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Design of a micro hydropower plant in Cameroon: An example of knowledge exchange in developing countries

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Abstract:

This paper presents activities of the so-called 'Fakultätsplattform Entwicklungszusammenarbeit' of the Technische Universität München (an association that supports knowledge exchange with developing countries) with the focus on the design of a micro hydro power plant for a renewable energy vocational school that is being realized in collaboration with two Cameroonian partners. The power plant which is situated in a remote area will provide the school with electricity and serve as an example for the education of the students. During a two-week research stay in Foumban close to Bafoussam several possible sites have been surveyed. Result of the trip was a feasibility study that examined four different layout options. Due to social and ecological reasons a site was chosen where only part of the water discharge at a natural step is used. A head of 10.88 m is gained within approximately 100 m of D = 0.5 m penstock. The hydro power plant has got an estimated output of 15 kW. A crossflow turbine combined with a synchronous generator will supply the island network. As hydrological data is scarce emphasis has been placed on ensuring flood protection.

Keywords: Knowledge exchange, international collaboration, hydro power, regional involvement

1. PREFACE

We can learn from history that engineering know-how in terms of protection from natural hazards as well as the control of water and food supply paved the path to civilization. Nowadays building infrastructure is the basis of a developed society and therefore civil engineers are essential to form it. This issue has been the notion for the foundation of a platform for knowledge exchange at the Faculty for Civil Engineering and Geodesy at the University of Technology in Munich, Germany (www.ez.bv.tum.de).

The scope of the initiative is manifold. Its core form lectureships which were held at Jordan University of Technology and Eduardo Mondlane University in Mozambique, where support is also given to build up a hydraulics laboratory. These courses comprise topics of renewable energy supply for buildings and hydraulics respectively hydraulic engineering. In the hydraulic laboratory practical trainings are given for students and teachers for which certain measurement devices are being provided. The work has been highly recognized by the Mozambican Prime Minister who even visited the Hydromechanics Laboratory of the TUM while being on state visit in Germany in May 2011.

Additionally to the academic exchange joint projects between students from Germany and countries in Latin America and Africa are being realized with the involvement of the local population. For instance the power supply for a medical care center in Burkina Faso was designed as well as the electrification of a primary school in Mozambique; a kindergarten with autonomous power supply was planned and constructed near Cape Town. Various

projects were conducted in the Ecuadorian rain forest where among others the drinking water supply of a village and a micro hydro power plant were designed [1, 2].
In 2010 a letter of intent has been signed by the association 'Green Step e.V.'[1] and TUM's platform for knowledge exchange aiming to build a hydro power plant (approx. 15 kW) for the electrification of a renewable energy vocational school in Foumban near Bafoussam in Cameroon. The power plant shall not only serve as power supply but also as an example for the students. During a research trip in May 2011 a possible site was located and two Cameroonian partners were identified:

- Action pour un Développement Équitable, Intégré et Durable (ADEID), which builts different plants from renewable sources and operates several micro hydro power plants and
- Institut Universitaire de Technologie de Douala, Cameroon.

Within this consortium the partners have worked collaboratively on the survey of the site, the design of the plant and on clarifying legal issues.

2. INTRODUCTION

A vocational training school for renewable energies is being erected close to Foumban, Cameroon. Its focus lies on practical application such that the students gather experience in production, distribution, installation and maintenance of these technical products as such responsibilities are generally not being taught in this country. Consequently pico hydro power plants and solar thermal systems will be produced and sold in the school [3]. Therefore power is not only needed to provide classrooms with electricity but also to operate the manufacturing machinery such as a lathe, welding rectifiers and drills. However, as the main function of the facility is to serve as an example for the students special emphasis is put on it to fulfill this requirement. Additionally to these conditions the generated energy should be used to electrify the quarters in the vicinity of the plant. The provided energy will improve the living conditions and enhance development of approx. 20 families. The electricity will be used for basic needs such as lighting, food preservation and communication.

