drained well with weeping holes to avoid sliding slopes
- Covered channel could also be replaced by a buried pipe → high costs
- Keep area along the channel free of vegetation → cut back regularly

Avoid steep eroding banks along headrace channel

How can I improve it?

- Do not build headrace channel close to steep eroding slopes
- Cut back slopes so there is no erosion material carried into channel
- Check headrace channel regularly, and clean as needed
- In sections where erosion material cannot be prevented, cover the channel e.g. with wooden boards
- Remove erosion material and sediments from the channel

Why?

- Steep banks without vegetation • more erosion material in the channel
- Erosion material can silt up and eventually block the channel
- Erosion material (=sediment) also reduces the flow capacity
- Erosion material could damage the turbine if not caught in the sand trap

The channel should be free of vegetation and away from steep slopes

Why is this a good example?

- The area along the headrace channel is free of vegetation → less debris from vegetation in the channel
- If steep slopes are away (or cut back) from the edge of the channel there is less risk of dirt and sediment dropping into the headrace
- Proper maintained grass is a good choice for earth slope, it stabilizes the banks and reduces erosion
- Inspection for operation and maintenance along the channel will be easy

But:

- The ditch between the channel and the slope must be cleaned from debris and kept open

Headrace channel must be free of vegetation

How can I improve it?

- Check headrace regularly and cut back vegetation
- Remove plants, leaves, debris, etc. from the channel regularly

Why?

- Vegetation in the headrace reduces the flow velocity and capacity which will cause more sedimentation in the channel and less flow to the powerhouse
- Too many leaves in the headrace may clog the trash rack

Vegetation well cut along the left bank

Why is this a good example?

- The area along headrace channel is kept free of disturbing vegetation
- Grass and shrubs are cut to keep path and left channel bank free

Note:

THE SLOPE ON THE RIGHT SIDE IS VERY STEEP AND EROSION MATERIAL WILL EASILY DROP IN THE EARTH CHANNEL. MAINTENANCE IS VERY IMPORTANT IN THIS SECTION OF THE HEADRACE!

TRY TO STABILIZE THE STEEP SLOPE WITH VEGETATION AND/OR OTHER BIO-ENGINEERING MEASURES!

Earth channel can erode easily when velocity is too high

How can I improve it?

- Line the channel with masonry or concrete, if possible
- Build drops in the channel to reduce the velocity of the flow
- Protect the drops with riprap against bed erosion
- Protect the outer curve of earth channels with rocks (riprap) to reduce erosion
- Prior to construction, draw a longitudinal section to determine the optimal slope based on the proposed channel material

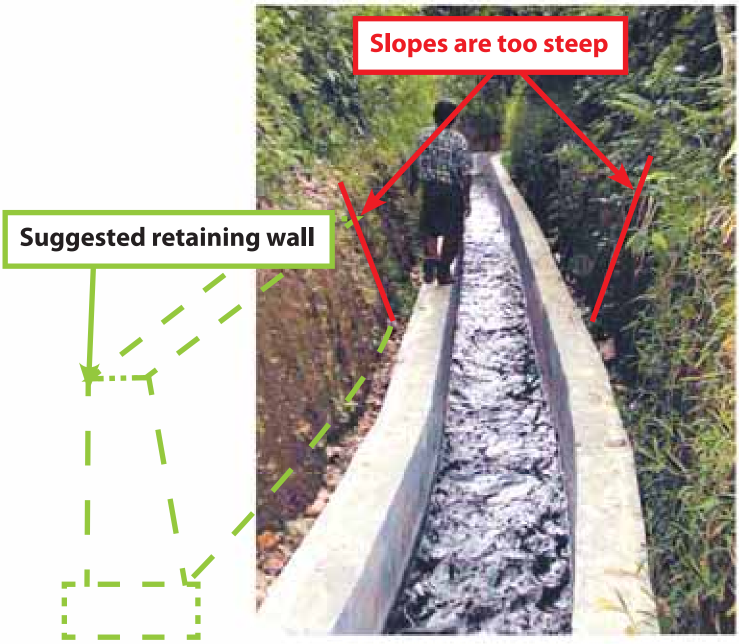
Why?

- The slope of the channel determines the velocity of the flow
- The force of flowing water can cause erosion depending on the channel material and slope
- Channels with too steep slopes flow too fast and thus will erode faster
- Channels with slopes too flat will be blocked by settled sediments
- Build channel slope according to recommended velocities in channels, unnecessary drops reduce the available head for MHP:
  - Earth channel : < 0.4 m/s
  - Masonry lining : < 2.0 m/s
  - Concrete lining : > 3.0 m/s
  - Minimum velocity : > 0.2 m/s to avoid sedimentation

Headrace channel is free of vegetation

Why is this a good example?

- Side slope is well back from edge of channel
- There is no vegetation growing into the channel
- As a consequence you can expect:
  - less debris in the channel
  - a clean trash rack
  - well operating turbine
  - efficient electricity generation
  - happy consumers



Headrace in a deep and steep cut section

How can I improve it?

- If the cut is not stable, build retaining walls to prevent erosion material from falling into the channel
- Cover the headrace with prefab concrete slabs or wooden boards
- Replace the open headrace channel with a buried pipe

Why?

- Deep and steep cuts will always be prone to bank erosion
- Excessive maintenance of steep banks may be very costly
- Steep banks may slide and block channel completely

Note:

SEDIMENT PARTICLES MAY DAMAGE PENSTOCK AND TURBINE!

Retaining wall stabilizes the toe of the slope

Why is this a good example?

- A retaining wall reduces the natural angle of repose of the slope
- Less erosion material will fall in the headrace
- Maintenance of the headrace is easier → less sediment, which however still must be removed
- There are narrow walkways along the channel for easier maintenance

This a not a good creek crossing

How can I improve it?

- Replace the wooden supports with concrete column supports
- Set the supports on good foundations, especially under water
- Add anchor blocks on both sides of the stream to support the pipe

Why?

- Pipe crossings need stable supports, otherwise the pipe may buckle and collapse
- Wooden supports may rot rather quickly with time, the pipe will sink and will eventually fail
- A sinking pipe causes the flange connections to come loose

Well-built pipe crossings in a headrace

Why is this a good example?

- The connection of the open headrace channel to the pipe crossing is a solid concrete structure
- The spillway upstream of the pipe inlet is a good solution to discharge extra flood water; it does not seem to affect the stability of the abutments
- The size of the crossing pipe is large enough to carry the flow in the headrace, therefore the pipe cross section equals the wetted area of the channel
- The pipe inlet should have a smooth, rounded transition to reduce head losses and backwater effects
- The spillway is located upstream of the crossing pipe, if there is too much backwater effect, the water will be spilled in a controlled way

What must I do to keep system running well?

1. Remove sediment and rocks from the channel
2. Cut grass and shrubs, and remove debris – do it regularly
3. Check slopes for erosion

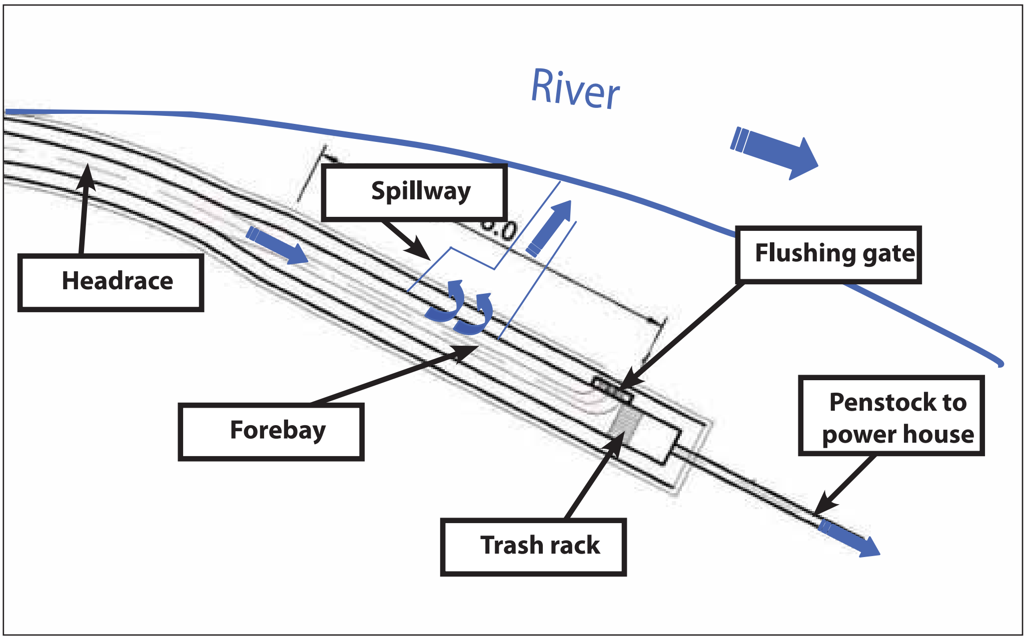
- Repair broken parts of the headrace
- Check functionality of stop logs and spillways - if existing

Note:

SEDIMENT PARTICLES MAY DAMAGE PENSTOCK AND TURBINE!

CHECK REGULARLY AS NEEDED!

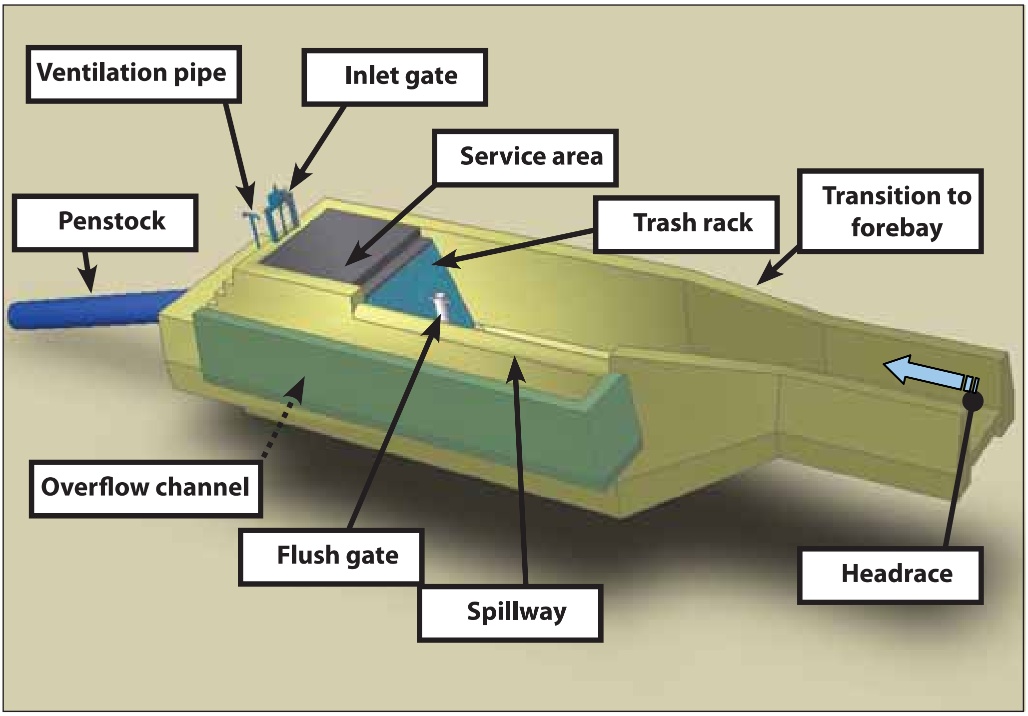
2.2.4 Forebay



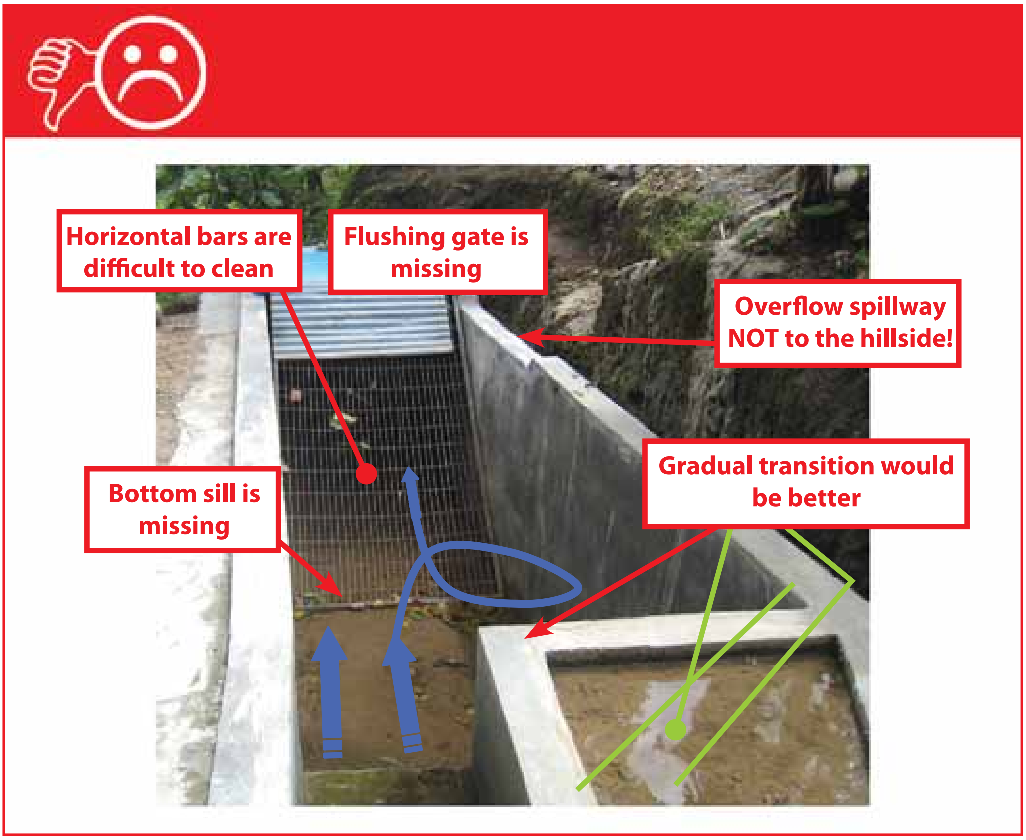
Main elements and functioning principles of a forebay:

- A forebay functions in a similar manner as a sand trap, the flow slows down so sediments can settle down
- The transition at the beginning of the forebay and the width of the forebay are essential for slowing down the flow velocity
- Sediments can settle out in slow flowing water only
- The trash rack at the end prevents debris from flowing into the penstock
- The forebay provides submergence for the penstock inlet to prevent air from entering
- The spillway allows excess and flood flows to flow back to the river, especially under rapid shut down conditions following load rejection
- The flushing gate is essential for cleaning the forebay of sediments as required

Main elements of a forebay



The drawing shows a typical forebay which marks the transition between the open headrace channel and the penstock. The water level in the forebay determines the head which is available for power generation. The trash rack in the forebay and the forebay itself is the last point to remove anything that could damage the turbine from the water, such as floating debris or sediment. Also it provides a controlled way of escape over the spillway for surplus water in case of a load rejection or when too much water enters the open channel part of the headrace.



Forebay without sedimentation

How can I improve it?

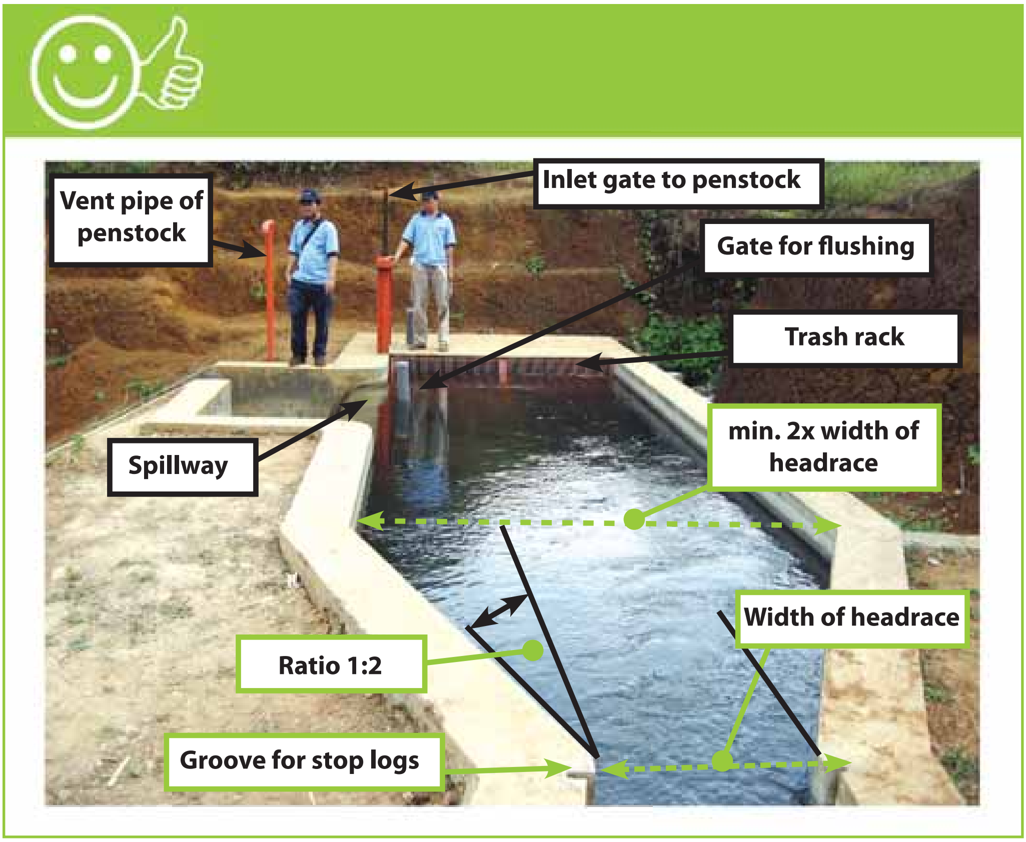
- Make gradual transition with an angle of 25° (ratio 1:2) or less
- Place the trash rack on top of a sill at the bottom of the forebay
- Install a flushing gate at the bottom of the forebay and connect it with the spillway
- Make spacing width of trash rack bars dependent on turbine manufacturer's requirements

Why?

- Avoid eddies and dead zones in the forebay
- Flow approaching the trash rack should be steady (linear)
- Wall (sill) will hold back the settled out sediments
- Flushing gate allows to empty and clean the forebay

Note:

SEDIMENT REACHING THE TURBINE CAN DAMAGE THE RUNNER!

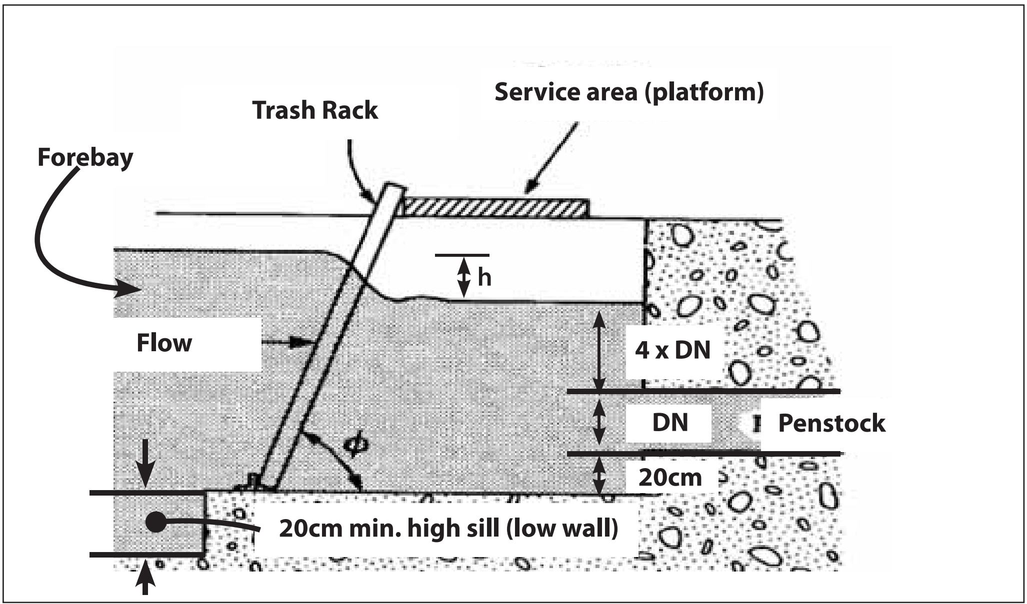


Forebay with sedimentation basin

Why is this a good example?

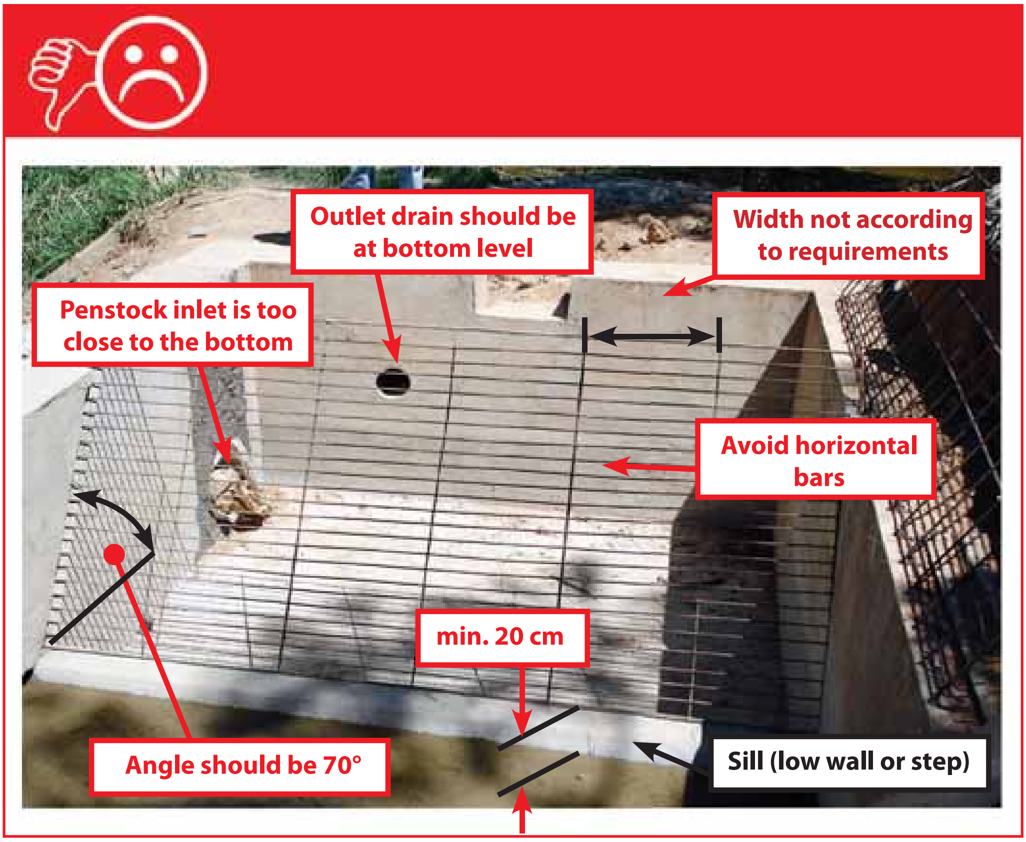
- Forebay with sedimentation must be wider and deeper than the headrace
- Width of forebay should be at least 2 times the width of the headrace channel
- Length of transition should be about 3 times the width of headrace, or the angle of the transition should be around 25 degrees (a ratio of 1:2)
- Stop log grooves allow the insertion of boards (=logs) to block the flow when cleaning and repairing the forebay

2.2.5 Trash Rack



Main design principles of a trash rack:

- The angle of a trash rack to the horizontal shall be 60° to 80°
- Trash rack should be fixed to the side walls and to the sill wall as well but in such a way that the trash rack can be removed for service
- Use ONLY vertical bars, which can be supported by horizontal bracing at the back, so that rack can be cleaned easily
- The bars must be designed to withstand the water pressure of a completely clogged rack with maximum water level upstream and no water downstream
- The space between bars should be half of the space between turbine runner or guide vane blades, in accordance with the turbine manufacturer. Here are some examples:
  Crossflow turbine (e.g. T 15): 12 mm
  Pelton turbine: 0.5 times nozzle diameter
- Trash rack shall be divided into sections so that it can be removed, repaired and transported more easily
- Provide a service area for easier cleaning, including a platform to stand on



Trash rack on top of a sill (low wall)

How can I improve it?

