LOW-COST CIVIL WORKS FOR MICRO-HYDRO SCHEMES

MICRO-HYDRO SCHEMES IN CAJAMARCA PERU

Civil works can suffer from cracking and significant scour damage. This document looks at some of the approaches that were taken to combat these problems in hydro schemes in the Cajamarca region of Peru.

An introduction to Practical Action's work

Practical Action in Peru (Soluciones Prácticas) works in some of the most mountainous parts of the Cajamarca region of the country promoting micro-hydro schemes (generating up to 500 kilowatts of power) to provide electricity. These 'run-of-the-river' micro-hydro systems do not require a dam or storage facility to be constructed. Instead, they divert water from the stream or river, channel it in to a valley and 'drop' it in to a turbine via a pipeline, which converts the kinetic energy of flowing water into electricity. See the Technical Brief *Micro-hydro Power* for more details on the basics of micro-hydro. These schemes provide low-income communities in rural areas with an affordable, easy to maintain and long-term solution to their energy needs.

Figure 1: The intake structure with stoplogs removed at El Regalado. The structure is made with reinforced concrete and erosion on the channel side slopes is visible. Photo: Sakthy Selvakurmaran.

There has been very little guidance available on how to provide micro-hydro systems through alternative low-cost design and construction methods. The systems currently employed by Soluciones Prácticas (Rodríguez and Sánchez, 2011) use modifications on traditional (larger-scale) schemes built in the region. These innovations have been permitted to reduce costs, but are based on sound engineering as well as the realities of the communities they serve. Although it is not necessary to use the same construction methods as those employed in large-scale hydroelectric works, the structures must still be efficiently and safely built. Moreover, the pressure to keep construction and maintenance costs down is even greater where resources are so limited. To be able to serve its communities effectively, Soluciones Prácticas depends on the expertise and ingenuity of its civil engineers.

In 2009, Soluciones Prácticas was looking to better develop its engineering analysis for the solutions that they have been using so that any potential risks can be minimised. This considered "safety versus investment" under a theme known as, "obras civiles de bajo costo para microcentrales" (low-cost civil works for micro-hydro schemes).

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Research theme and reasons

Soluciones Prácticas highlighted two particular focuses for research they were interested in in relation to these projects: evaluation of the civil works constructed (intake structures, channels, etc.) and a geotechnical study of slope failures. A research project investigating the effectiveness of and issues concerned with the structures in these schemes was selected. The objectives of this research project were:

1. Better develop the analysis of the solutions implemented, analysing the safety and integrity of the structures and assessing current designs against technical standards.
2. To analyse the design, materials, dimensions, etc., to determine whether the design being implemented uses the best available technology.
3. To evaluate the safety and integrity of the designs against costs based on risk & value assessment.

Figure 2: One of the concrete lined channels. These are built very cheaply with no shuttering, minimal expansion joints and thickness of just 50 – 75 mm.
Photo: Sakthy Selvakurmaran.

During summer of 2009, site investigations were carried out for research based on two civil components of the micro-hydro system, the intake structure and the water channels. A sample was selected to show systems of different sizes, and to show projects ranging from those in operation for some years to projects still in the process of being constructed.

Figure 3: Reinforced concrete intake structure at Chontabamba – despite being only a few years old, there is already significant concrete and scour damage.
Photos: Sakthy Selvakurmaran.

Site investigation - Main fieldwork observations

Concrete cracking and failure

Many of the structures constructed by Soluciones Prácticas in this region remain functioning for decades; however, some site inspections revealed extensive cracking and significant scour damage, despite the fact that the structures were only a few years old. These problems existed where low-strength concrete with insufficient reinforcing steel was used. However, Soluciones Prácticas systems as currently implemented cost over 35% less (Villanueva and Ramírez, 2006) than traditional designs made to Peruvian national standards for larger works adaptations and these adaptations and innovations could be permitted in order to reduce cost of smaller schemes. This cost reduction was managed both in terms of materials and workmanship, with reduced concrete, formwork and reinforcement.

Reasons for concrete failure

In building the structures, preparation of concrete and correct integration of reinforcement are critical and could well have contributed to problems in some of the charity's structures. The under-strength concrete may have been caused by imbalances in the water:cement ratio. As is well-known, lower water:cement ratio leads to higher strength and durability but may make the mix more difficult to work with, while too much water results in settling and segregation of the water, cement, sand and aggregate components. Furthermore, a mix that contains too much water will experience more shrinkage as excess water leaves, resulting in internal cracks and visible fractures, reducing the final strength of the structure and exposing reinforcement to the elements. It is possible that the cracks observed may have been caused by site workers ignoring this limit and putting more water in the mix to make handling easier.