To successfully realize the scheme local and international partners work on their particular fields of expertise under the general management of 'Green Step'. The association 'Ingenieure ohne Grenzen' (Germany) works on the school's business plan, the 'University of Applied Sciences in Regensburg' (Germany) and the 'University of Guelph' (Canada) have designed a pico hydro power turbine that will be produced and sold at the school. The 'Fakultätsplattform Entwicklungszusammenarbeit' has constructed the hydro power plant in collaboration with ADEID and the University of Douala. ADEID is also responsible for legal issues (e. g. water rights) whereas the latter assists in providing hydrological data. Finally Green Step brings the partners together, handles the funding, deals with social aspects and runs the school.

An appropriate site for the hydro power plant has been found in the proximity of the school. The constructional tasks include the overhaul of an already existing weir integrating the intake structure with a sand trap (Fig. 1). An approximately 100 m long penstock with a head of 10.88 m will deliver the water to a cross flow turbine generating 15 kW. The power house is placed on the left embankment to ensure flood protection. The design of the structure minimizes the ecological impact. An already existing channel on the right embankment serves as a fish pass.

[1] green step is the vocational school's executing organization.

Fig. 1 Downstream view with weir overhaul and intake structure

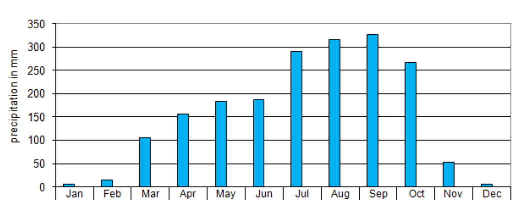
3. SCOPE

The school's scope is to educate students in renewable energy technologies which makes it obvious to provide the school with energy from such sources. The poor reliability of electricity supply makes an independent island grid evident. A feasibility assessment has been made for various systems whereas a high potential for hydro power has been identified due to the reliable precipitation and the topography of the area. Consequently, within a field trip the school's hydro power supply has been examined for possible installation sites in its proximity and relevant data has been collected for further analysis.
Off-site tasks included negotiations with stakeholders and material suppliers as well as gathering particular local know-how. Many examples show that a sustainable development of comparable projects could only be realized in collaboration with future associates, local authorities and residents who help with information and labour. So a quite decisive concern is the legal and administrative part of the planning so that ADEID's experience and expertise in erecting locally built water turbines is a major benefit.

4. HYDROLOGY

4.1 Climatic boundary conditions

Cameroon is characterized by a great variation of climatic types. This is why it is called 'Africa in miniature'. It ranges from the wet southern equatorial regions to the arid parts in the 'Extreme North'. Cameroon can be subdivided into four climatic and geographic zones: the Sudano-Sahelian, the savanna, the coastal, and the tropical forest [4].
Foumban, the location of the hydro power installation is located in the tropical forest zone which has mostly well-watered surface water. The surface is mainly covered by metamorphic and igneous rocks. The climatic type of this area is named 'Equatorial monsoon'. It is determined by two distinct seasons. The dry season lasts from November to March, the rainy season from April to October. Precipitation maximum can be observed in July to September. The total annual precipitation in Foumban is around 1908 mm.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly precipitation in mm	5	14.1	105.7	155.8	182.6	187.2	290.3	316.4	326.5	266.1	53	5.5
Days with precipitation > 1mm	1.1	2.4	9.5	15.4	19.1	20.2	23.3	24.4	24.9	22.9	6.3	1.1

Fig. 2 Average annual precipitation in Foumban [7]

4.2 Hydrologic characteristics

Cameroon has got two major catchment areas. The area around Foumban is part of the western highlands, also called the 'Cameroon Volcanic Line'. It is part of the Atlantic drainage basin, which is dominated by the Sanaga river system. The catchment area of the river at the installation site is characterized by a longitudinal tributary area, which ranges around 11.5 km from the spring to the installation site. It has several smaller confluences.

Fig. 3 Catchment area (source google.maps)

In order to get approximated discharge variation values, comparisons to neighboring river gauges have been done. The following Fig. 4 shows the hydrograph of the rivers Noun and Mbam[2]. The run off has been normalized by the annual average yielded out of the monthly mean values. The red line indicates the base flow reduced hydrograph of the Noun catchment area (excluding the outflow of Bamendjing reservoir). Through its very similar characteristics, this curve should fit the hydrograph at the site best.