- Use trash racks with vertical bars only
- Space between bars should be half the size of a particle which can move through the turbine without doing any damage
- Place trash rack at an angle of around 70° to the bottom
- Fix trash rack with bolts to the side walls and to the bottom wall – but it still should be removable
- For larger trash racks, divide it in separate sections
- Height of sill (low wall) be a minimum of 20 cm

Why?

- Vertical bars make cleaning the trash rack easier
- Trash rack placed at an inclined angle will not clog as easily with debris
- A place to stand as service area will make the maintenance easier

Debris causes head losses and/or reduces the water flow into the penstock

Why is this a good example?

- Trash rack is mounted at an angle of about 70° from the horizontal
- Trash rack is fixed to the walls - but it should still be removable
- The trash rack has vertical bars which makes it easier to clean
- The gaps between bars appear tight enough to keep damaging debris away from the turbine
- Large service area and a place to stand for easy maintenance
- Debris can be cleaned and temporarily stored in the service area

A too small open area causes head loss & penstock inlet is not enough submerged

The gaps are too narrow and rack is not fixed at an angle of about 70°

Horizontal support should be at the rear side of the rack

Trash rack to be bolted & fixed to the side walls - not just leaning on them

Some bad samples – avoid them!

Rack properly fixed to the walls

Service area for maintenance

Trash rack fixed on top of a bottom sill or step, with service opening

Some good examples – do like this!

What must I do to keep system running well?

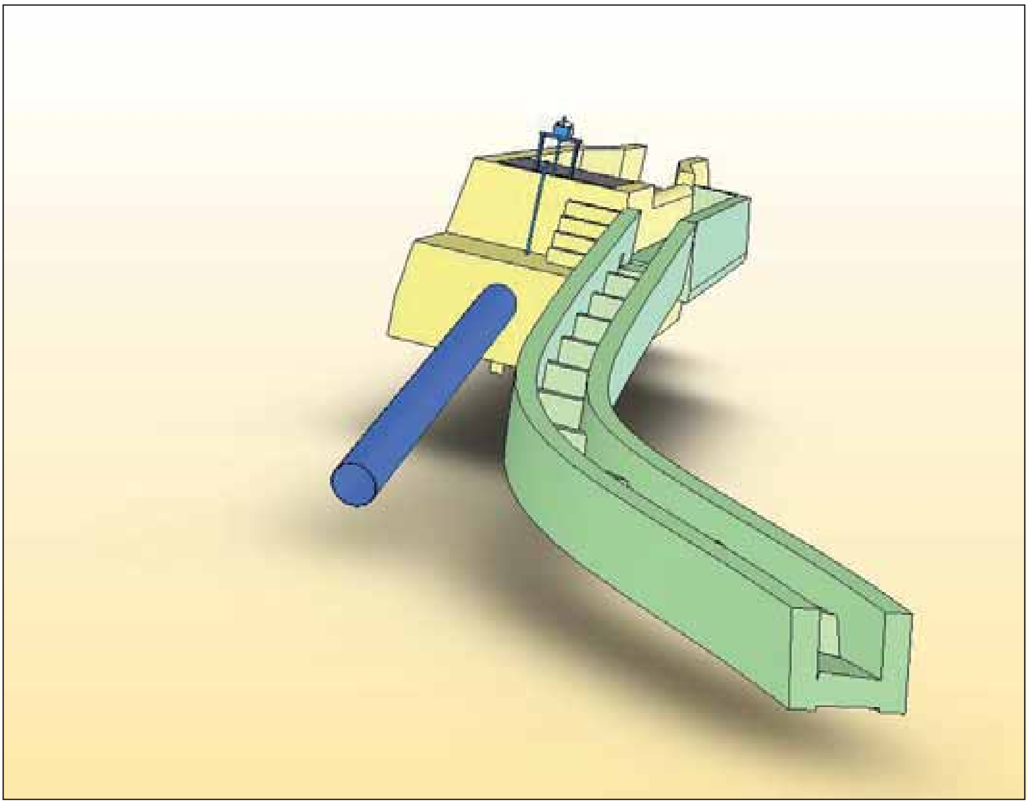
1. Remove all debris and rubbish – a rake is a good tool for this job
2. Trough at the top end of the trash rack makes the removal of debris easier → store organic debris on a compost pile

Note:

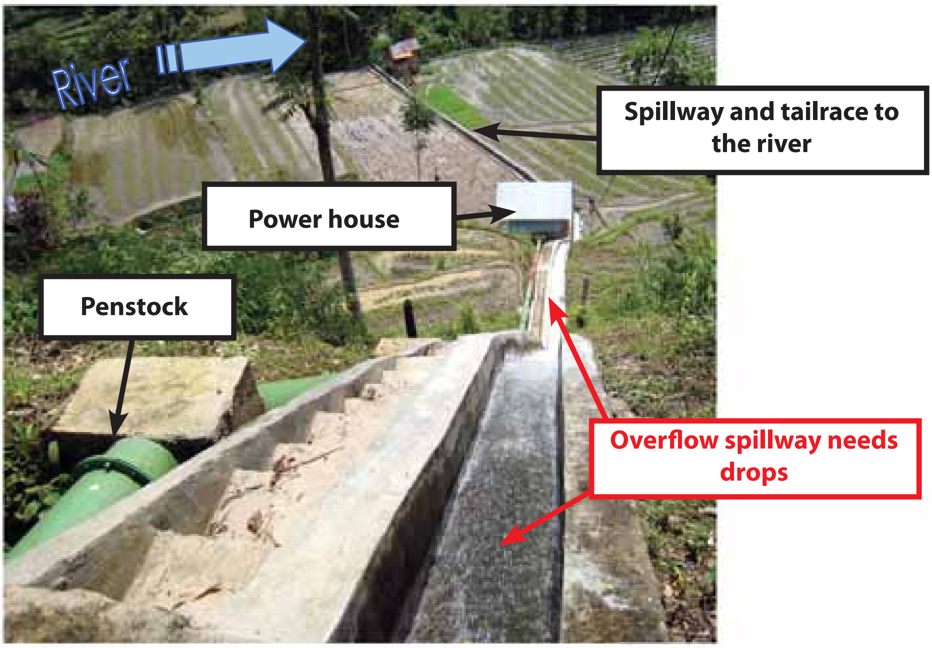
DEBRIS MAY DAMAGE THE TURBINE!

CHECK AT LEAST TWICE A DAY AND EVEN MORE OFTEN DURING STORMS OR FLOODS!

2.2.6 Spillway



This drawing shows an example of a forebay and a stepped spillway which allows excess water to flow back to the river over the spillway without doing damage to the penstock or its supports. The steps in the spillway reduce the velocity of the water and cause energy dissipation. This is very important to prevent damage from the spill to the powerhouse and other structures.



Water carries high energy when flowing down a steep slope

How can I improve it?

- Build obstacles into the spillway to reduce the velocity and dissipate the water's energy
- It would even be better to build drops in the spillway, which is then called a stepped spillway

Why?

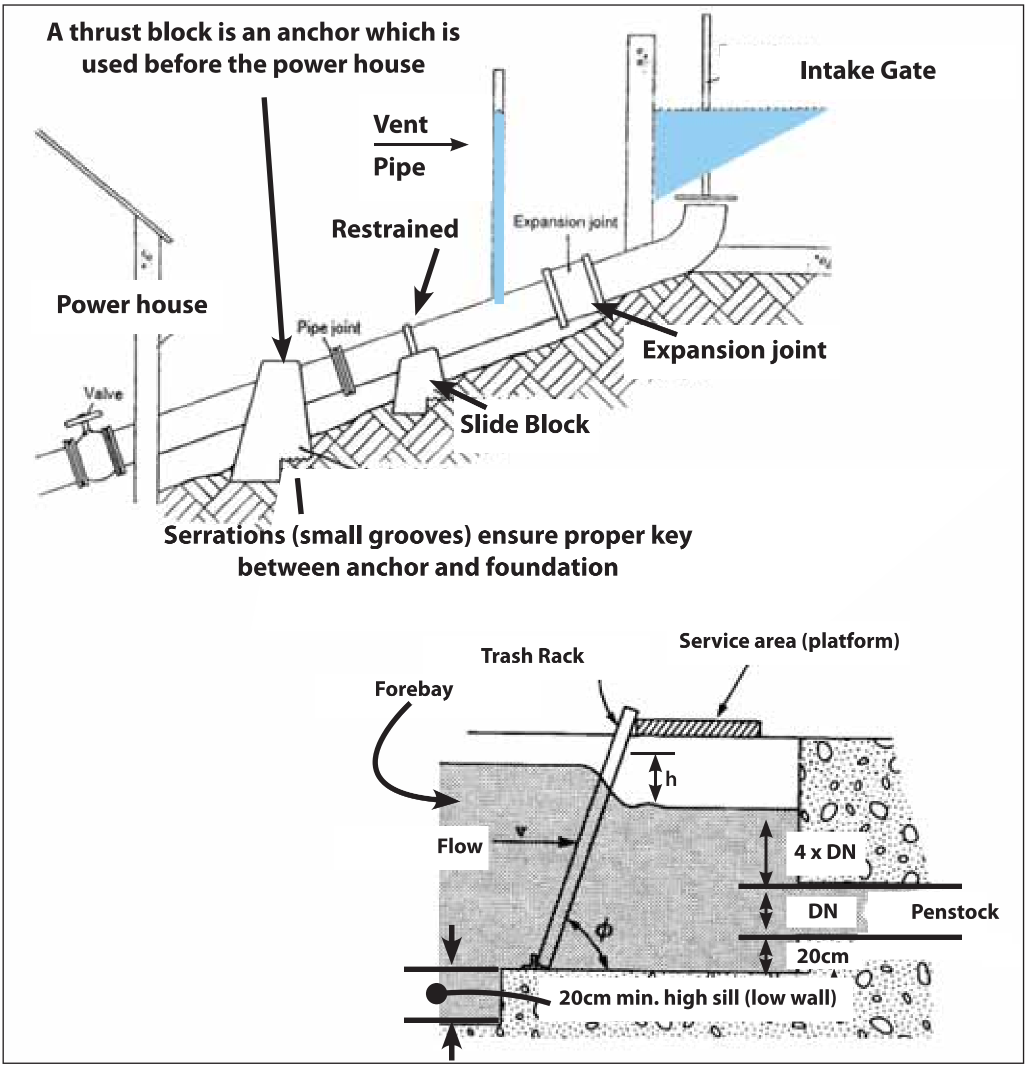
- The dynamic force of water is very high when flowing down a steep slope • it could damage and destroy even concrete structures

Energy dissipation is happening at every step

Why is this a good example?

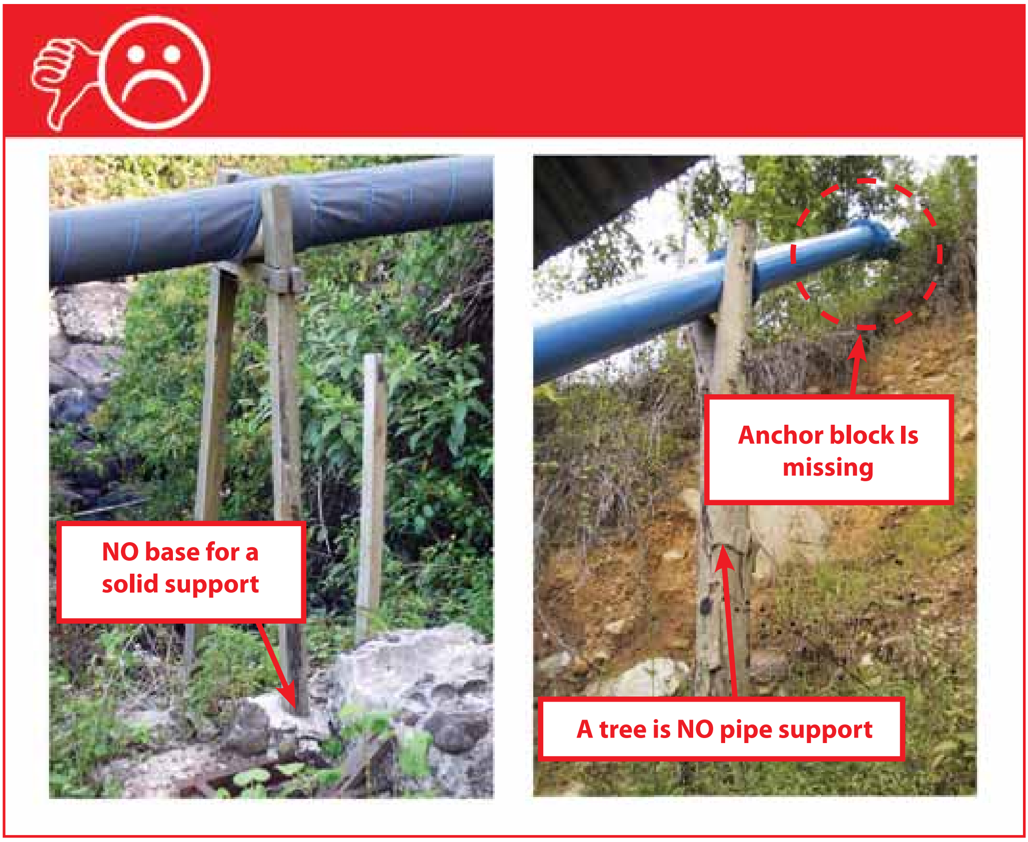
- A stepped spillway reduces the velocity and dissipates the (in this case harmful) energy of the water – step by step

2.2.7 Penstock and Support



Main design principles for a stable penstock:

- Set anchor block at each change of direction – horizontal and vertical – of the penstock
- Support each piece of pipe with a (slide) block
- Fasten the penstock to the supports with steel straps
- Ensure that all blocks have a solid and stable foundation, which depends on ground material and slope
- Before penstock enters power house there must be a thrust block to absorb all dynamic water forces in the pipe
- Penstock inlet must be 20 cm above bottom invert, and water depth above inlet should be 4 times the diameter of the penstock pipe



Penstock must have solid supports at regular intervals

How can I improve it?

- Use concrete (or steel) support, set on a solid foundation
- There must be an anchor block at every horizontal and vertical bend in the penstock pipe
- Pipe must be fixed to the supports with steel straps

Why?

- Trees and trunks rot and lose their strength
- Anchor blocks resist the hydraulic forces at bends in the pipe
- Weak or unstable supports may cause the penstock to move which could cause undue stress on the pipe → risk of major failure
- A break in a (high) pressure penstock could cause serious water damage

Note:

PVC PENSTOCKS HAVE TO BE COVERED TO AVOID PVC MATERIAL BECOMING BRITTLE AND EVENTUALLY FAILING!

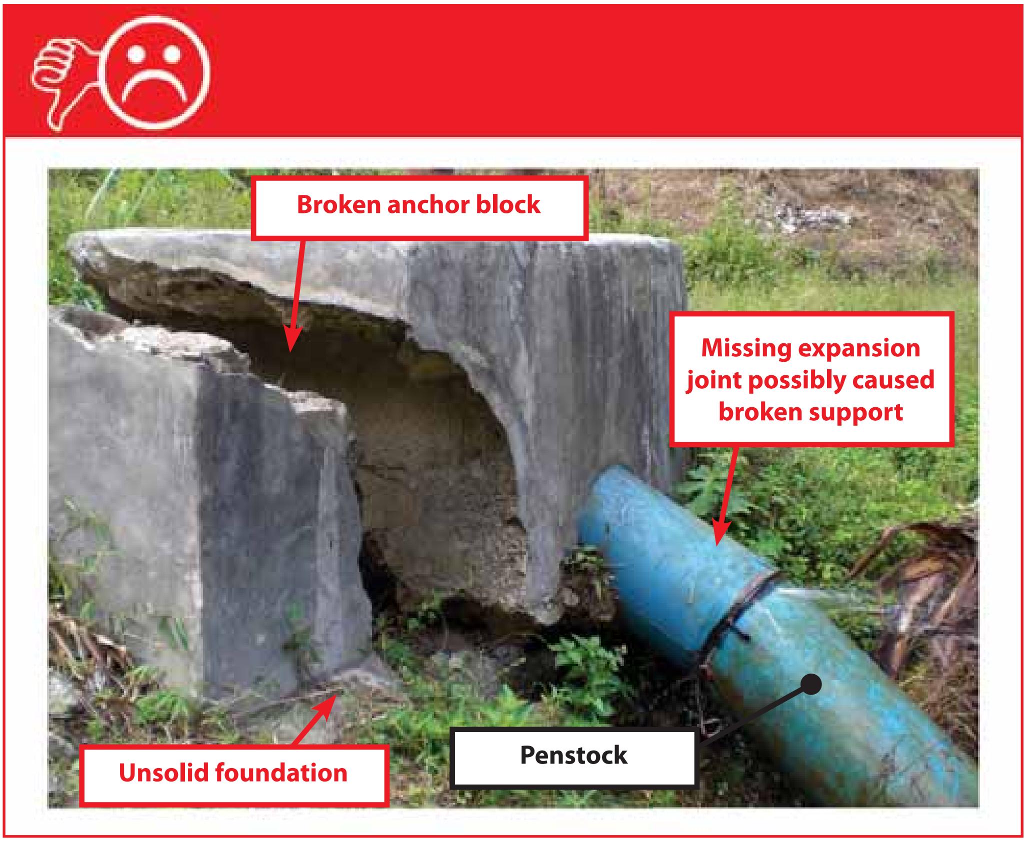
The penstock pipe sections are well supported

Why is this a good example?

- Every pipe section is well supported
- Pipe is fixed to the concrete supports with steel straps
- Concrete is the best material for pipe supports
- Pipe is about 0.3 meter above the ground
- Proper trench drainage → important for long-term stability of supports

Note:

STEEL PENSTOCKS REQUIRE EXPANSION JOINTS BETWEEN ANCHOR BLOCKS AND FOR SECTIONS LONGER THAN 30 m → INSTALL EXPANSION JOINTS DOWNSTREAM OF ANCHOR BLOCKS!



Expansion joint must be installed in penstock after each anchor block

How can I improve it?

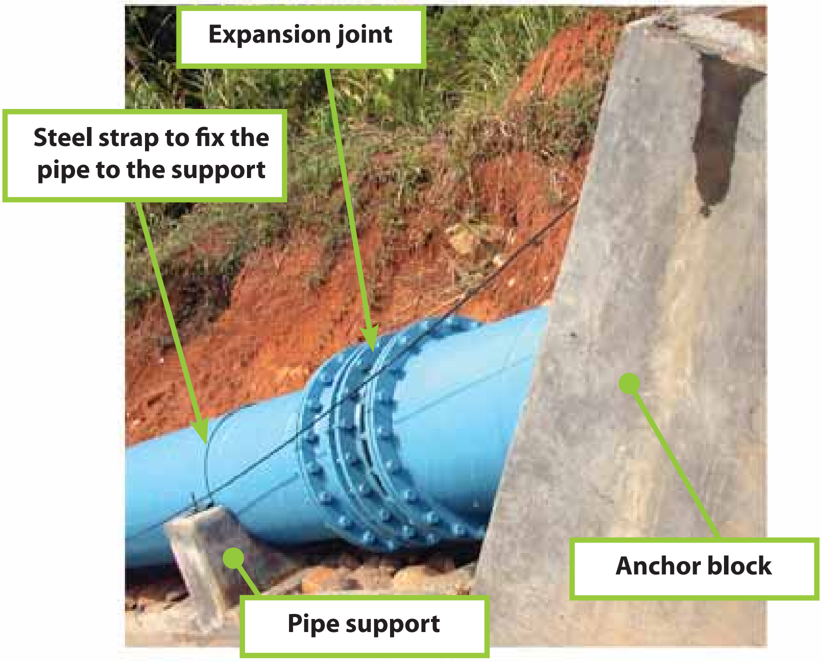
- Build a new anchor block with a solid foundation
- After each anchor block there must be an expansion joint on the pipe

Why?

- If there is no expansion joint the pipe cannot absorb the longitudinal movements of the pipe due to hydraulic forces and temperature changes
- A break in a (high) pressure penstock could cause serious water damage and wash out the supports and even damage the powerhouse

Note:

RISK OF FAILURE!



An anchor block with an adjacent expansion joint

Why is this a good example?