In some cases, the reinforcement was not placed in the appropriate location. For example, reinforcement placed at the bottom of the structure with little or no cover leads to corrosion. While this practice could be improved at practically no extra cost, further improvements to reinforcement come at a high cost.

Failure of adjacent slopes

The initial brief was to investigate the structural considerations of the intake structure and diversion channels. Nevertheless, site investigation made it clear that these factors cannot be isolated from the effect of adjacent slope behaviour. While the development of deep-seated failure surfaces is possible with the geology and geography of the land in this region, the more common findings during site investigations were relatively shallow slope failures. If left unattended, these lead to the gradual deterioration of the slopes either side of the channel, and eventually their collapse. Landslides and soil creep have resulted in the destruction of channels in some schemes, and pose a threat to various structures across others.

Figure 4: The diversion channel at Yanacancha after a slope collapse – faults due to soil creep are clearly visible.
Photo: Sakthy Selvakurmaran.

Possible reasons for adjacent slope failure

The geological characteristics of the land vary between schemes across the Cajamarca region, but as an example to illustrate a typical scenario where problems occur, the Yanacancha Micro-Hydro system can be used. In terms of morphology, the area is located in the middle-lower part of the river basin that drains the Llaucano River. The valley presents mountainsides of moderate slope with good vegetation cover consisting primarily of grasses and some pine, eucalyptus and queñuales (a genus of shrubs and small trees endemic to the Andes). The land where the micro-hydro structures are located is predominantly dedicated to livestock grazing and to related agricultural production. Towards the downstream end of the system where the settling tank and the turbine house is located, the terrain becomes more rugged with steeper slopes. The zone around the intake structure is composed primarily of a sedimentary rock formation composed of limestone, marl and fine clays. These conditions make for fairly unstable soils that slide easily – particularly during the rainy season from November to April, but also when under the influence of excessive moisture from infiltration and uncontrolled flood irrigation applied to the grasslands.

In several schemes, the channels run through land which is used for other purposes (such as agricultural farming) and the land is irrigated, adding water to the soils and aggravating the instability. In negotiating use of land to construct such schemes, it is also important to consider such effects, and how use of the land by owners may impact on the scheme during operational use.

Development of possible solutions

To create an improved system, it is necessary to combine improvements in the stability of the slope with structures that are able to withstand the local environment. In addition, more effective and efficient practices need to be combined with a solution that can be delivered and maintained using local resources at a low cost. In the case of some solutions proposed, the costs associated with materials, equipment and skilled labour proved prohibitive, while in others the access for heavy machinery did not exist, or the electrical power supply required to operate the machinery was not available. Such solutions included reinforced soil and soil nailing, precast reinforced concrete headwalls and sheet-piled headwalls.

Figure 5: Buried pipe can be used to replace channels that have been destroyed by slope collapse but this is expensive. Photo: Sakthy Selvakurmaran.

A proposed design for intake structures – that improves both the structural integrity and stability of the slopes at the same time – involves constructing the intake wall from gabions as an alternative to concrete, as occasionally used in existing schemes to protect slopes above the turbine. Whereas concrete elements would still be needed along the faces adjacent to the river to prevent water loss from the river into adjacent ground, gabions have advantages over more rigid structures because they can conform to ground movement, dissipate energy from flowing water and drain freely. However, maintenance of gabion walls may be greater as vegetation is able to grow on them. This would have to be regularly cleared to prevent roots from growing between the stones and damaging the concrete-lined wall, or interfering with the free flow of any outfall pipes present.

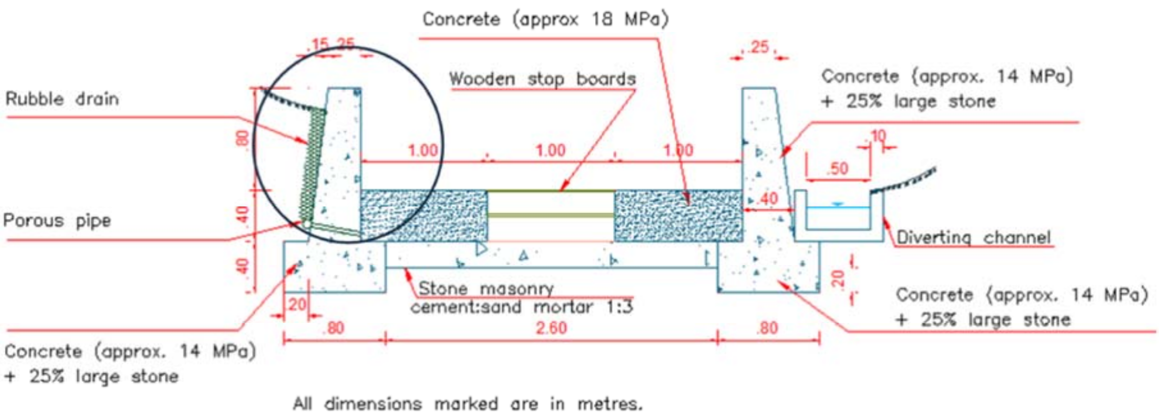

Figure 6: Retrofitting existing intake structures with side drainage features will increase stability of surrounding slopes during periods of high rainfall. Photo: Sakthy Selvakurmaran.