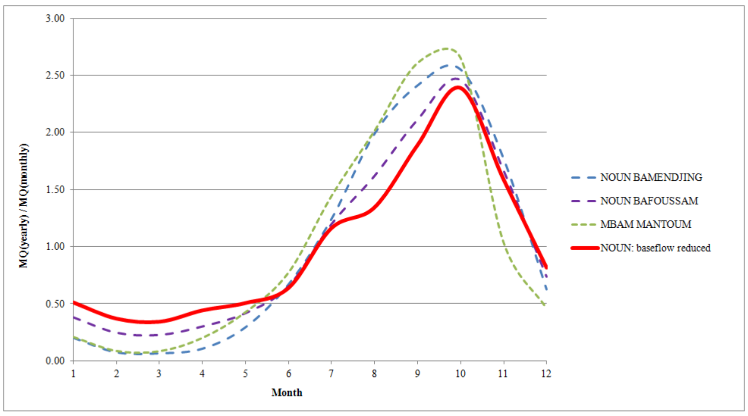


Fig. 4 Discharge hydrograph of gauges at comparable neighboring rivers [6]

The discharge measurements available have all been conducted during dry season, so that they can be assumed as low level discharges. This has also been verified by local residents. Currently further data is yielded with two fixed level gauges that have been installed and operated by ADEID. One is located above the weir intake; the other one is placed close to the powerhouse installation site. A resident, working close to the site will check the water level daily and hand the data over to ADEID.

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[2] Distances and directions of gauges from site; measurement period. Noun, Bamendjing, 43 km west, 1965-1973. Noun, Bafoussam, 48 km south-west, 1952-1975. Mbam, Mantoum, 36 km south-east, 1965-1980.

4.3 Conclusions

Unfortunately there is a major lack of hydrological data, however, the project is not endangered as the site boundary conditions are nearly perfect. Moreover, the power output requirement allows a comfortable safety margin – for low run offs and for flood events. Due to the insecure run off data special emphasis has to be placed on flood security. The discharge measurements were done in May which is at the end of the dry season (see Fig. 4). Hence one can conclude that the measurements reflect run off minima.

5. SITE SURVEY

The first step of the on-site research was to get a better understanding of the geographic, hydraulic and morphologic situation in the school's surrounding. Therefore the most important task was to explore the water course of the close-by river and possible feeder streams.

5.1 Discharge measurement

In order to get an estimate of current discharge at different parts of the river, several measurements were conducted. The techniques used were based on flow velocity and cross section analysis. At specific locations hydraulic methods were applied e. g. flux approximation at critical flow conditions. Subsequent to the on-site measurements two fixed water gauges were installed by ADEID to assess the annual flow duration curve. The data is needed to estimate flood scenarios as well as energy yield.

5.2 Surveying data

The possible sites were surveyed with a tachymeter. The exact head differences were of major interest but also the elevation and position of probable penstock tracks were captured.

5.3 Flood security and occurrence

Assessing the difficulty of flood protection is a quite hard but also essential task in the planning process in such areas. Due to the fact that there is almost no reliable river discharge or area precipitation data available for most parts of Cameroon one has to rely on other sources. The most efficient and easiest way was traced by consulting the nearby residents and workers around the sites. As this information is rather vague and most likely to be biased it is even more important to set a sufficient safety margin. Concerning the occurrence of flood incidence one statement of a local worker was like "about two to three times a year for about one week the water level is about here" – just to give an idea. Historical maximum flood levels of this creek are essential for the design, however, information on it could not be collected.

5.4 Sites

The investigations resulted in two possible installation sites with quite different characteristics. Each site would further allow two different layout options each (see Fig. 5 and Fig. 6).

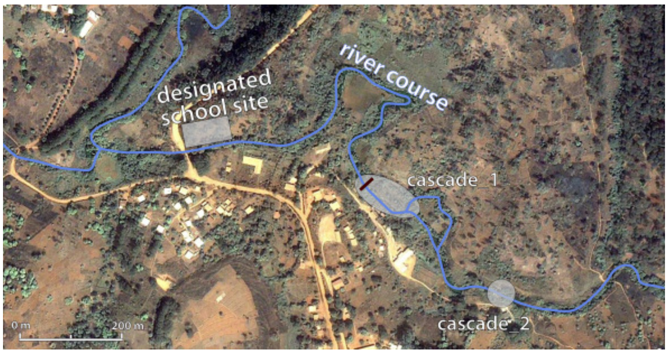

Fig. 5 Overview of geographical position of different installation sites (GPS data on google.maps)

Fig. 6 Possible installation sites, left: weir at cascade 1, right: cascade 2

The following table gives a comparison between the two possible installation sites and their different layout options.