- The anchor block absorbs the weight and hydraulic forces of the pipe section above the anchor block
- Expansion joints allow for longitudinal movements of the pipe section downstream of the anchor block
- Pipe can expand or contract as a result of temperature changes and hydraulic forces

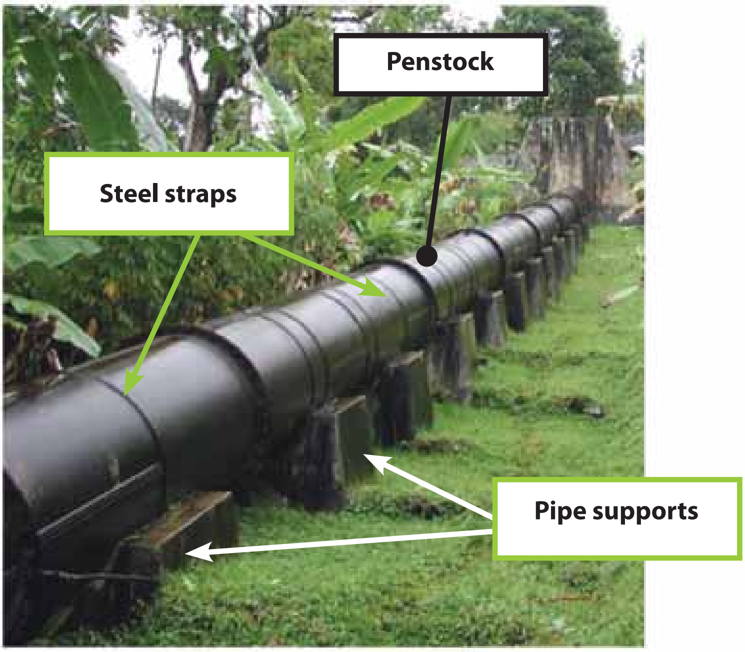
Several examples of poorly installed penstocks

How can I improve it?

- Do periodic inspection and maintenance to find and fix problems
- Add steel straps to fix the pipe to the supports
- Replace pipe sections when pipe is leaking or cracked
- Use flanged fittings for pipe connections
- Replace faulty (expansion) joints

Why?

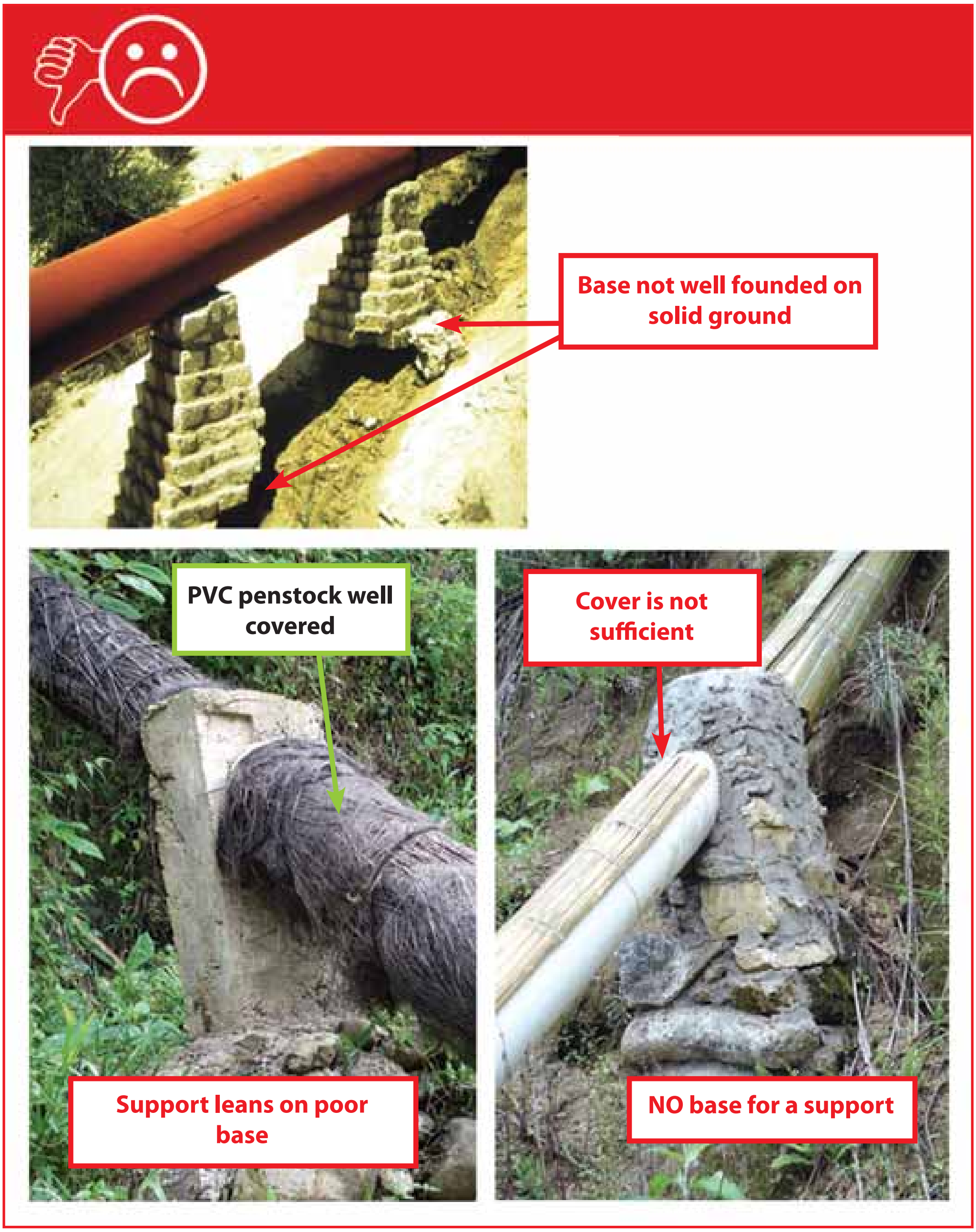
- Leaking or faulty pipes and joints could cause a burst pipe and serious water damage → NO electrical power generation would result
- Water in the power house or at the transformer can cause electrical shocks
- Improperly supported and fixed pipe could fail, resulting in loss of power and requiring costly repairs



A well built and properly maintained penstock

Why is this a good example?

- There are 2 supports for each pipe section due to the pipe's high weight
- Steel straps fasten the pipe to the concrete supports
- There is adequate ground clearance of about 30 cm
- There are no signs of movements, deformation or cracks
- The pipe is well painted as protection against corrosion
- Grass, other vegetation and dirt have been cleared away from penstock



Some bad examples of penstock supports – to be avoided!

Some good example of penstock supports

Penstock inlet gate without required ventilation pipe

How can I improve it?

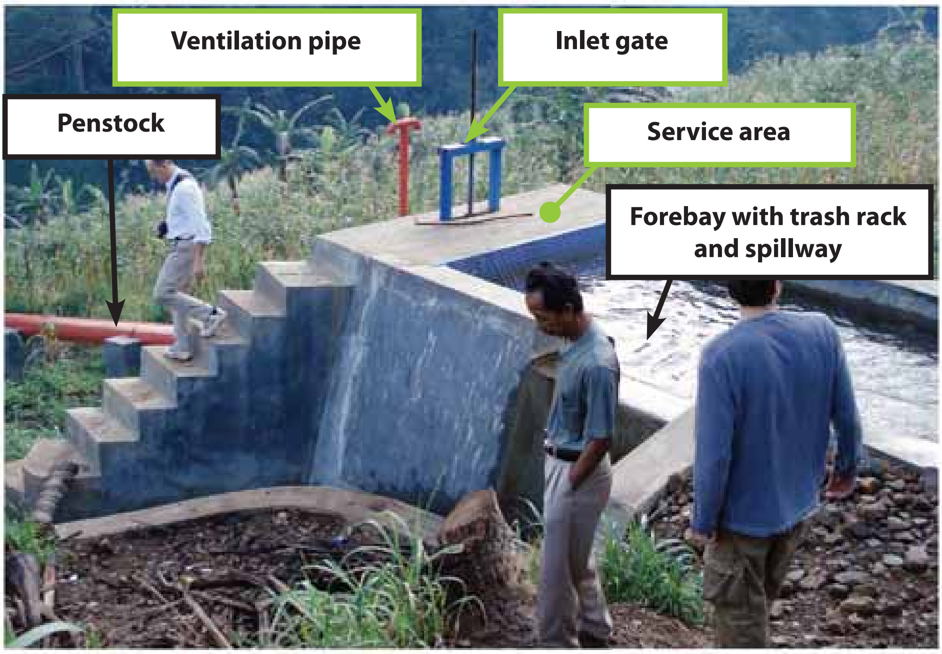
- Install a ventilation pipe in the penstock downstream of the gate

Why?

- The ventilation pipe allows air to enter the penstock when the penstock is rapidly emptied. Without ventilation pipe the penstock could easily be damaged by a vacuum collapse of the pipe
- If penstock is equipped with an inlet gate there must be a ventilation pipe

Note:

A PENSTOCK <u>WITH INLET GATE</u> REQUIRES A VENTILATION PIPE!



Penstock inlet gate and ventilation pipe

Why is this a good example?

- Penstock pipes with an inlet gate must have a ventilation pipe
- Diameter of ventilation pipe depends on penstock diameter

Note:

THE VENTILATION PIPE PREVENTS A VACUUM COLLAPSE OF THE PENSTOCK PIPE WHEN IT IS EMPTIED!

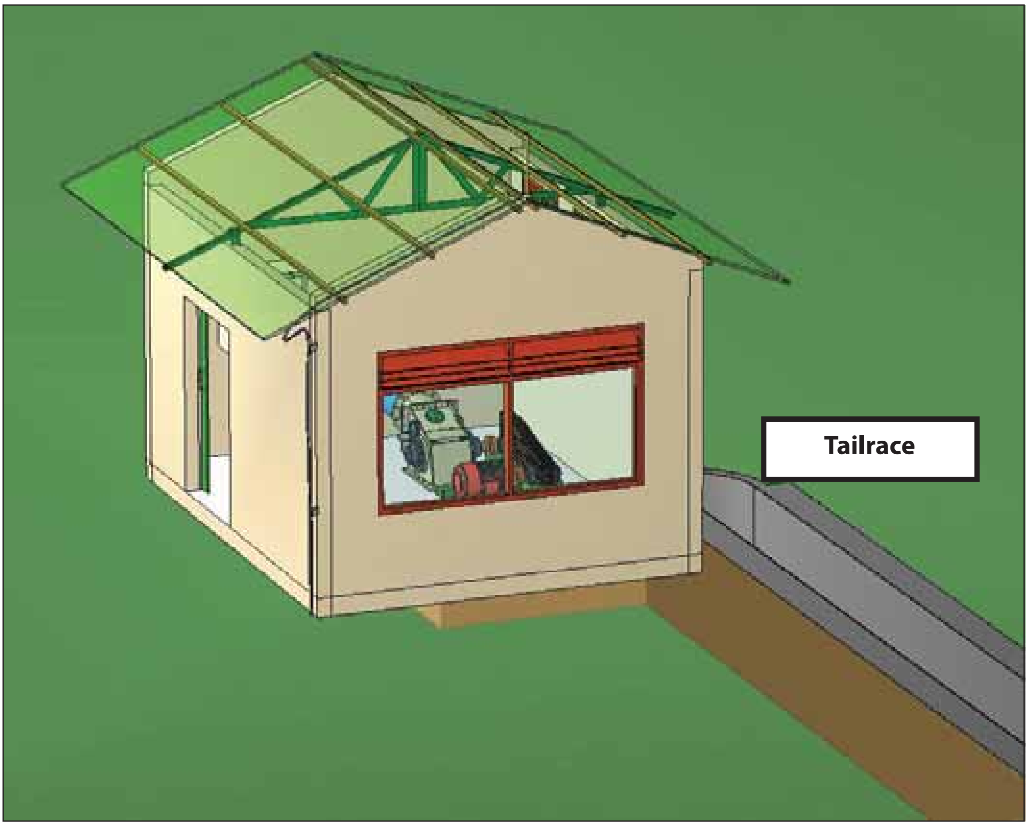
What must I do to keep system running well?

1. Check for rust and condition of paint – clean and re-paint as needed
2. Check pipe supports and anchor blocks for deformation, settlings or any other movements – repair cracks with cement grout
3. Check tightness of nuts & bolts of flanges and straps – tighten as needed
4. Check all joints, especially expansion joints, for leaks – fix if needed
5. Remove grass, shrubs and dirt – do it regularly

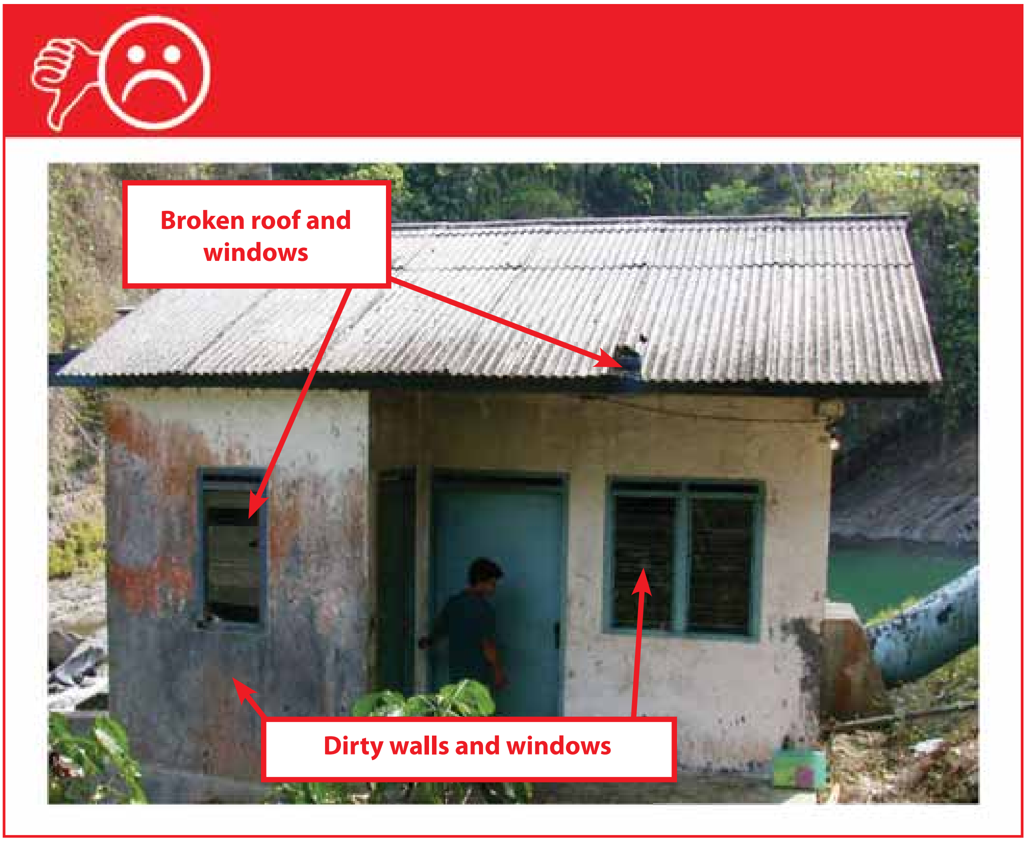
Note:

CHECK PENSTOCK AT LEAST EVERY THREE MONTHS!

2.2.8 Power House and Tailrace



The drawing shows a typical setup for a small powerhouse and a short tailrace which takes the water back to the river once it has flown through the turbine. The powerhouse must clearly sit well protected and above possible flood water levels in the river so it cannot get damaged. The tailrace is a part of the hydraulic system of the MHP and needs to function well just like the headrace. It must not be blocked or full of vegetation or debris. Usually the tailrace is very short but there are also MHP with tailraces several hundred meters or even kilometres long. This depends on the specific situation or topography.



This power house is NOT a safe place for valuable equipment

How can I improve it?

- Paint the walls as well as the wooden parts like windows and door
- Fix the roof
- Keep the floor tidy
- Clean the outside working space

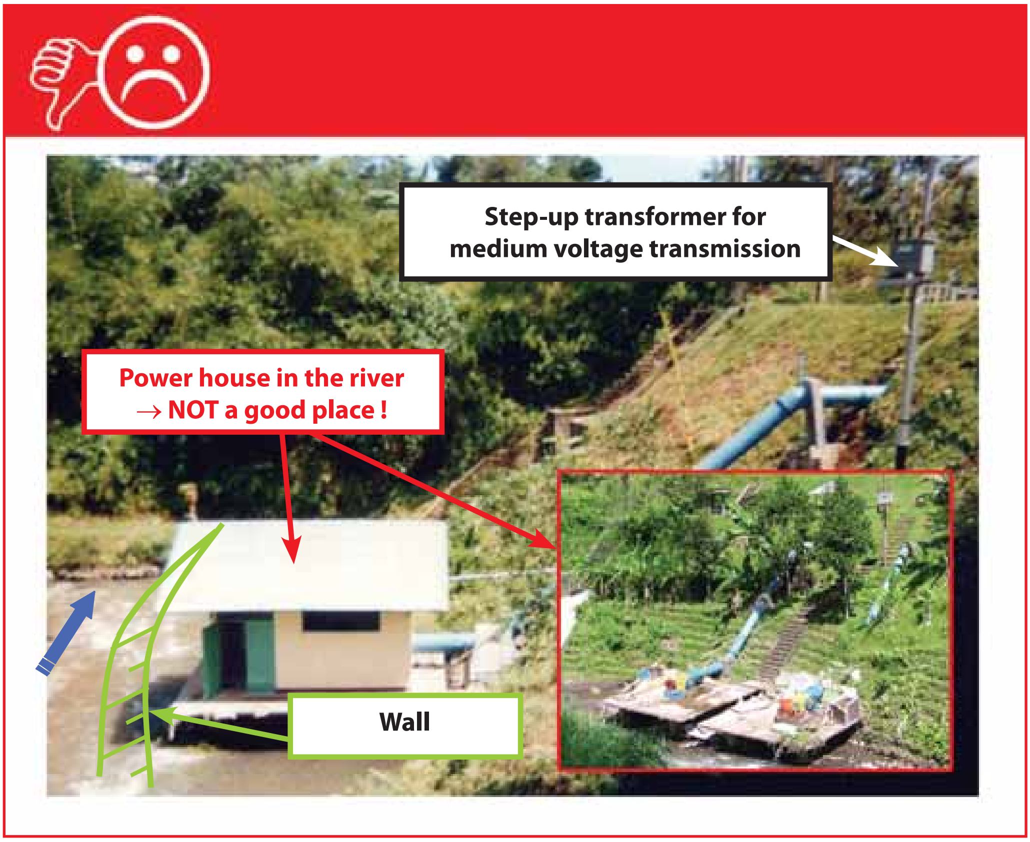
Why?

- The power house protects costly mechanical & electrical equipment
- It prevents access by unauthorized persons
- Adverse weather conditions could damage the equipment

A well built and maintained power house located at a suitable place

Why is this a good example?

- All important elements have been considered
- All necessary features have been included
- The building is well maintained and makes a neat impression
- The house is well accessible which is important particularly during night hours



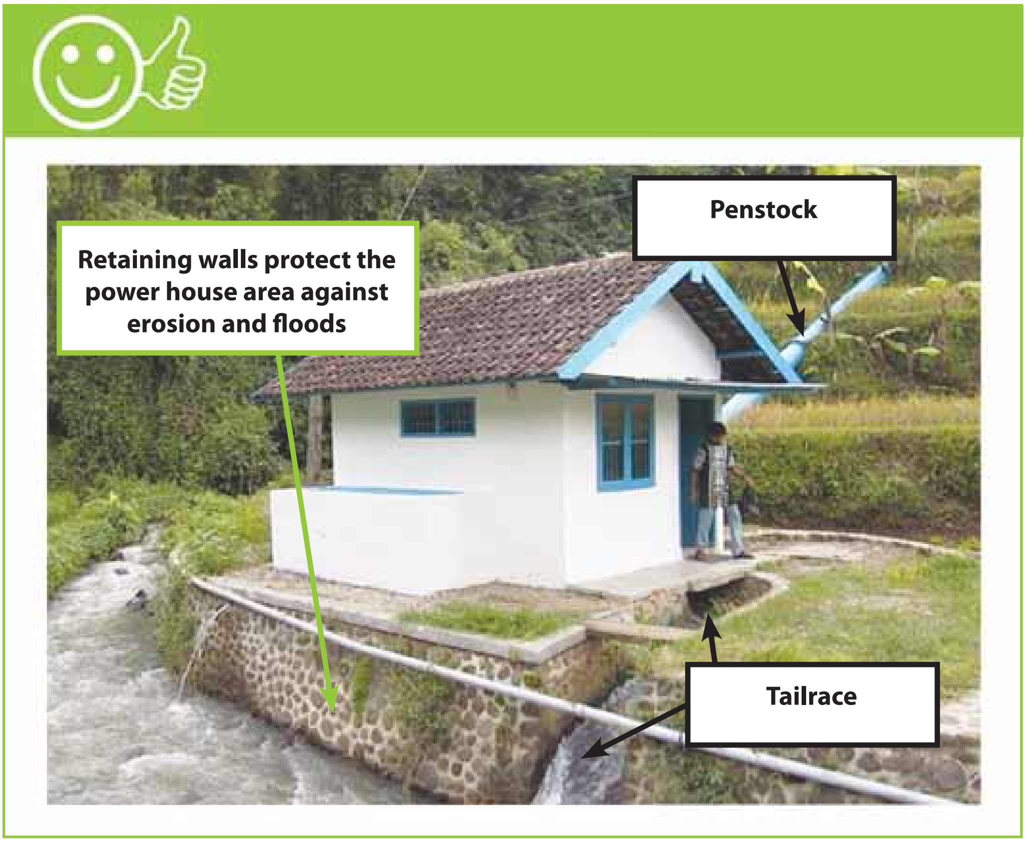
This power house proved NOT to be flood-proof

How can I improve it?

- Build a retaining wall around the building and backfill the area to protect the foundations of the power house. Take care to not block the flow of the river by the wall

Why?

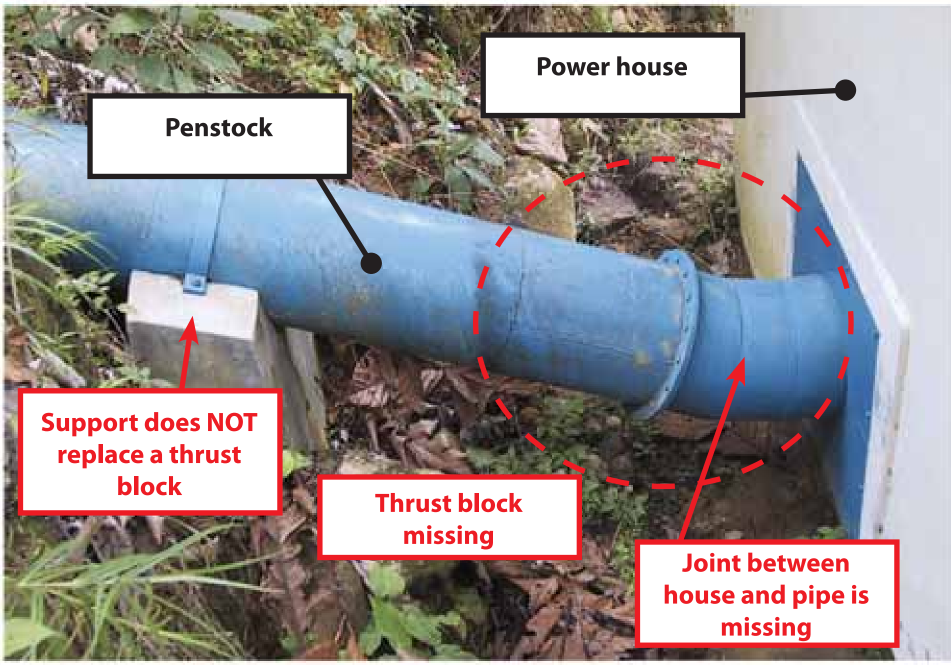
- There is costly mechanical & electrical equipment in the power house that must be protected. Even with a retaining wall, this power house is not flood proof because it is located too low in the river. Waterproof doors and temporary sand bags can help possibly in case of a smaller flood. Better, close the window and door opening with concrete and build a new access via the roof. Keep pumps ready in the power house in case of a flood to protect the equipment
- As the picture in the right corner shows, a severe flood which occurred shortly before completion of this book has caused serious damage – unfortunately even to a second turbine which was installed at the same location



A well located and properly built power house

Why is this a good example?