Tab. 1 Comparison of different installation sites and layout options

<table>
<tr><th>Installation site comparison</th><th colspan="2">Big cascades with already existing weir (“cascade 1”)</th><th colspan="2">Cascade below local washing area (“cascade 2”)</th></tr>
<tr><td>Head</td><td colspan="2">10.88 m</td><td colspan="2">3.71 m</td></tr>
<tr><td>Discharge</td><td colspan="2">approx. 300 – 500 l/s</td><td colspan="2">approx. 1 m³/s</td></tr>
<tr><td>Power Output</td><td colspan="2">10 - 30 kW</td><td colspan="2">15 - 25 kW</td></tr>
<tr><td>Inlet structure</td><td colspan="2">+
(integration into
already existing weir)</td><td colspan="2">-
(to be built at left embankment)</td></tr>
<tr><td>Water rights / Usage</td><td colspan="2">+ / -
(water partly used only by local water supply company SNEC – negotiations ongoing)</td><td colspan="2">-
(intensively used as the local washing and bathing area)</td></tr>
<tr><td rowspan="2">Layout type</td><td>Layout 1</td><td>Layout 2</td><td>Layout 1</td><td>Layout 2</td></tr>
<tr><td>penstock along embankment</td><td>penstock on cascade course</td><td>conventional turbine</td><td>water wheel</td></tr>
<tr><td>Penstock length</td><td colspan="2">○
ca. 100 m</td><td>+
ca. 10 – 15 m</td><td>+
/</td></tr>
<tr><td>Flood safety</td><td>+</td><td>-</td><td>○ / -</td><td>○</td></tr>
<tr><td>Overall result</td><td>+</td><td>-</td><td>-</td><td>○ / -</td></tr>
</table>

5.4.1 Big cascades with already existing weir ("cascade_1")

At the grand cascade an output of 10 kW to 30 kW depending on the abstraction can be generated. With a head of 10.88 m only a minor part of the water is needed to meet the required power output. The first layout (cascade_1 – layout 1) marks the option where the penstock is aligned along the orographically left embankment of the cascade (see Fig. 7). This is also the preferred layout. The advantage of this is a more or less constant penstock slope and therefore fewer pipe bends. A second central pro is that it is less prone to damage caused by floods as it is away from the main flow path and does not need to be fixed upright above the ground. The advantageous location of the intake structure as well as of the powerhouse makes this option the preferable one.

Fig. 7 Installation site "cascade_1" with two different layout options

Another possibility for the penstock track would be to guide it along the cascade course itself (cascade_1 – layout 2). There are some islands along the cascade where a fixation on the underground rock would be possible. The big issue here is the flood risk as at higher flow rates this layout can be affected by floating debris. However, the underground conditions are clear and do not bear any risks.

5.4.2 Cascade below local washing area ("cascade_2")

Cascade 2 offers an output potential of 15 to 25 kW. One option for this cascade would be the use of a conventional turbine with a short penstock track of only around 10 to 15 m (cascade_2 – layout 1). The intake could be placed at the orographically left side right above the cascade whereas the powerhouse would be located on a minor rocky spot. As the discharge is quite high ($Q \approx 1$ m³/s) the use of great pipe diameters or more than one pipe would be necessary.

Fig. 8 Two different layout options at "cascade_2"

Using an overshot water wheel is another option, although it comes along with a number of uncertainties (cascade_2 – layout 2). The intake situation is similar to layout 1. A channel will have to be constructed to lead the water right above the wheel with a diameter of around 2.50 m. The water wheel could be stationed as indicated in Fig. 8. The generator and electrical equipment could be placed on top of the embankment. The power transmission can be realized with a gear belt. Here, difficulties arise in terms of a high constructional effort, especially concerning the fixation and foundation. The latter is also quite undetermined due to the lack of investigation of the underground conditions. Another drawback is the safety issue, as the area above the site is intensively used by the residents as their local washing and bathing area.
A comparison regarding flood security leads to the fact, that a conventional turbine with penstock brings the advantage of being placed more hidden. The second issue is that a turbine- / powerhouse can be easily fixated on the underground and does not have to bear with dynamic forces as a water wheel does.