- The power house is well protected against floods in the river because it sits above flood water level
- The water in the tailrace returns to the river with a small drop and does not erode the river bank
- The power house is a solid and neat looking structure



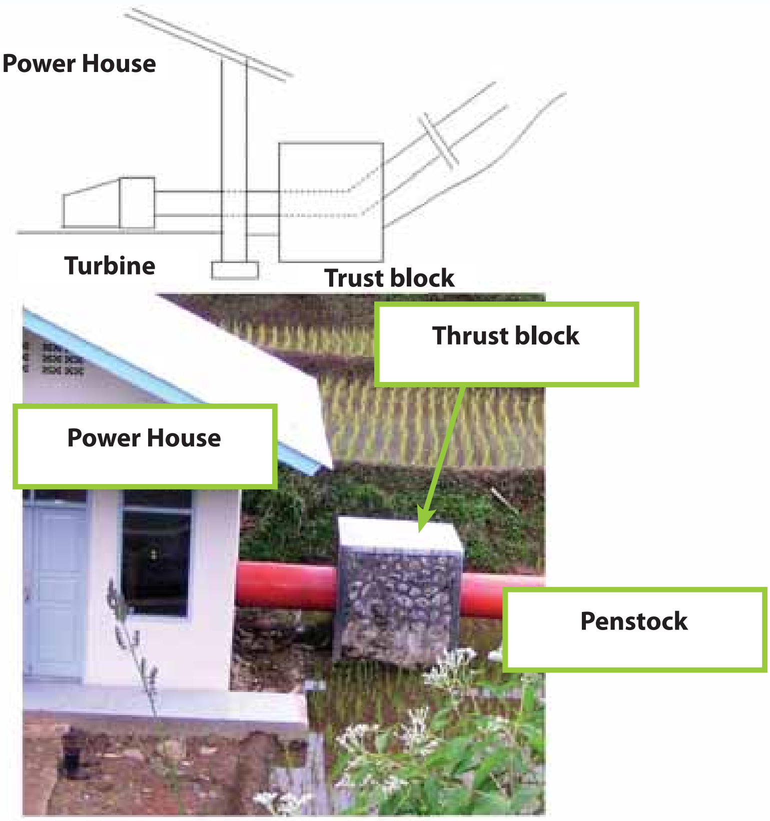
Pipe support does NOT replace the need for a thrust block

How can I improve it?

- Build a concrete thrust block around the penstock
- Leave a joint between the block and the building
- Install an expansion joint ahead (upstream) of the thrust block

Why?

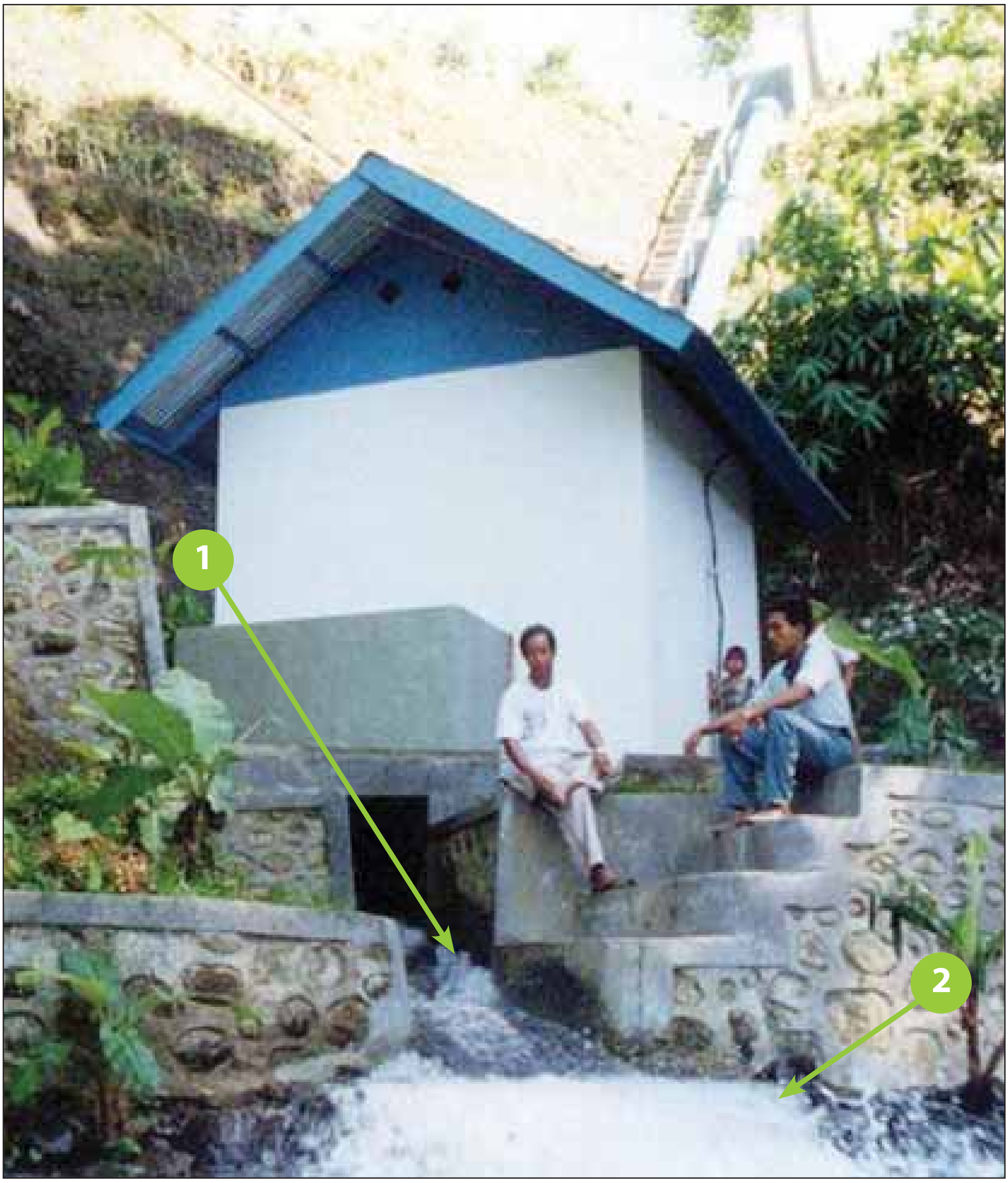
- A thrust block absorbs the penstock's weight and hydraulic forces of the water in the penstock
- An expansion joint absorbs pipe expansion due to temperature changes, and also the hydraulic forces in the pipe between anchor blocks



Solid thrust block prevents the penstock from moving

Why is this a good example?

- The thrust block assures that the penstock is fixed and does not move and push or pull the house wall
- It is better if the thrust block is separated from the house
- Drainage ditches around the building keep surface water away from the power house



What must I do to keep system running well?

1. Keep tailrace clean and free of debris
2. Check for erosion in the river

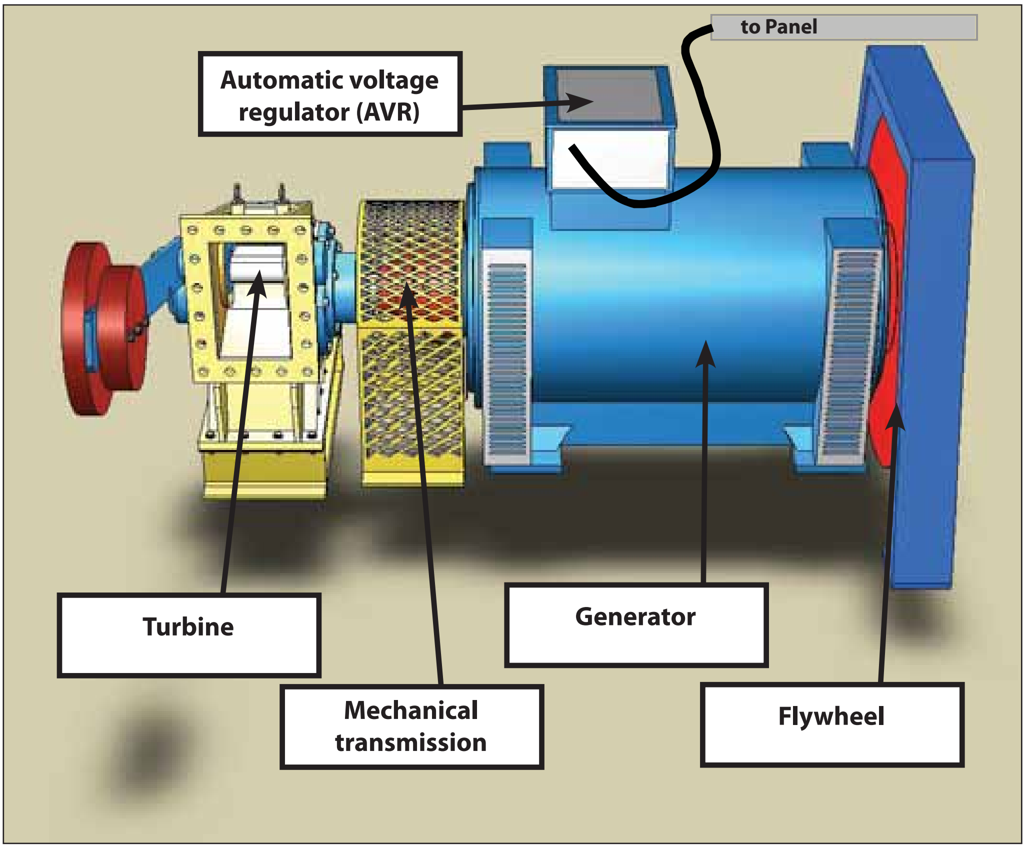
Note:

ONLY FREE FLOW IN THE TAILRACE KEEPS THE TURBINE RUNNING!

CHECK AND CLEAN AS NEEDED!

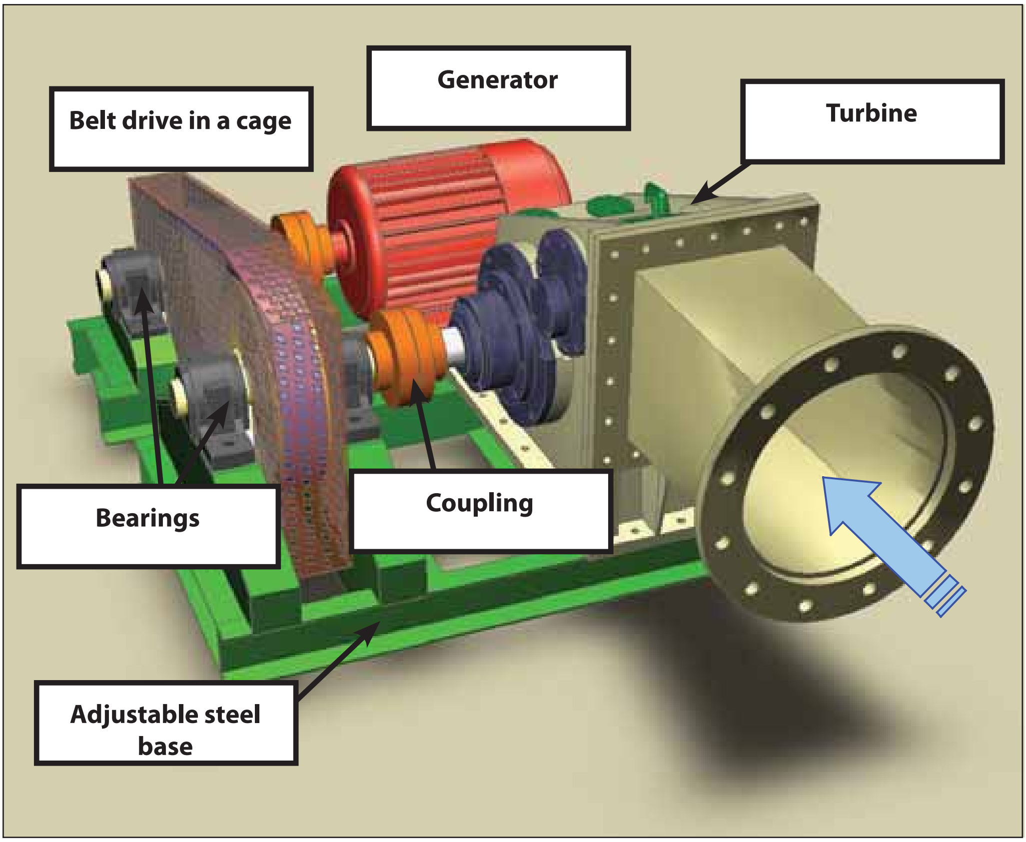
3. Electro-Mechanical Equipment

3.1 BASICS



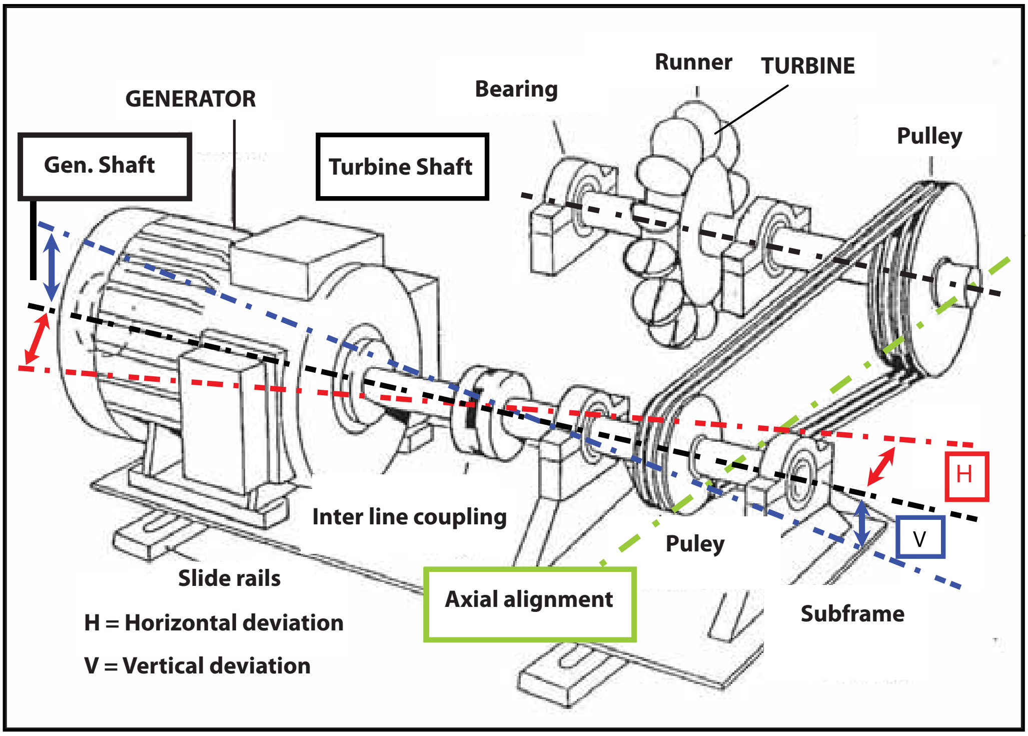
Typical electro-mechanical elements of a Micro Hydro Power Plant

- Turbine
- Mechanical transmission / gear
- Generator
- Turbine controller
- Control and power cabinet



What are the main challenges to set up these machines?

It is most important that the electro-mechanical components and their baseframe are sitting on a solid and stable foundation and that the shafts of all components are perfectly aligned as required.

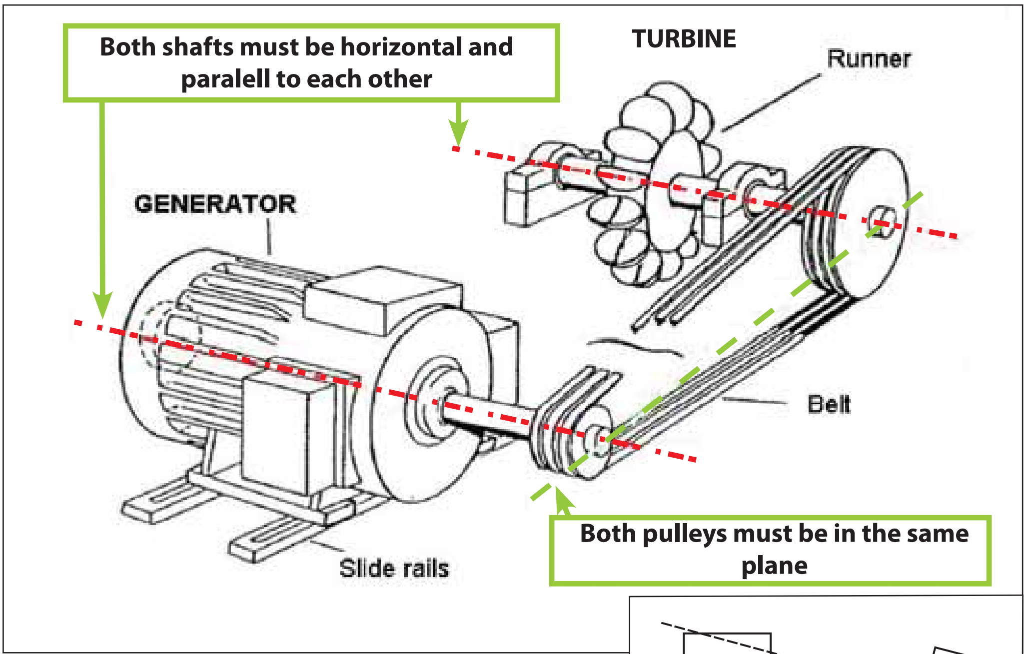


Perfectly aligned shafts are essential for good operation

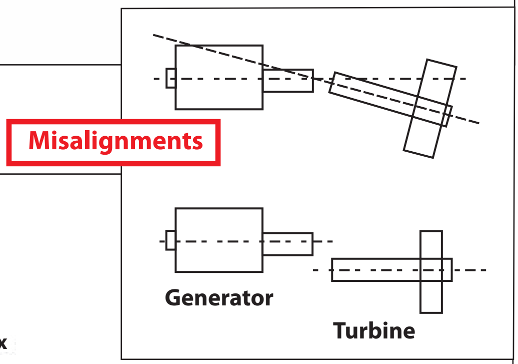
What should be considered for good workmanship?

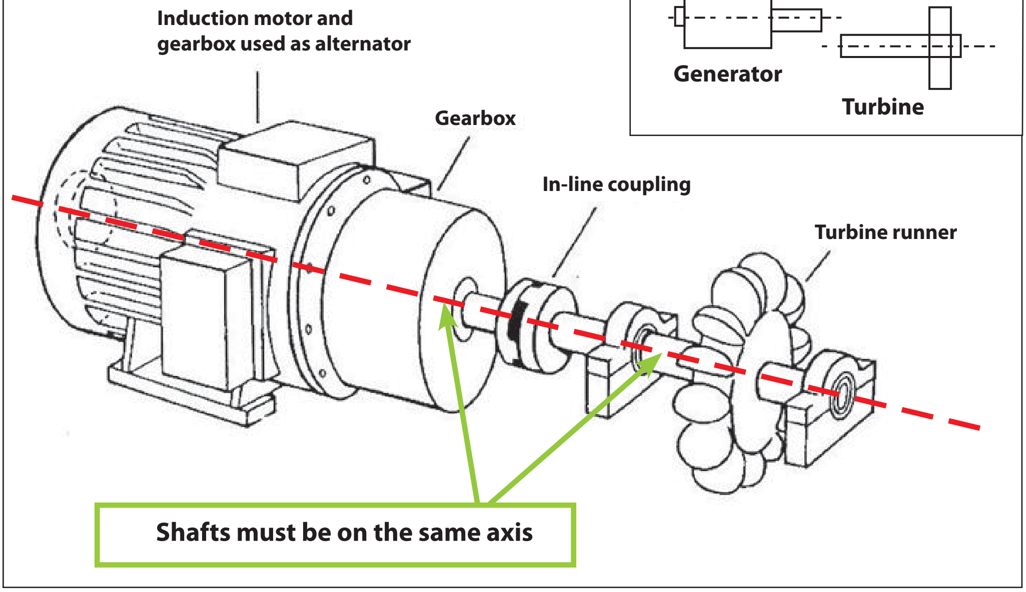
- The installation of turbine and generator must be done with care
- Make sure that the shafts of turbine and generator are perfectly parallel to the horizontal and to the vertical plane!
- This parallel alignment is very important for a smooth transmission and longer lifetime
- Belt pulleys require axial alignment
- The adjustments of the shafts must be done with a lot of care
- Subframe needs to be adjustable, in order to allow precise alignment
- For belt tightening, the subframe should always be moved in parallel
- Misalignment causes transmission problems: there will be a lot of wear and tear on belt and bearings – they may have to be replaced much sooner
- Care should be taken during casting of the concrete foundation to get it perfectly horizontal to make adjustments of the equipment bases at a later stage easier

Belt driven Generator



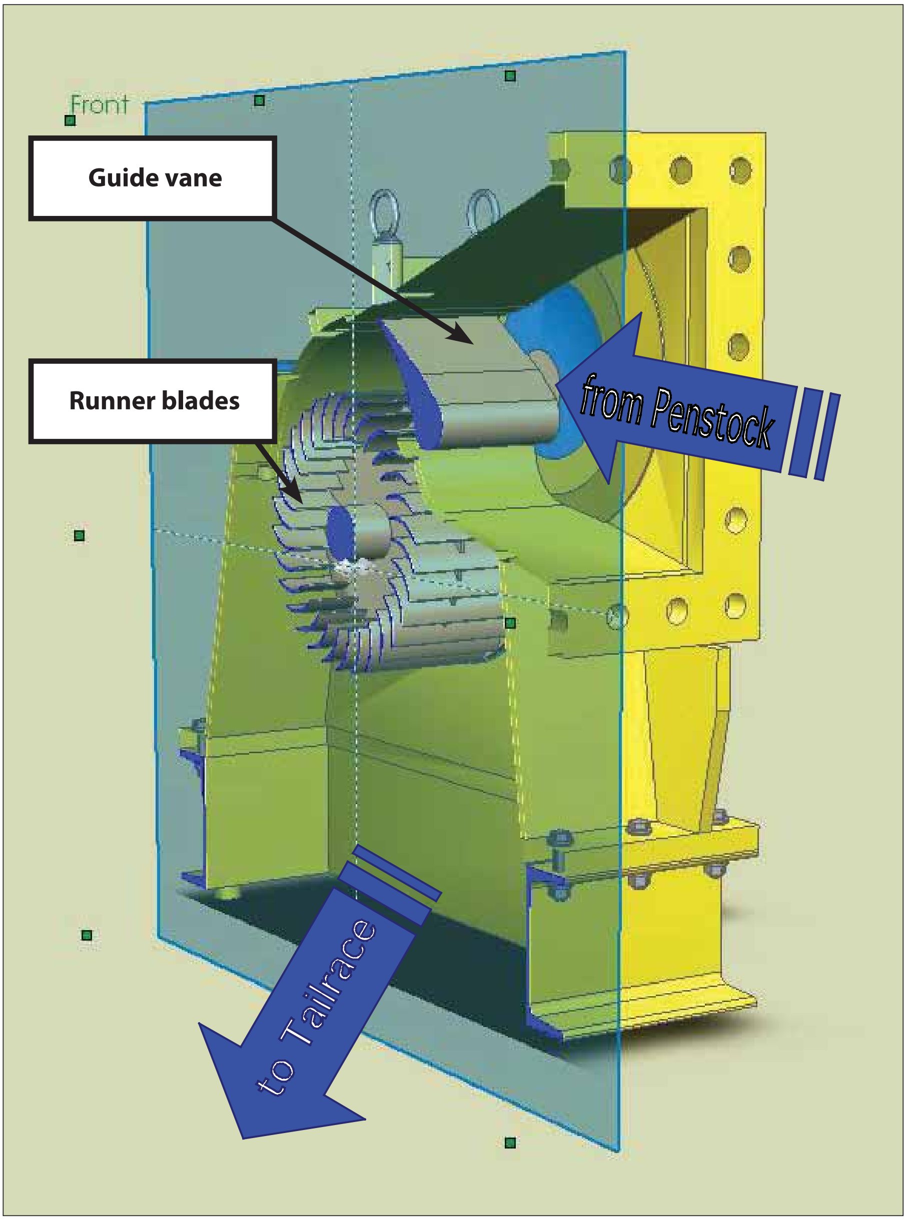
Direct driven Generator





3.2 INDIVIDUAL COMPONENTS

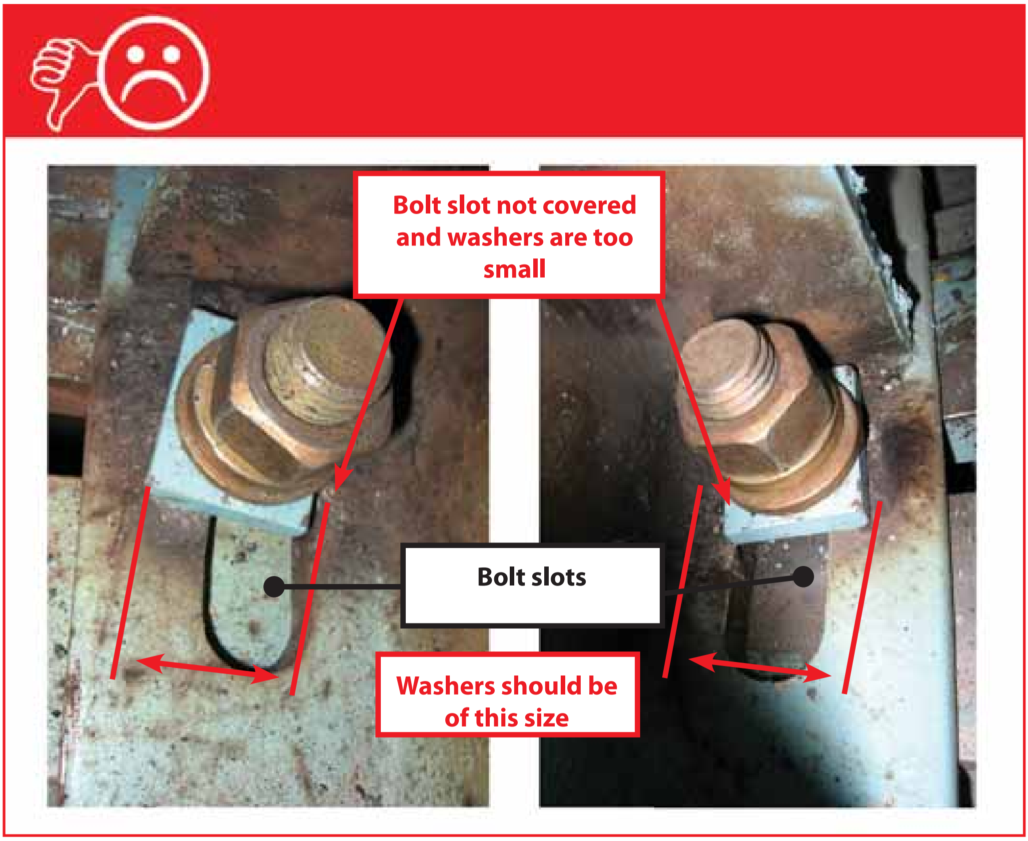
3.2.1 Turbine



Main elements of a crossflow turbine

Note:

THE GUIDE VANE REGULATES THE FLOW TO THE TURBINE!



Incorrect size of washers

How can I improve it?

- Use the correct size of washers (in this case: larger)
- The edges of the washers must be parallel to the bolt slot and must cover it completely

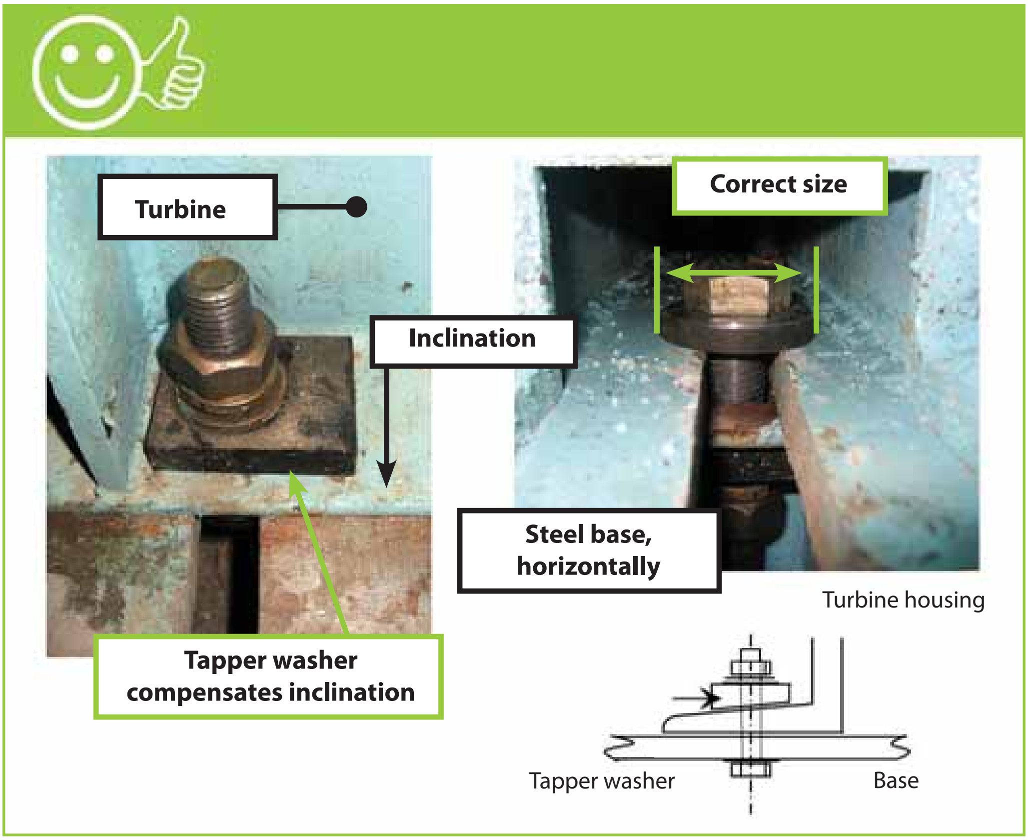
Why?

- Bolts connect the turbine to the steel base and fix its position
- The washers distribute the load evenly on the steel base

Note:

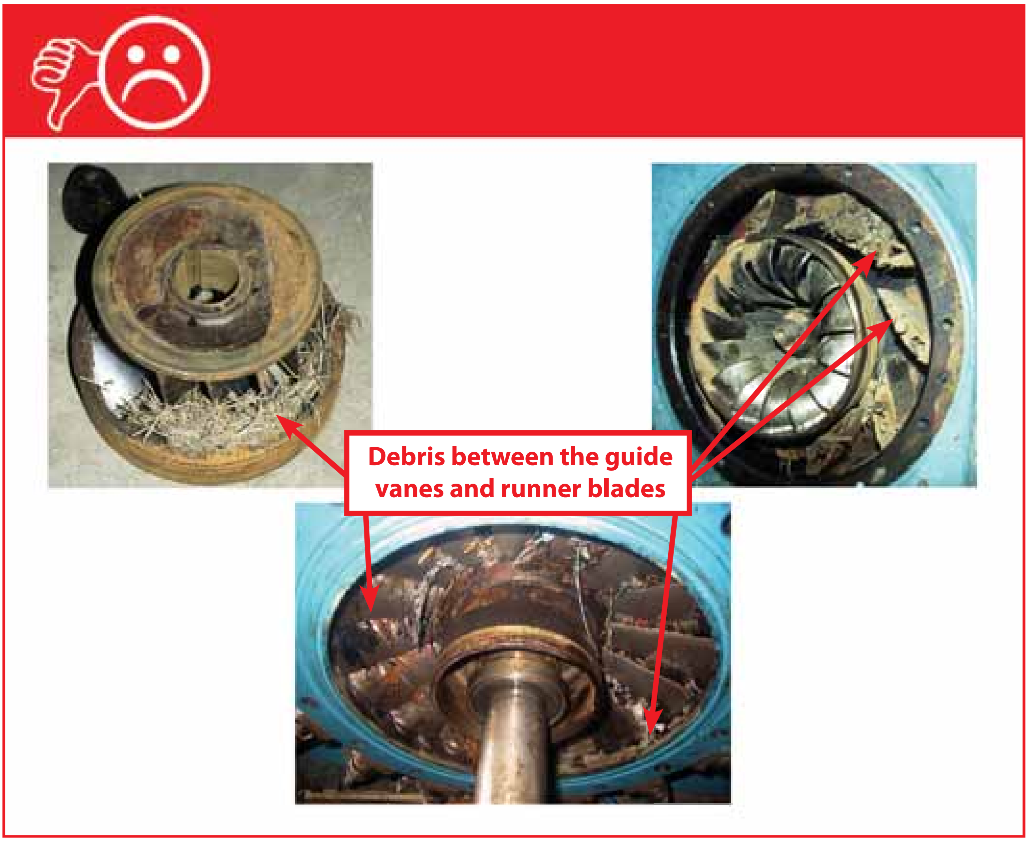
WASHER SIZE SHOULD BE TWICE THE DIAMETER OF THE HOLE!

BOLT SLOTS ALLOW A PRECISE ALIGNMENT OF THE EQUIPMENT!



Why is this a good example?

- The washers have correct dimensions and are centered to the hole
- The tapper washer is necessary to compensate the slope of the steel section with the horizontal steel base
- Screws have to be installed vertically



Clogged runner and guide vanes

How can I improve it?

- Prevent debris from getting into the penstock by installing a fine trash rack according to the requirements of the turbine manufacturer
- Clean and maintain the trash rack regularly

Why?

- Debris in the turbine blades initially reduces the performance of the turbine but eventually will clog and damage the turbine
- Especially Francis and propeller turbines are susceptive to get blocked by debris

A turbine in good condition – thanks to a functional sand trap and trash rack

Why is this a good example?

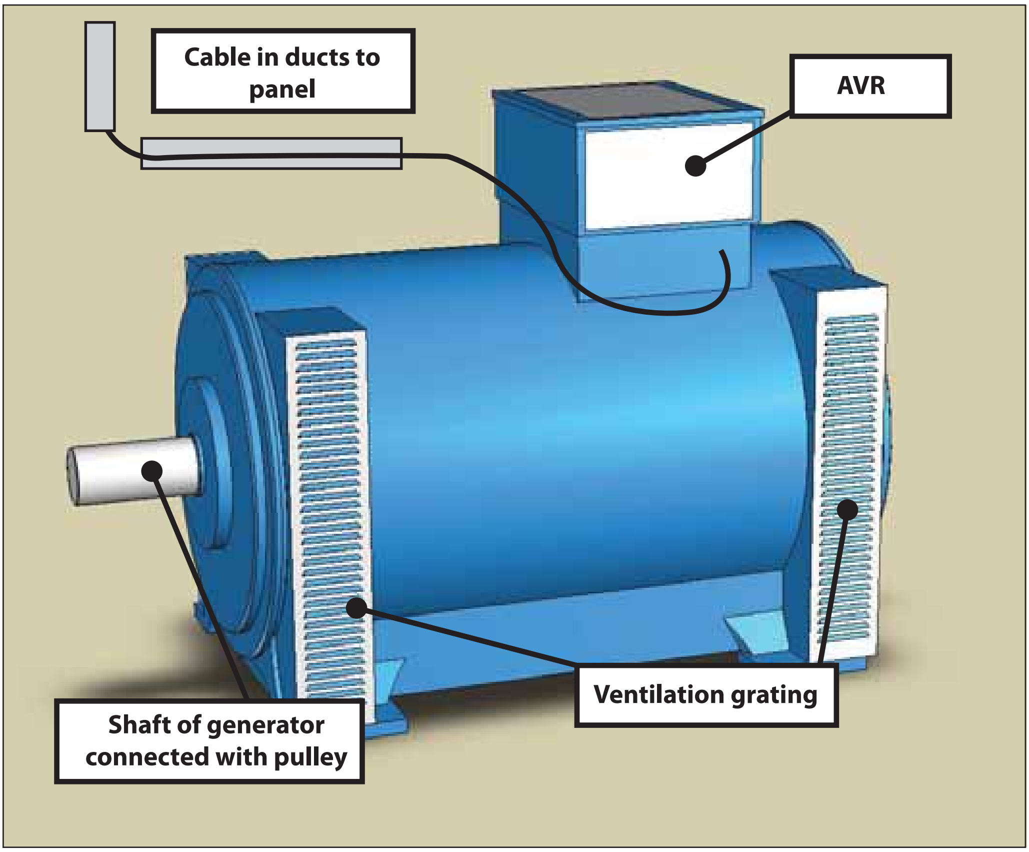
- The performance of the turbine is not influenced by debris
- The trash rack is built according to the recommendation of the turbine supplier and keeps the turbine clean
- Thanks to a sand trap no abrasion is visible on the turbine runner

Note:

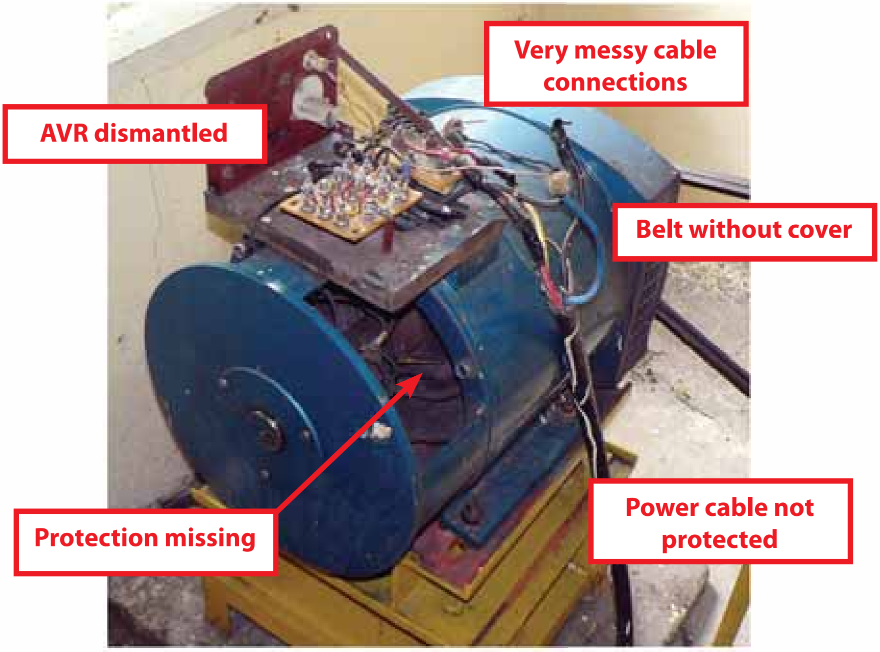
PROTECT THE TURBINE AND IT WILL KEEP RUNNING FOR A LONG TIME!

CLEAN TRASH RACK AND SAND TRAP REGULARLY!

3.2.2 Main Elements of a Generator



The drawing depicts a synchronous generator with an AVR (Automatic Voltage Regulator). In island mode, the AVR controls the generator voltage which is the system voltage as well. In grid-connected mode, the AVR is not able to change the system voltage but by adjusting the excitation current it can determine the reactive power characteristics. Asynchronous generators do not have an AVR.



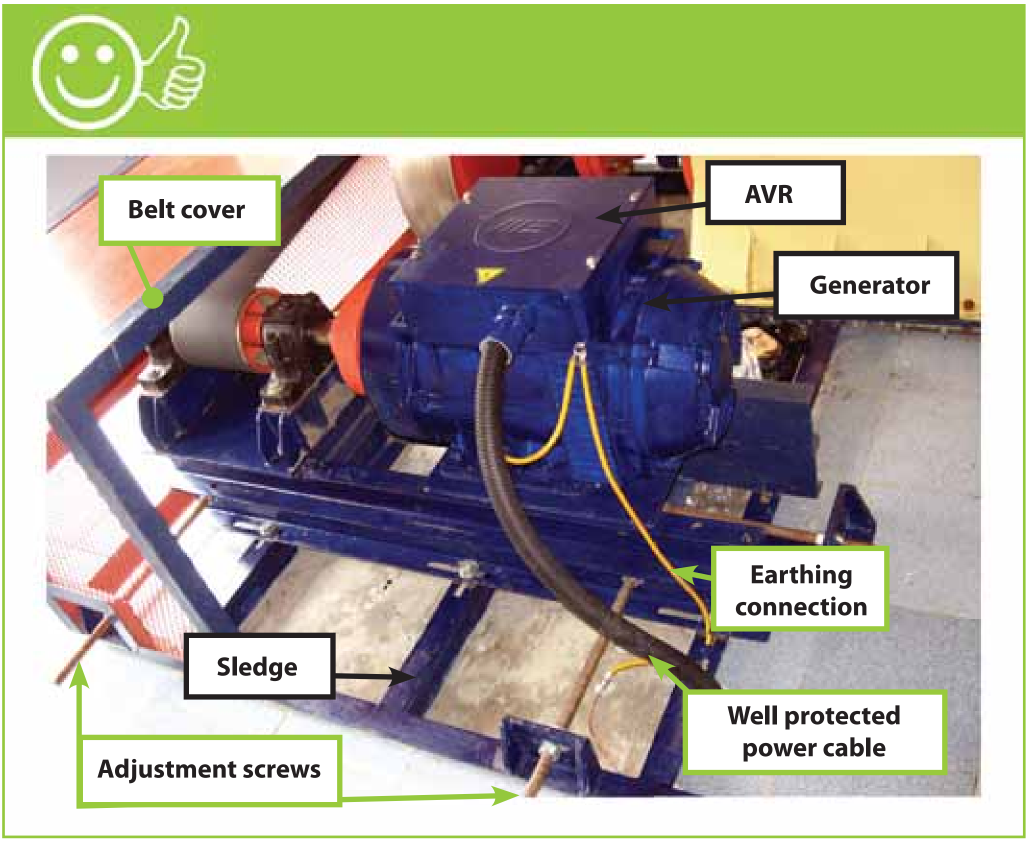
Generator and AVR – in bad condition

How can I improve it?

- Replace all missing parts of the generator and AVR
- Make proper cable connections in accordance with safety regulations
- Power cable must be laid in a duct
- Connect generator and controller to an earthing system
- Transmission belt must be protected with a cage

Why?

- The presence of untrained persons in the powerhouse is possible. They must be protected from the dangers of electricity and mechanical power.
- Safety regulations always make sense and have a reason, they help to prevent accidents and injuries
- Good and conscientious operation and maintenance work will lead to good operation

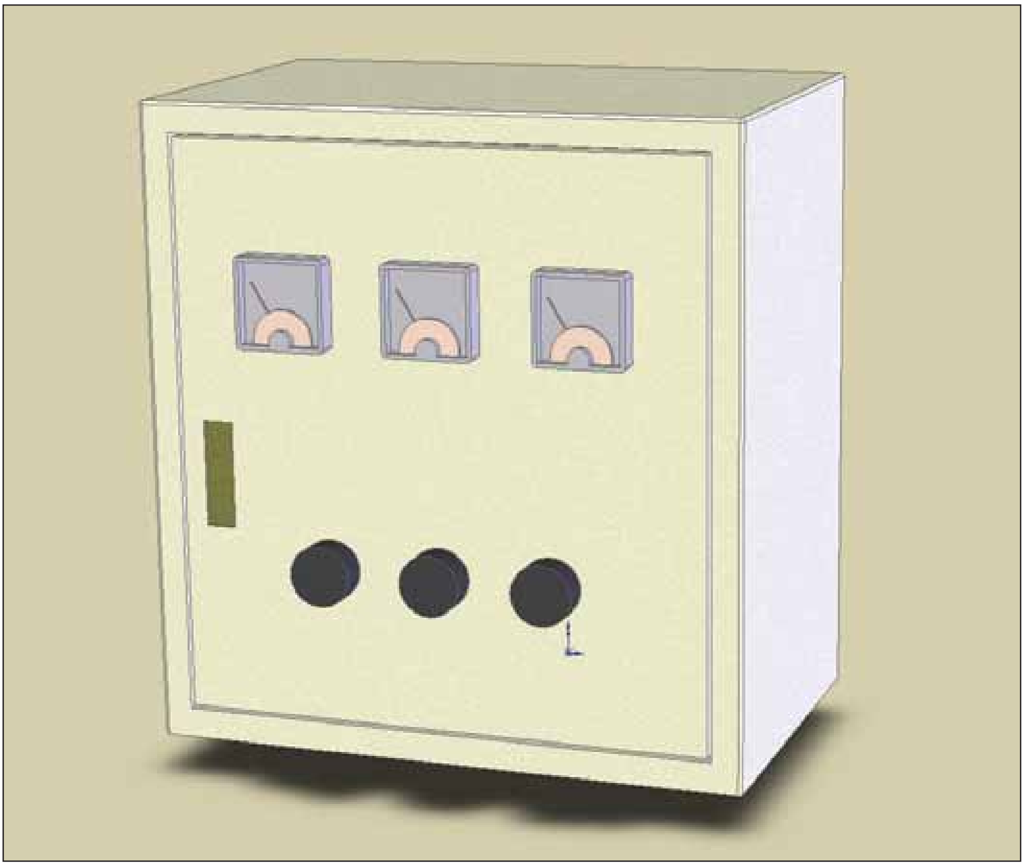


Generator – well installed

Why is this a good example?