5.5 Conclusions

As the first option at the big cascade promises to be the most attractive the main focus will be put on this one. The second cascade below the local washing area can be an alternative to "cascade_1" although its power output is smaller. As the location is strongly used by locals, compensatory measures would be necessary.

6. DESIGN

In the following layout 1 of the big cascades is being elaborated. Due to flood security reasons the powerhouse will be placed 2 m above the regular water level of the plain. There a perfect place was found where the powerhouse can be anchored to the rocks and natural shelter is provided. Including the height of the powerhouse structure the geodetic head reduces to 8.38 m.

Fig. 9 Overview of intake situation at "cascade_1"

6.1 Intake

The intake structure is placed on the orographically left side and will be integrated in the weir (see Fig. 10). The tulip-like inflow opening is incorporated in a locked housing which also includes the sand trap. This structure guarantees the entitled amount of water for SNEC and the slaughterhouse. Emphasis is put on safety issues as locals fish on the weir and children play/swim in its proximity. The opening of the whole structure is parallel to the main flow direction and equipped with a narrow rack. It should be noted that frequent rack cleaning will be necessary and will be conducted by the school staff.

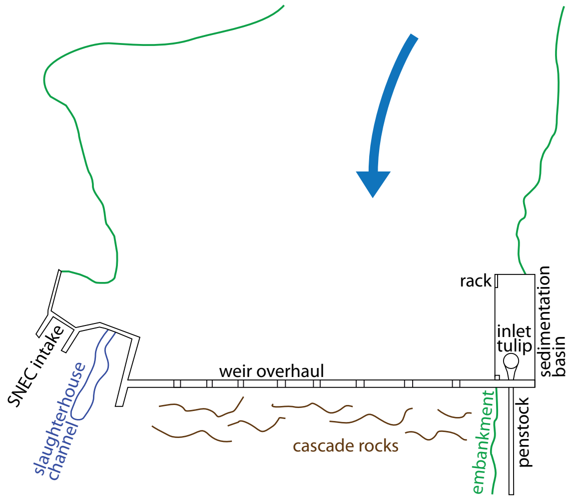

Fig. 10 Sketch of weir and intake situation

6.2 Pipe layout

As a constant pressure turbine is proposed (see Chapter 6.3) the Darcy-Weisbach equation underlies the pipe design in the following notation according to the energy plan (Fig. 11).

$$H_{geo} = \frac{8Q^2}{D^4\pi^2 g}\left(\frac{\lambda l}{D} + \zeta_I + \sum \zeta_B\right) + \frac{Q^2}{A_{Nozzle\perp}^2 2g} \quad (1)$$

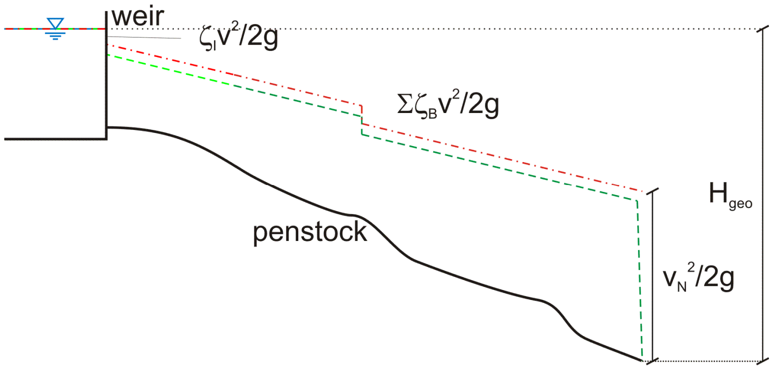

Fig. 11 Energy plan of the proposed layout

Applying Eqn. (1) the pipe diameter was optimized using the data in Tab. 2 and a discharge depending efficiency factor between 40% and 76%.