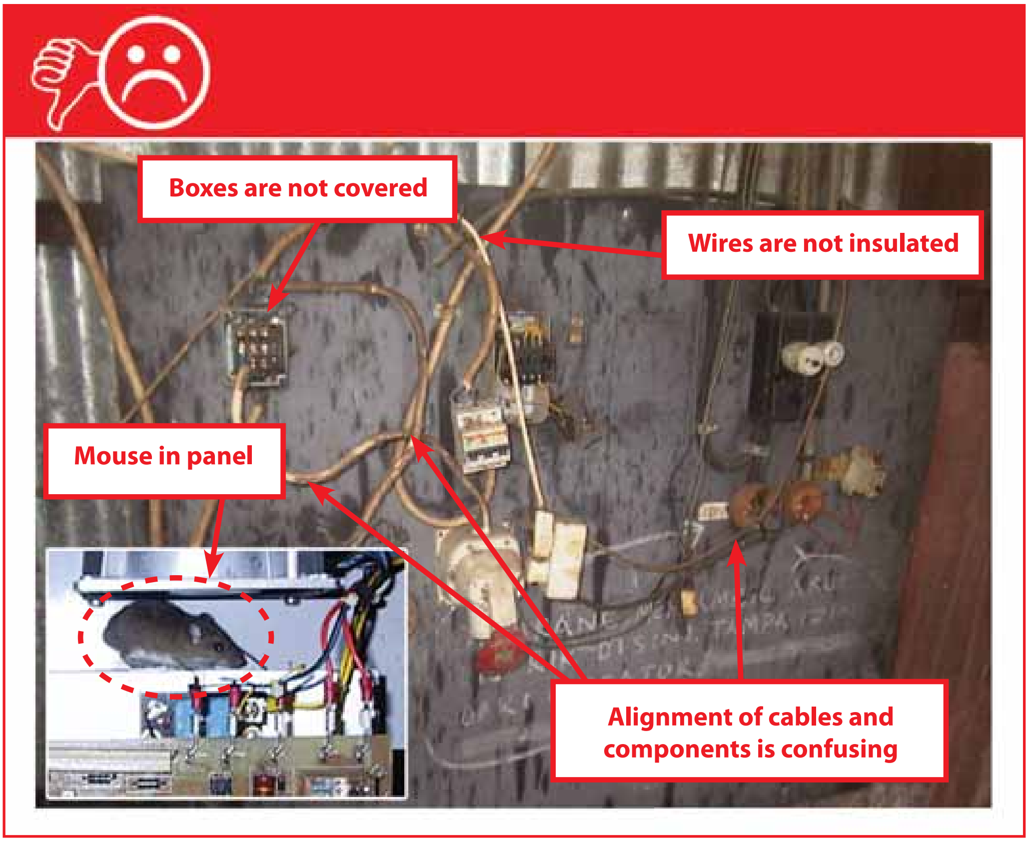
- The equipment is installed in accordance with safety regulations
- Power cable is protected by a flexible pipe
- Generator and controller are connected to the earthing system
- The belt is protected with a cover
- There is enough space to shift the generator into the right position. The belt can be tightened by moving it on the sledge on the frame
- The floor is clean, allowing to detect water leakages & other irregularities immediately

3.2.3 Panel, Controller and Ballast



A safe place for all electrical devices

The control cubicle provides a safe place, dry and free of dust, for the electrical devices and also protects people working in the powerhouse from electrical shocks.



Bad example of wiring and electric components

How can I improve it?

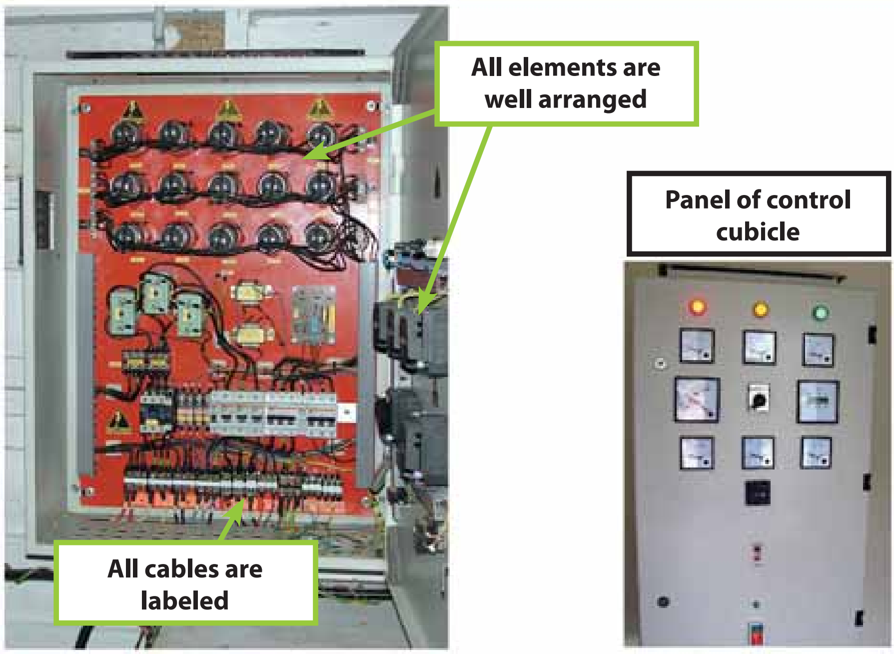
- Mount electric components and wiring in a well-arranged scheme
- Electrical components must be installed in a lockable metal case
- Prevent public access to electric components & wiring – including access for animals which can bite away the insulation of cables

Why?

- Improperly built panels are a potential source for technical failures
- Even experts can understand (and thereafter fix) a system only when it is well-arranged
- Bare wires are dangerous

Note:

RISK OF INJURY & DEATH!



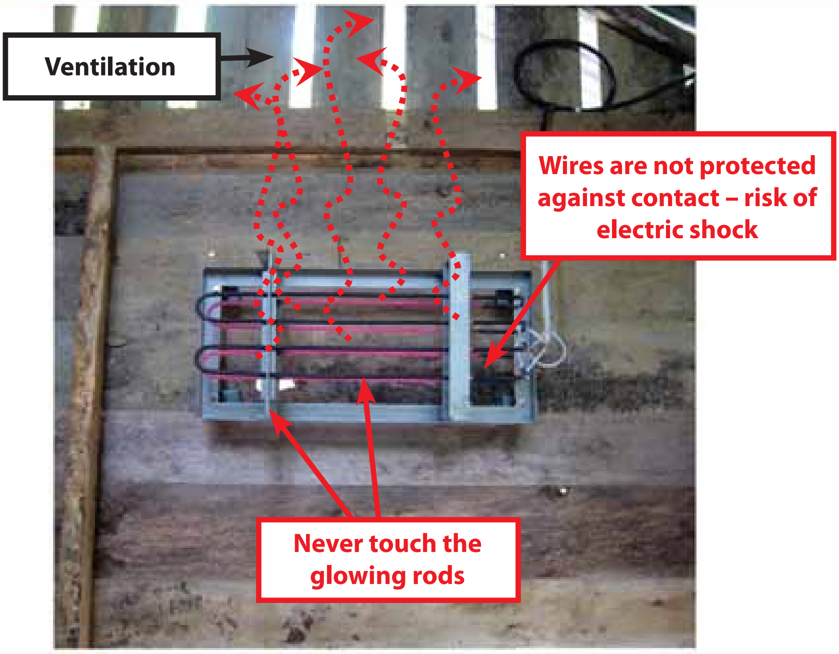
Example of a well arranged control cubicle

Why is this a good example?

- Clear arrangement of all components makes maintenance simple and fast
- Cables and devices are properly labeled
- Repairs are quick and easy to do
- Working on the cubicle is safer

Note:

DURING OPERATION THE PANEL MUST BE CLOSED AND SHOULD BE LOCKED!



Unprotected ballast presents a real hazard

How can I improve it?

- Re-install ballast at a well ventilated place
- Attach ballast higher – out of reach of people
- Mount a safety cage around the ballast
- Install a heat shield against the wooden wall and ceiling boards

Why?

- Hot ballast is a fire hazard especially for wooden boards
- Plastic cable coatings may melt
- If the ballast is installed too low somebody may touch it and get burned

Note:

RISK OF INJURY!

Well protected ballast at outer wall of the power house

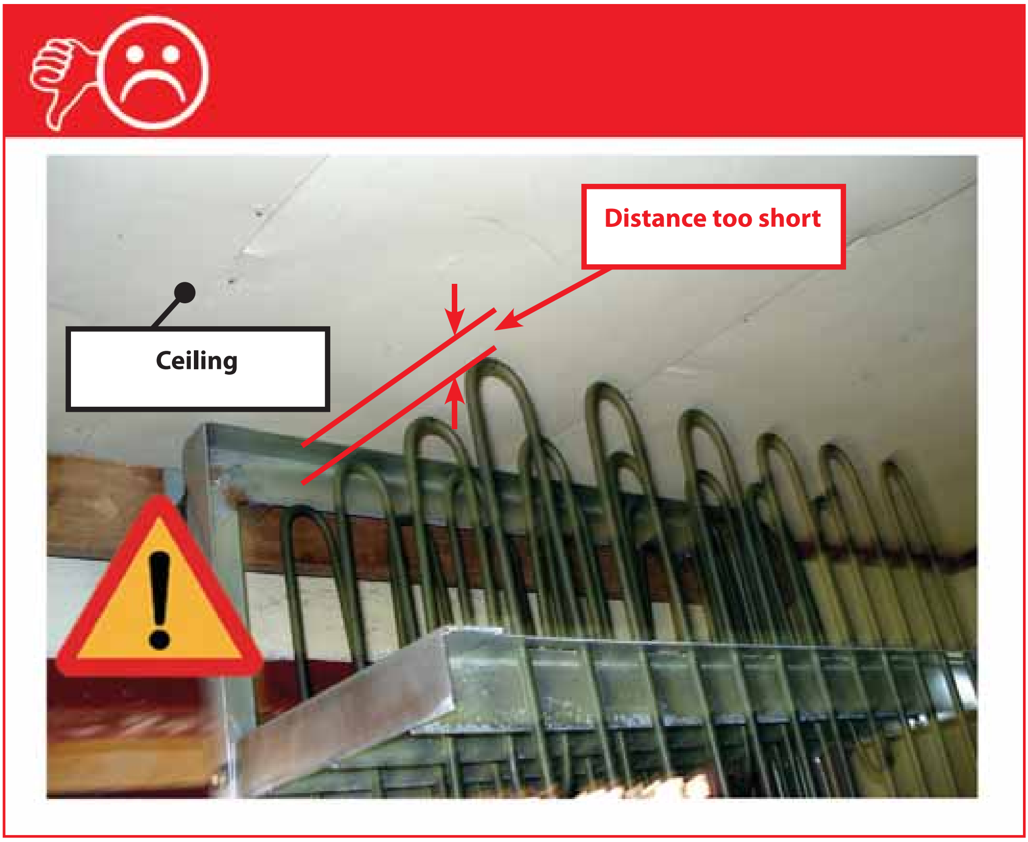
Why is this a good example?

- The roof protects the ballast installation against rain
- Ballast is well ventilated
- The outer cage prevents access by unauthorized persons

Note:

IN CASE OF LOW LOAD IN THE VILLAGE (WITH MOST APPLIANCES SWITCHED OFF) THE CONTROLLER DIVERTS ELECTRICITY TO THE BALLAST WHERE IT IS CONVERTED TO HEAT!

RODS ARE GLOWING HOT!



The distance between ceiling and the top edge of ballast must be at least 50 cm

How can I improve it?

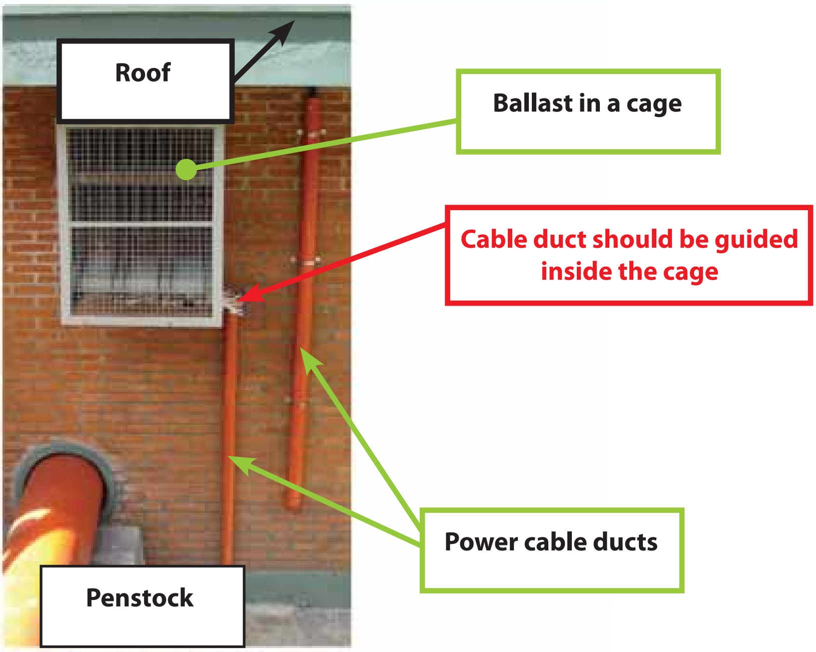
- Install ballast lower, or if that is not possible, outside of the power house
- Protect the ballast with a safety cage
- Provide ventilation for the glowing rods

Why?

- If the electricity demand is low, the excess energy is sent to the ballast. The rods get very hot and enough space to the roof plus a good ventilation is required to convey the heat

Note:

RISK OF FIRE!



A good installation of ballast

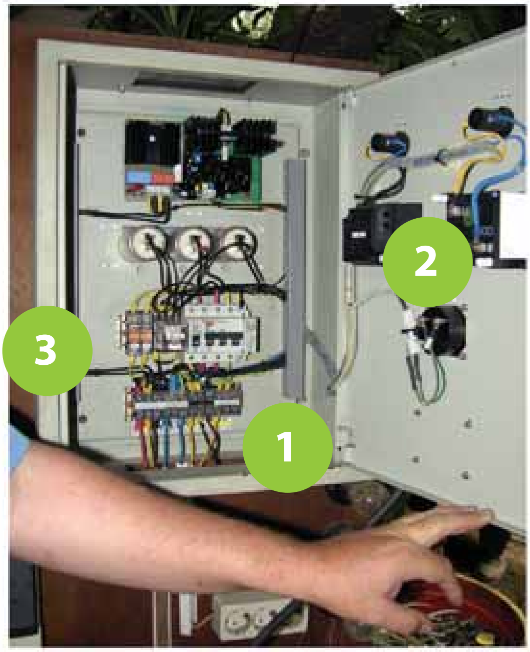
Why is this a good example?

- Ballast is well protected in a steel cage
- Ballast is properly ventilated as it gets very hot
- Installation under the roof is a good rain protection
- The wiring to the ballast is run through ducts
- Unauthorized persons have no access to the ballast and could not be burned by the glowing rods

Note:

CABLE DUCTS SHOULD BE GUIDED INSIDE THE CAGE TO PREVENT DAMAGE OF THE CABLES!

IF THESE CABLES ARE INTERRUPTED THE TURBINE CANNOT BE CONTROLLED ANYMORE!



What must I do to keep the system running well?

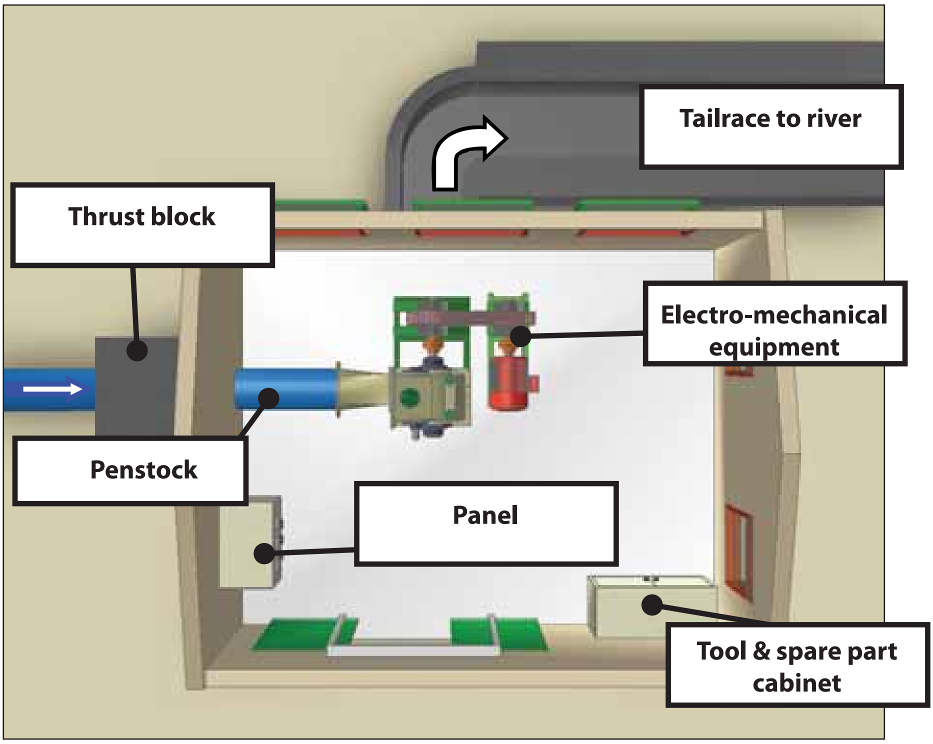
1. Keep panel clean of dust and grease
2. Check all electrical devices and control instruments for functionality
3. Make sure that all cable connections are okay

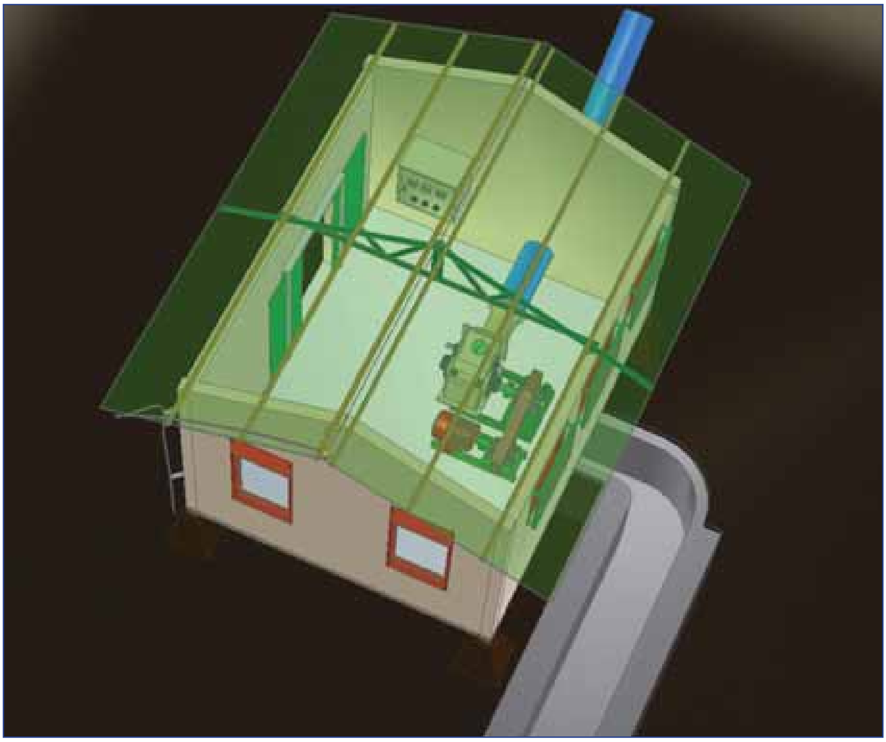
Note:

ONLY PROPERLY WORKING DEVICES PRODUCE ELECTRICITY!

CHECK AT LEAST ONCE A WEEK!

3.2.4 Inside the Power House





Main equipment is too close to walls

How can I improve it?

- At the design stage enough space must be planned around the turbine and generator
- Try to re-arrange equipment or enlarge power house to make more room around main equipment

Why?

- Adequate working space is required for service and maintenance
- For disassembly of the turbine shaft, a certain minimum space is needed dependant on the length of the shaft

Here is adequate space around the equipment

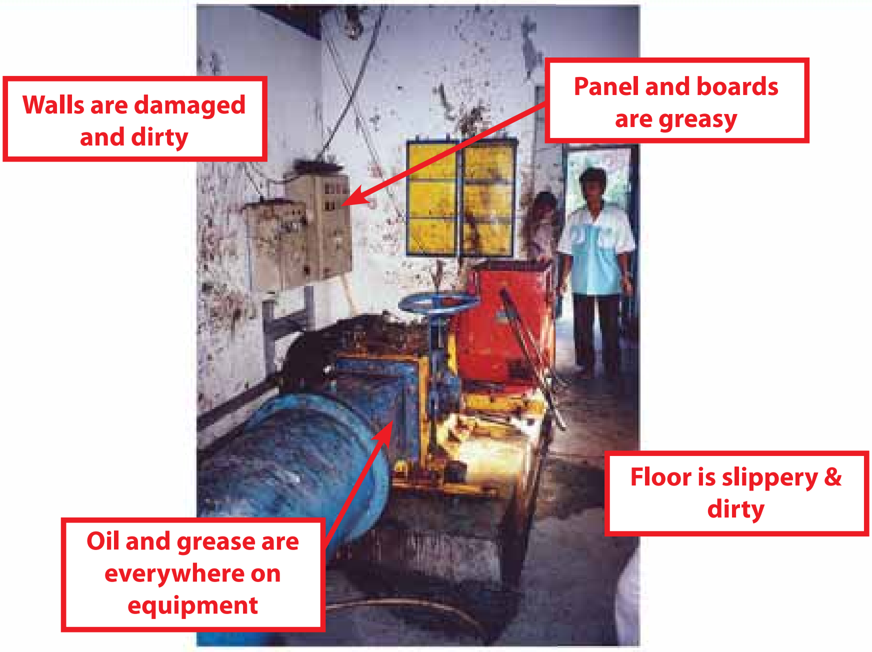
Why is this a good example?

- There is sufficient space for operation, maintenance, repair and assembly / disassembly work around the generator and turbine
- Recommended space:
  - A = minimum 1.5 m when also entrance area
  - B = minimum 1.0 m
  - C = minimum 1.5 m or at least length of turbine shaft plus 0.5 m
- Area around all electro-mechanical equipment is kept clean → no greasy and/or wet surfaces

Note:

WATER CONDUCTS ELECTRIC CURRENTS VERY WELL!

HAZARD FOR OPERATOR!



A poorly maintained, run-down power house

How can I improve it?

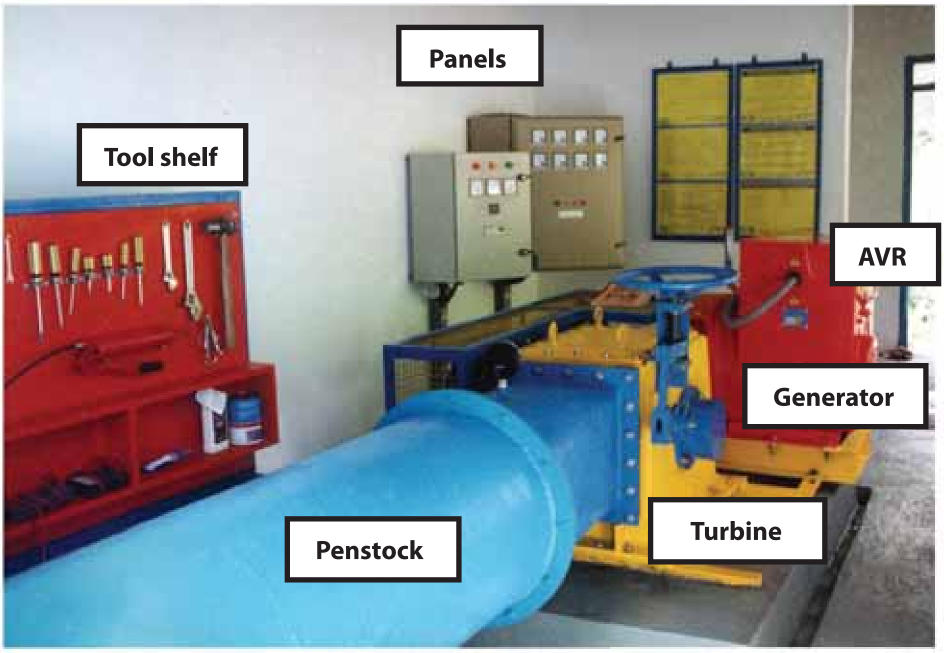
- Clean up the power house
- Clean hands thoroughly after maintenance work with grease & oil
- Wipe floor every time after working in the power house

Why?

- Expensive equipment must be kept clean to work well
- Work in a clean environment is much safer and also enjoyable
- Oil could reach water and soil and pollute it
- Dirt and grease can cause the electrical equipment to fail

Note:

A GREASY FLOOR IS SLIPPERY AND UNSAFE!



All equipment is well arranged, clean and well maintained

Why is this a good example?

- Operation and maintenance is easier when all equipment is well arranged
- All equipment – tools, spare parts etc – is within easy reach
- Cleanliness and tidiness assure that nothing is lost or damaged by dust or filth
- A clean floor prevents it from becoming slippery and makes work safer

Power house is NO stage for a show or family visits

How can I improve it?

- Keep out all persons who have no business in the power house, especially children
- If unauthorized persons enter the power house, stop moving equipment immediately to avoid accidents
- Act in accordance with all safety regulations and procedures

Why?

- A power house is not the place for visits or meetings when fast-moving equipment is in operation and electricity is generated

Note:

BE AWARE THAT AN UNPROTECTED ROTATING BELT DRIVE, FLYWHEEL AND TURBINE-GENERATOR SHAFTS ARE DANGEROUS FOR (UNAUTHORIZED) PERSONS → CLOTHES CAN EASILY BE CAUGHT!

A RISK TO EVERYBODY'S HEALTH!

What must I do to keep the system running well?

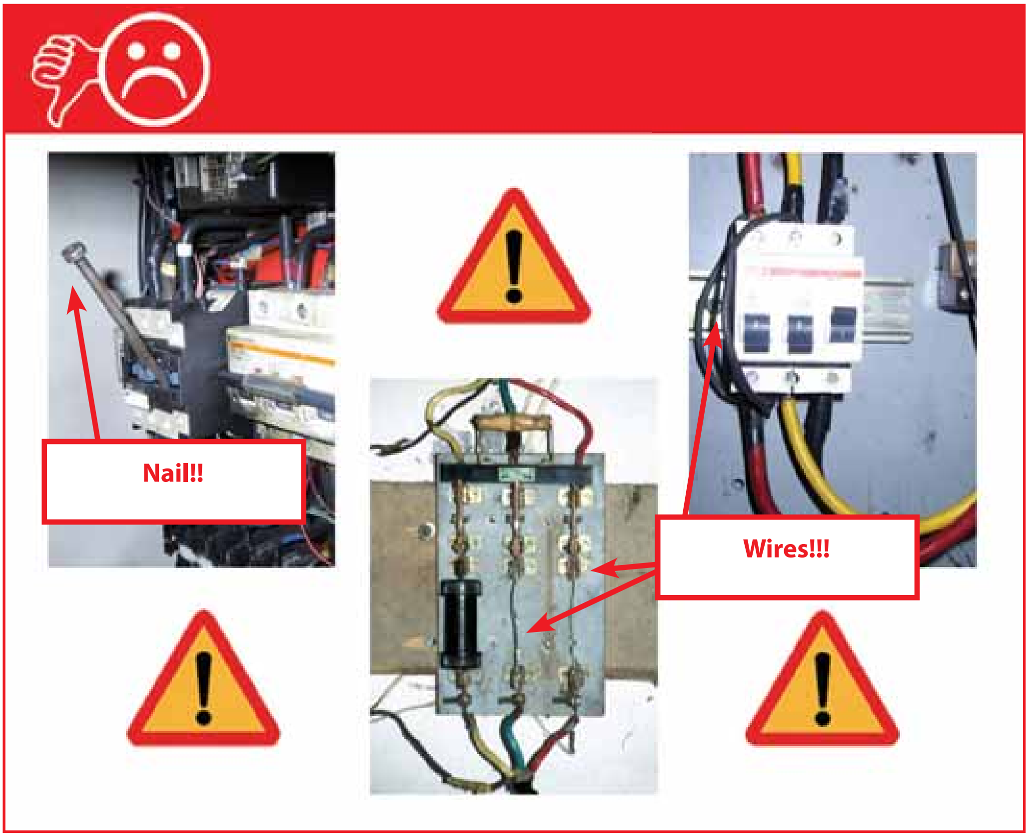
1. Keep floor and walls clean and tidy
2. Clean all parts of the equipment after maintenance
3. At the end of maintenance work put all removable parts back in place again

Note:

ONLY CLEAN EQUIPMENT WORKS WELL!

CLEAN AT LEAST AFTER EACH MAINTENANCE ROUTINE!

3.2.5 Power House Wiring



Never bridge fuses → it is far too dangerous!

How can I improve it?

- NEVER replace fuses with a wire or other metallic object
- Insert all fuses required in the panel and keep panel closed during the operation
- It is operator's responsibility to have fuses in stock

Why?

- Fuses implement important electric safety functions
- Bridged fuses cause short circuit and can injure the operator or burn down the power house

Note:

DEADLY DANGER!

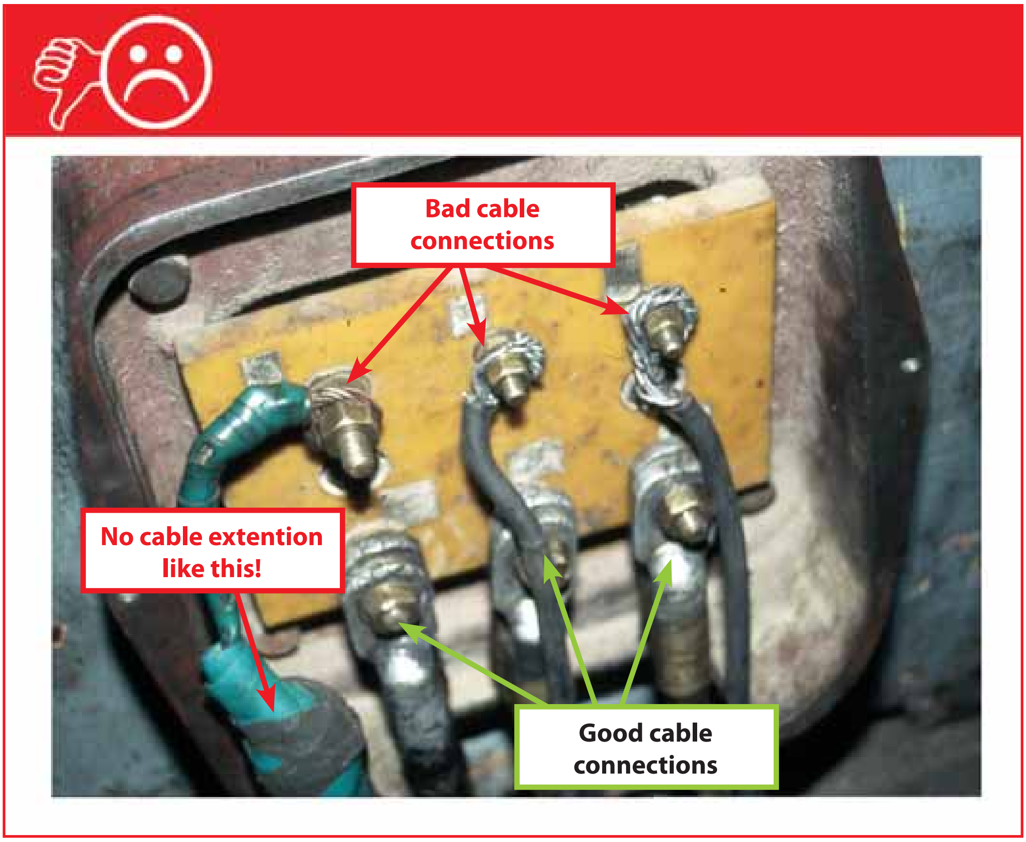
Devices of power and control cubicle

Why is this a good example?

- Clear layout of all wires and devices, which makes the search for failures much easier
- The cubicle is kept clean
- Every device is labeled, facilitating an easy understanding of the system

Note:

CLOSE CUBICLE DURING OPERATION!



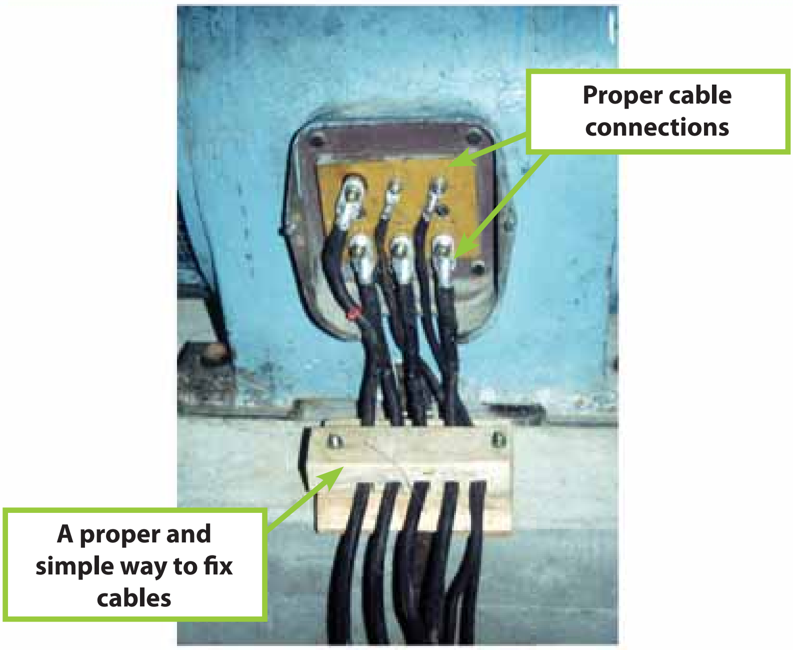
Bad cable connections are a source for major damages

How can I improve it?

- ONLY use cable shoes for cable connections – there is NO alternative

Why?

- Electrical wires have to be connected properly to avoid losses
- Bad connections cause improper operation and can be the reason of short circuits
- Short circuits are hazardous for operation and equipment and lead to unnecessary interruptions in operation



Cables are properly fixed with cable shoes

Why is this a good example?

- Cable shoes are according to cable diameter and are fixed with screws
- Cable connections cannot move because they are fixed to the wall before entering the panel
- No tension on cables

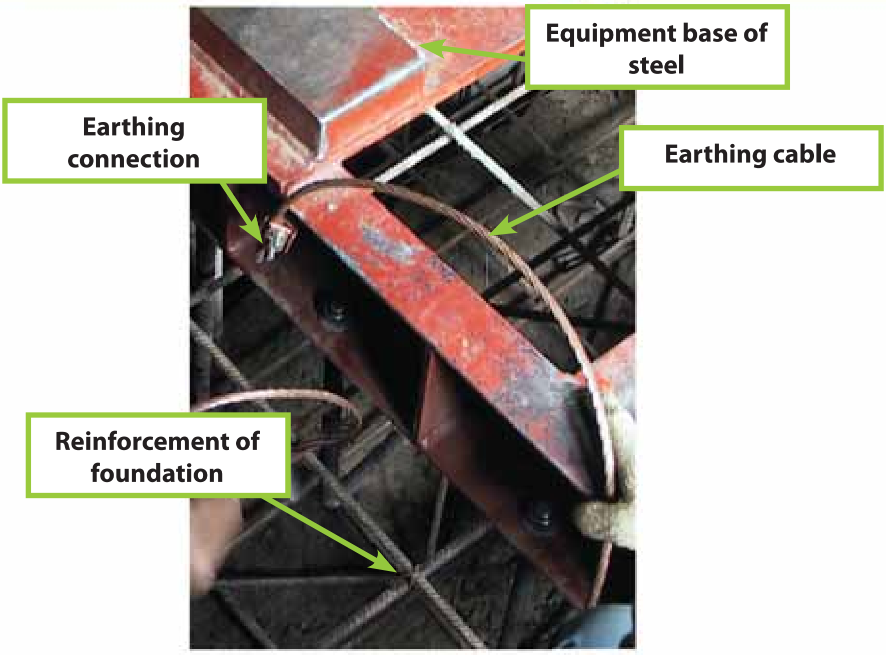
Earthing connection will probably not work

How can I improve it?

- The earthing ring must be connected to all main installations in the power house – e.g. reinforcement of foundations of power house, equipment and all the other pieces
- Use earthing clamps for any connection to the earthing system

Why?

- The earthing system is a safeguard system for installations, appliances and people in the power house
- The distance between the earthing ring – which is laid around the power house – and the installations has to be at least 1 m and must be done with earthing clamps
- This above-the-ground-connection is essential to measure the resistance in order to find out if the earthing system functions properly



Reinforcement of foundation & steel base connected to earthing rod

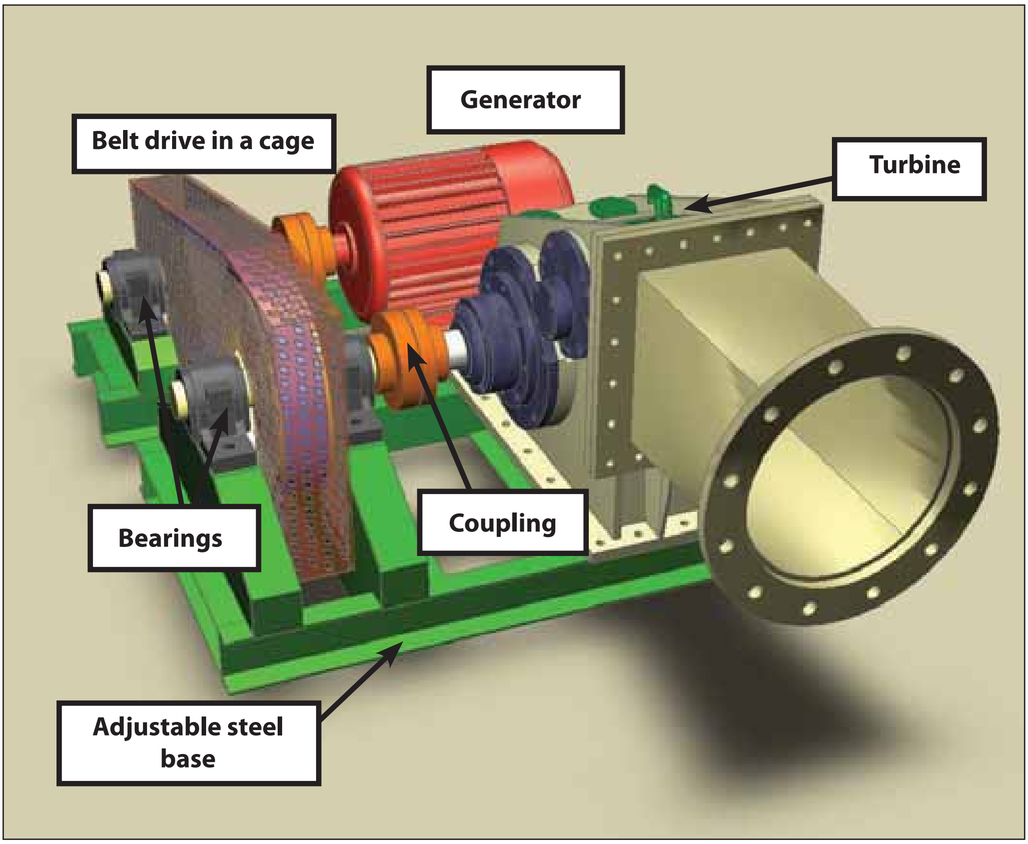
Why is this a good example?

- Reinforcement of the foundation base and the equipment steel base must be connected to the earthing system with earthing clamps
- This connection avoids severe damage to people and equipment in case of malfunctioning of a device
- Earthing system protects all machines and equipment, wiring, power house and the people working there against lightning and stray currents

Note:

NO EARTHING – A DEADLY DANGER!

3.2.6 Mechanical Transmission



The mechanical transmission links the turbine to the generator. It is also often called speed increaser. It is needed because the generator usually runs at a much higher rotational velocity than the turbine. There are different types of transmissions; in the case of MHP with crossflow turbines, belt drives are very commonly used. They are not suitable for turbines and generators with more than 100 - 200 kW.

Flywheel and belt are not protected in a cage

How can I improve it?

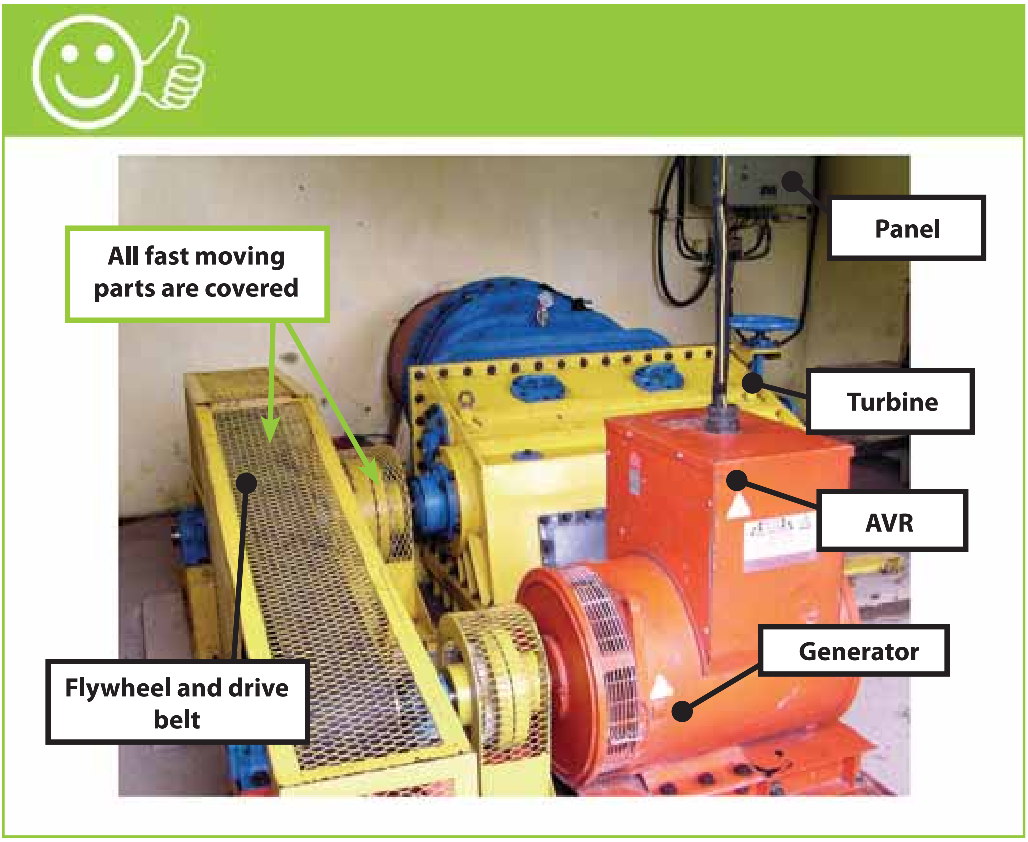
- Put the safety cover back over the flywheel and belt before re-starting operation
- Follow all safety regulations and procedures

Why?