Tab. 2 Input data

Geodetic head	H_{geo} = 8.38 m	Kinematic viscosity	$\nu_{(25°C)}$ = 9E-7 m²/s
Pipe length	l = 100 m	Inflow loss	ζ_I = 0.5
Roughness	k_s = 8E-6 m	Sum of bend losses	$\Sigma\zeta_B$ = 2.5

Examining Eqn. (1) for different pipe diameters and appropriate turbine layouts (see Chapter 6.3) yields Fig. 12. From the plot it can be seen that a pipe diameter[3] of 0.50 m is essential for a reasonable output but also maintainable water hammer pressure peaks. The nozzle area is subject to the turbine design in 6.3.

[3] PVC pipe diameters in Cameroon were considered only: d = 0.125 m, d = 0.25 m, d = 0.50 m

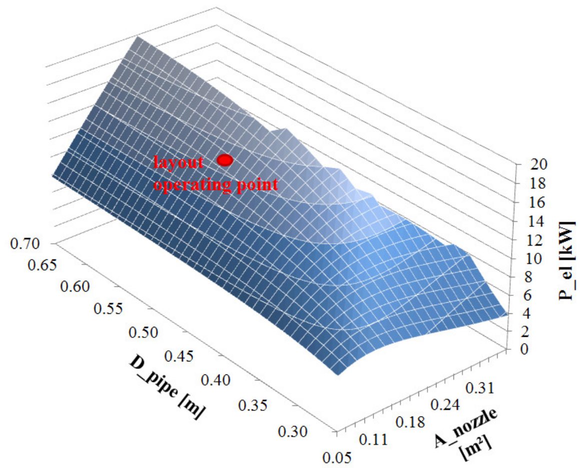

Fig. 12 Operating point of the system – pipe diameter dimensioning

The use of two or more smaller pipes does is not an alternative as can be seen from Fig. 12. The following specifications were yielded with a pipe diameter of 0.50 m.

Tab. 3 Hydro power plant specifications for different discharges

Q [m³/s] (discharge)	**A_{nozzle} [m²]** (adjusted nozzle area)	**H_n/H_b** (net head / gross head)	**v_{pipe} [m/s]** (pipe velocity)	**v_{nozzle} [m/s]** (velocity at nozzle)	**Δp [bar]** (Joukowsky hammer)	**p_{total} [bar]** (total max. pressure)	**P [kW]** ($\eta_{HPP}\cdot\rho\cdot g\cdot Q\cdot H_N$)
0.100	0.031	99%	0.51	3.19	0.98	1.80	**4.5**
0.150	0.047	98%	0.77	3.17	1.48	2.30	**7.8**
0.200	0.064	96%	1.02	3.15	1.97	2.79	**10.7**
0.250	0.080	95%	1.27	3.12	2.46	3.28	**13.3**
0.300	0.097	92%	1.53	3.08	2.95	3.77	**14.3**

6.3 Turbine

A crossflow turbine has been chosen due to its robust construction and perfect applicability at the suggested site. Crossflow turbines, also called Ossberger or Banki turbines are radial-flow impulse turbines. Because of their low maintenance requirements and simple construction they are frequently used as small and micro hydro power plants in remote areas. As the mechanical system is not very sophisticated, repairs can easily be performed by local mechanics. The proposed discharge ranges from 0.025 to 13 m³/s for heads of 1 to 200 m [8].
Although the peak efficiency of a crossflow turbine is somewhat less than other conventional turbines it has the advantage of a flat efficiency curve under varying load. This can yield better annual performance at variable discharge rates. To achieve good part-load efficiency it is possible to divide the split runner and turbine chamber at a ratio of 1 to 2 at varying flow rates [9]. Since the turbine runs at low speed it is not severely affected by suspended solids. The high durability, low price, simple construction and reliable operation make these turbines ideal for the use in developing countries.

6.4 Constructional tasks

6.4.1 Weir overhaul / intake construction

A lot of leakages that currently exist in the weir make an entire overhaul mandatory. In order to be able to exploit a steady discharge by the facility it is important to keep a constant water level above the weir. In the event of very high discharges a secured HQ-release will be provided on the weir crown. The concreting process of the weir will be carried out section by section.