- Unprotected fast moving parts (wheels and drive belt) are a hazard to the operator (and everybody else entering the powerhouse)

Note:

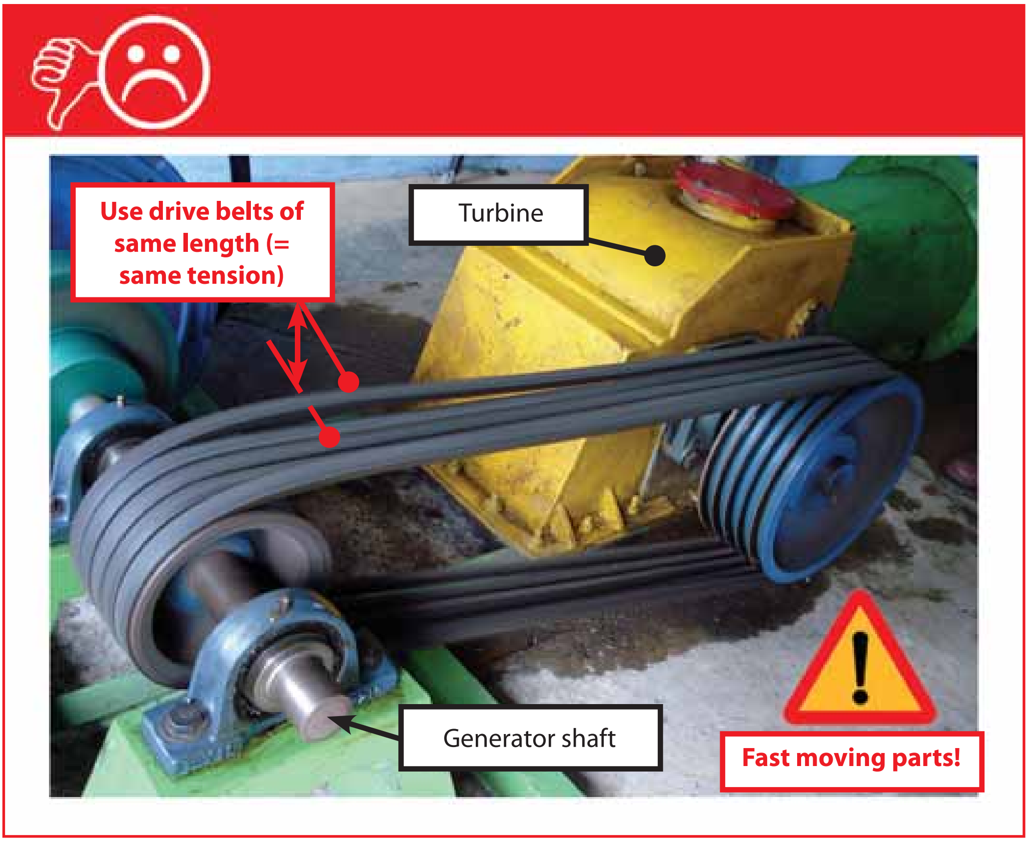
FAST MOVING PARTS – A SERIOUS HEALTH HAZARD!



Flywheel, drive belts and couplings covered by safety covers

Why is this a good example?

- The safety covers prevent accidents when the turbine is running
- Floor is clean and tidy
- There is enough working space around the equipment



Tension of drive belts is very important for efficient transmission

How can I improve it?

- If the tension of the drive belts feels or looks insufficient, tighten them by shifting the position of the flywheel and generator subframe
- Use only drive belts of the same manufacturer and same age → buy and replace all belts at the same time
- Always keep pulleys and drive belts free from any grease

Why?

- For an efficient transmission it is essential to have equal tension on all drive belts
- A well-running generator produces more

Tension of all belts must be the same

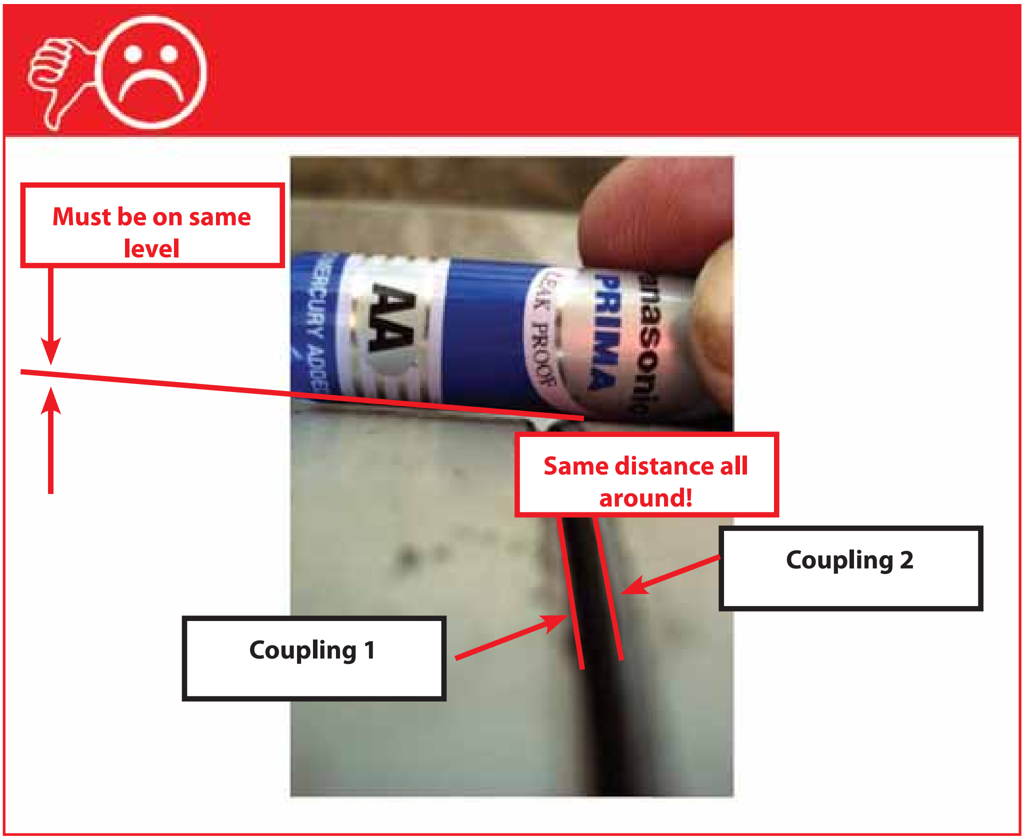
Why is this a good example?

- A properly aligned and tensioned transmission leads to a high efficiency
- Uneven tension of the drive belts leads to more strain on the more tightened ones, reduces efficiency and can cause additional strain on bearings

Note:

OPERATOR MUST CHECK TENSION OF DRIVE BELTS BEFORE START-UP!

PULLEY AND BELT MUST BE KEPT FREE FROM GREASE!



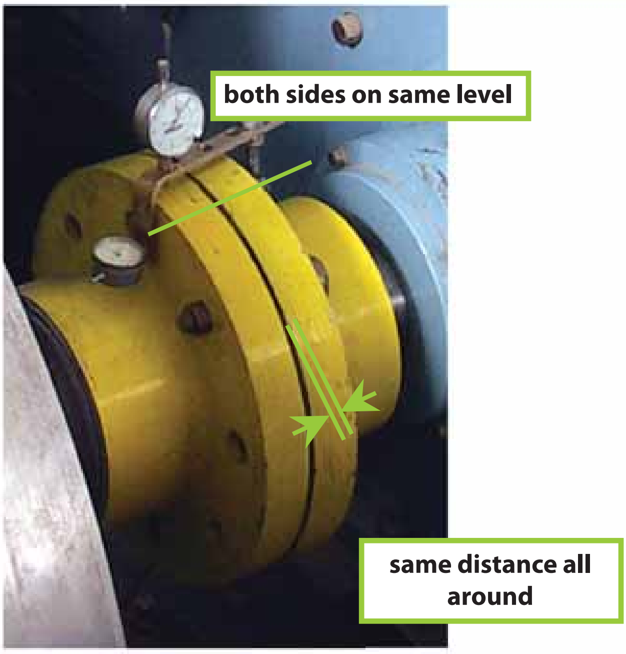
Precise work is required when coupling is being adjusted

How can I improve it?

- The distance and elevation between parts of the coupling must be the same • equal pressure is necessary to ensure long service life of the coupling

Why?

- Proper coupling alignment is very important as it extends the service life significantly
- Misalignment leads to unnecessary and premature damage of the coupling



Connection adjustment check

Why is this a good example?

- The required distances of the coupling elements are respected exactly
- It is very important, that the alignment of the connection is done carefully, otherwise the seal will soon be destroyed and has to be replaced more often → avoidable costs

Note:

EVERY INTERRUPTION OF THE OPERATION CAUSES A POWER OUTAGE FOR THE CONSUMERS AND MEANS NO INCOME FOR THE MHP!

More grease on the floor than in the bearing

How can I improve it?

- Handle grease with care
- Press grease only in the nipples where it is needed
- Clean all equipment and floor after greasing
- Keep the floor clean and tidy

Why?

- ONLY the moving parts of the equipment need lubrication
- Grease on the floor is a serious risk for the operator and anybody else in the power house → floors become slippery

Note:

SLIPPERY POWERHOUSE – HIGH RISK OF INJURIES!

Grease properly applied

Why is this a good example?

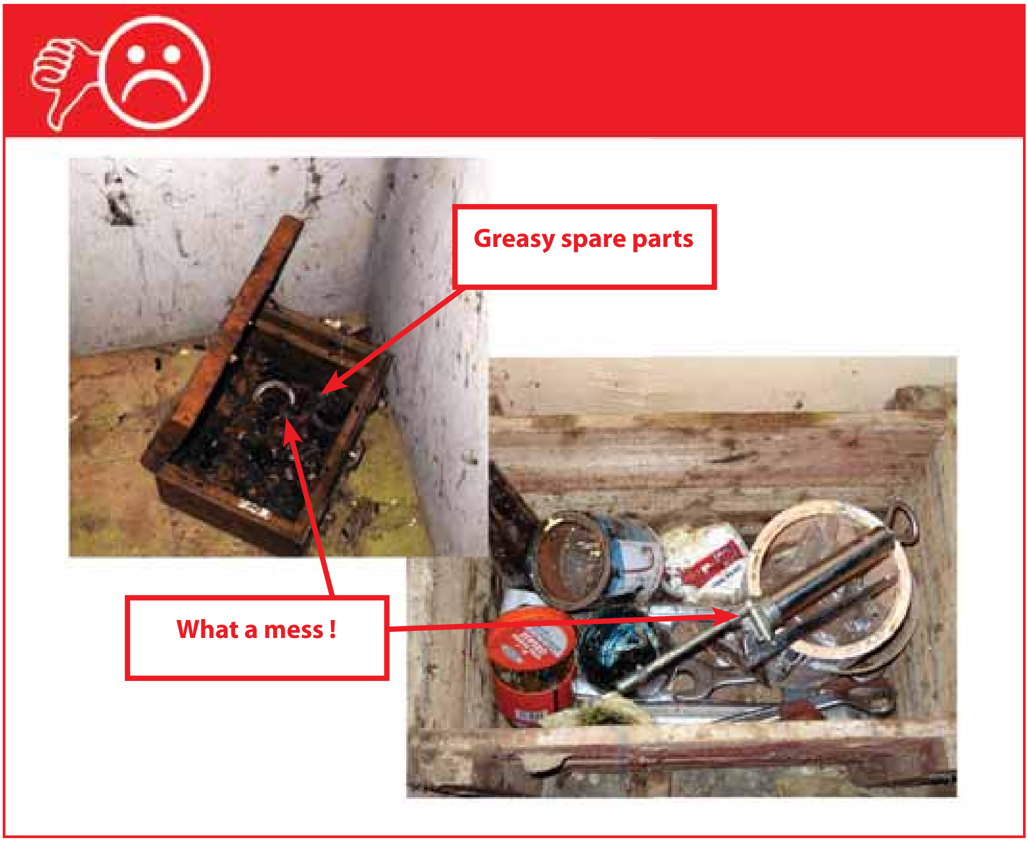
- All moving parts of a machine need grease for good operation
- Apply grease until it starts to ooze out – then it is enough
- Clean off surplus grease
- Prevent greasy floors – always clean up after lubricating machines

Note:

TOO MUCH GREASE CAN TEMPORARILY LEAD TO AN INCREASED BEARING TEMPERATURE!

IT IS ADVISABLE TO GREASE CAREFULLY AND OBSERVE THE BEARING TEMPERATURES!

3.2.7 Tools and Spare Parts



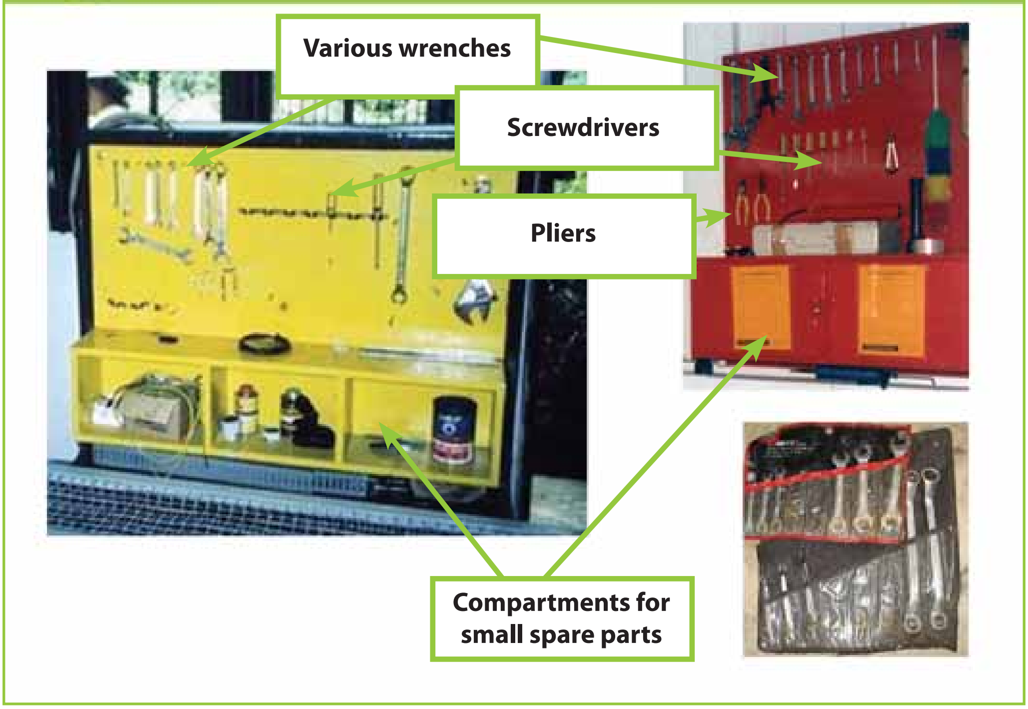
Spare parts and tools have to be cleaned and stored well organized

How can I improve it?

- Store spare parts in a cabinet or tool box and keep it locked
- Store frequently needed tools readily on a tool shelf or board
- Always clean tools immediately after use

Why?

- The operator must know which spare parts are in stock and which he should order
- The operator should keep a written inventory of all tools and spare parts, and update it regularly
- This will save money because only what is needed will be purchased
- The condition of the tools and spare parts shows the quality of the operator and his work



Well stored tools – always within easy reach

Why is this a good example?

- For frequent work tools should be within easy reach of the operator
- Tools are stored on the tool boards and shelves after use
- The tool boards and shelves are clean – this is also good for a safe working environment
- Work is probable more enjoyable when tools are at hand and clean

Proper tools & lubricants: essential for operation & maintenance

What must I do to keep the system running well?

1. Electrical tools are essential for electrical maintenance
2. Various accessories for effective maintenance
3. Equipment for lubrication and grease must be available
4. Common electrical spare parts must be stocked
5. Common mechanical spare parts must also be stocked

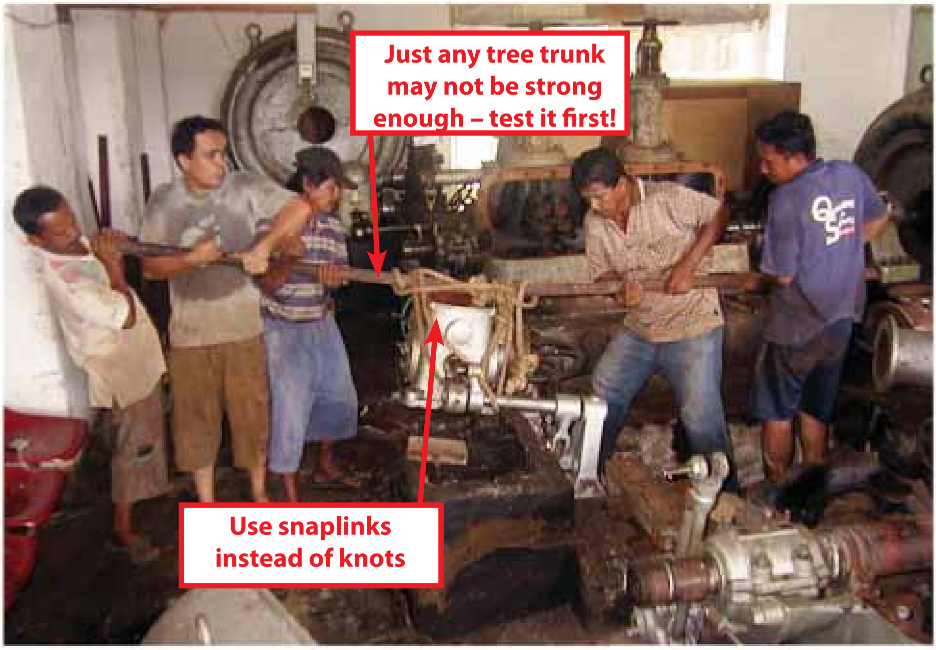
Note:

KEEP TOOLS AND SPARE PARTS CLEAN AND COMPLETE ALL THE TIME!

GOOD TOOLS MAKE THE JOB EASY!

SPARE PARTS IN STOCK SHORTEN MAINTENANCE WORKS!

CHECK COMPLETENESS OF TOOLS AND SPARE PARTS AT LEAST AFTER EACH MAINTENANCE ROUTINE!



Heavy and costly equipment must only be moved with a lot of care

How can I improve it?

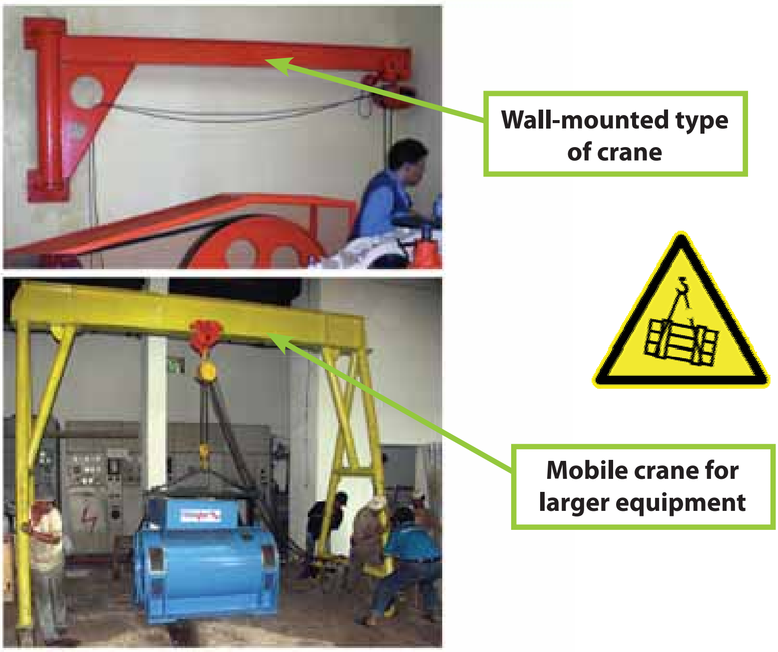
- Use proper lifting equipment
- Alternatively, use a sufficiently strong tree trunk, structural piece of wood or steel, or a heavy steel pipe (but test it first for its strength)
- Use snap links instead of knots because snap links do not open during lifting

Why?

- Hydro power equipments is costly and hard to replace
- Improper lifting of heavy equipment may put the work team at risk

Note:

RISK OF INJURIES!



Two types of lifting equipment for heavy loads in larger power houses

Why is this a good example?

- Strong lifting equipment is essential for both, installation and maintenance
- The movement and / or transport of heavy equipment must be done with a lot of care and with regard to all necessary safety procedures

Three tree trunks – tied together as a tripod – look rather weak

How can I improve it?

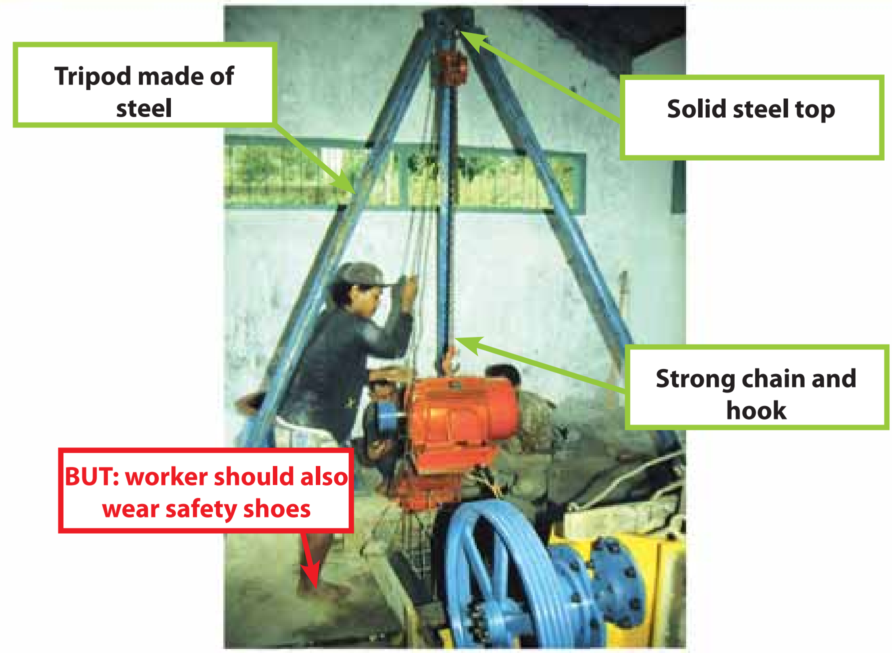
- Preferably replace this kind of tripod by using steel sections or pipes
- If it can be afforded and managed, use a crane, or similar equipment, for moving heavy loads
- Use snap links instead of knots for safe lifting

Why?

- Wooden trunks can break when lifting heavy loads and hooked equipment can get damaged and hurt operator

Note:

RISK OF INJURY!



Strong tripod used for lifting a heavy piece of equipment

Why is this a good example?

- A steel tripod, meeting all safety requirements, including a strong steel chain and hook, is used for lifting and transport
- Heavy and expensive hydro power equipment is being lifted / transported very carefully

But:

- The feet of the worker also need protection!

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