6.4.2 Penstock fixation

The fixation of the penstock depends on the underground conditions. At "layout 1" there is a certain thickness of the top soil layer. Below the soil, solid rock is expected as it forms the basis of the whole cascade. At the current stage it is assumed that the reinforcing steel can be anchored to these rocks. In order to give final instructions further underground and fixation analysis is mandatory.

6.4.3 Powerhouse

The powerhouse contains the core of the whole facility and therefore requires special safety precautions. First issue to be considered is flood protection. As the generator and further electric equipment is located in the powerhouse it has to stay dry under any conditions. Further safety precautions against electric shock have to be performed. In addition all facilities must be inaccessible for any unauthorised person (health safety, sabotage etc.).

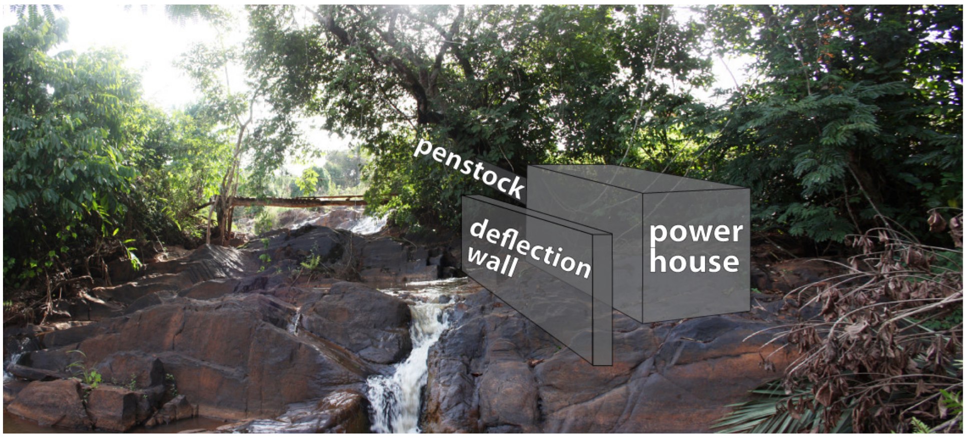

Fig. 13 Sketch of powerhouse construction and layout

7. SOCIAL AND ECOLOGICAL IMPACT ASSESSMENT

The main issue regarding ecological consequences of the new built hydro power plant concerns the fish and hydrologic fauna friendliness of the whole structure. As the weir will be kept in its actual dimensions there will not be deterioration for organisms through the construction. Nevertheless an improvement of the current situation will be aspired. Fish harming through the turbine can be avoided by a rack with narrow spacing at the intake; the velocity head is negligible anyway. The site is ideal because already existing structures are used. Therefore the plant will not have an impact on the flood security of the residents. Furthermore the structure does not deteriorate the migration behavior of the endemic fish species, e.g. cyprinids and catfish. The ecological passability can be even improved by reshaping a bypass supplying a slaughterhouse to serve as a fish pass.

8. EDUCATION CONCEPT

The hydro power education will focus on hydraulics, hydraulic engineering and hydrology. A concept for descriptive courses has been published in [10]. However, an entire engineering course cannot be offered – and is not intended. Basic applicable know how will be provided so that the students are enabled to conduct similar projects. This prerequisite implies secure underground conditions and flood safety for both – the plant itself and the surrounding area. Ecological impact minimization and awareness will be the principles to be taught.

9. OUTLOOK

Result of the current work is that construction can be done very efficiently under the evaluated circumstances. With the examined site layout the ecological impact can be minimized to an almost negligible value. The social impact on the local residents can be rated throughout positively. Long term operational safety has a very high priority.

To be able to give a final proposition and determination of all duties necessary there is still research to be done and already in progress. This is for example the recording of a hydrograph, currently organized by ADEID by installing a fixed water level gauge. The issue of electrical distribution, control and supplying the energy consumers will be dealt in another study. All in all the proposed design serves as an example for a hydro power plant built in an area where hydrological data is scarce but flood security can be guaranteed. It improves the living quality of the locals whereas an ecological deterioration cannot be identified.

10. ACKNOWLEDGEMENTS

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