Where retaining structures exist along water courses, the intake design should incorporate protection against under-scour of the existing structures. This can be achieved by founding the gabion wall below the anticipated depth of scour or by using a gabion mattress to provide a scour apron. All river walling should have a geotextile membrane vertically behind as well as below the wall. The depth of mattress is dependent on water flow velocity and river bed soil type. To spread the load over a greater area and reduce the bearing, gabions can be used as a founding course. The back faces of the retaining walls that form either side of the intake structure are likely to be subjected to hydrostatic forces from groundwater. These hydrostatic forces could be reduced by the provision of a drainage path at the face of the wall. Such a drain could be provided by a layer of gravel, rubble or porous blocks, with pipes to collect and remove the accumulated groundwater.

Calculations also showed there is potential for the build-up of excess pore-water pressures caused by surface run-off water flowing down the mountainside. These can be relieved using pressure relief pipes that penetrate the concrete side walls of the structure, allowing this water to be released. This type of system could be based on a typical design currently in use but modified to make use of such features.

Figure 7: An example of a Peruvian stone wall constructed in the last decade to dissipate energy from landslides moving down the Rimac River. Intake structures can be constructed in a similar way. Photo: Sakthy Selvakurmaran.

Peruvian history and existing examples – making use of existing technology

Peruvian culture has a history of stonemasonry structures that dates back thousands of years – structures built by Incan civilisations that have withstood earthquakes and landslides remain standing to this day. Masonry walls have been used on a small scale in some of the micro-hydro systems to repair damaged zones. Where sufficient stones are available, a masonry solution could be used to construct the intake structure itself (such as a mass gravity side wall structure) and would help stabilise the slopes on either side.

Importance of knowledge transfer

A key part of this work involved the transfer of knowledge so that improved technology can be developed and implemented effectively in the communities where it is needed. Practical Action has a centre in the town of Cajamarca dedicated to training local people. The site work conducted showed that often, a large proportion of the community took an active involvement in the issues surrounding the operation and maintenance scheme, with responsibility given to operatives trained in the use and maintenance of such schemes.

Further community engagement covering potential design options, early warnings and prevention of failures from the point of view of local people, such as farmers who own surrounding land and may contribute to the over irrigation of land, or the general population could help anticipate failures in the systems constructed.

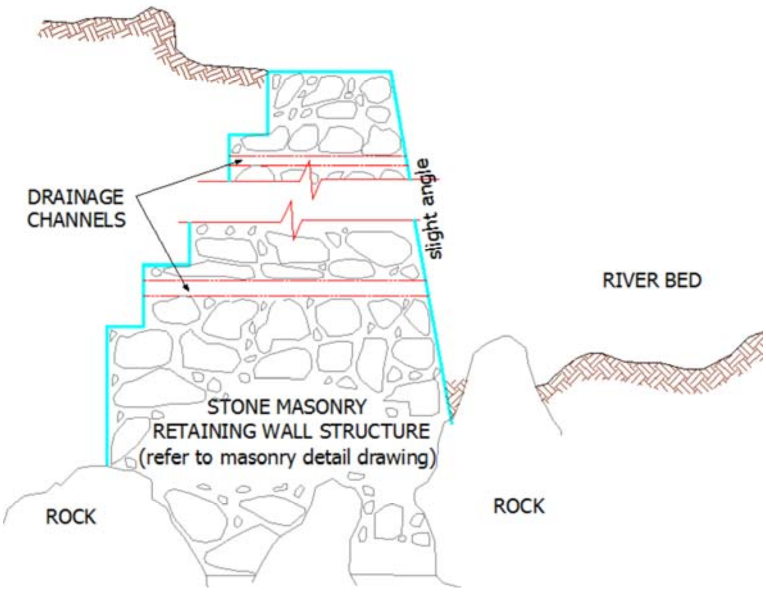

Figure 8: Section of a masonry mass gravity side wall for an intake structure, incorporating drainage channels for relieving excess groundwater pressure. Photo: Sakthy Selvakurmaran.

technical brief

Lessons learned

- Remembering the need to consider not just the focus of the research but its interaction with the surroundings
- Making the most of local knowledge and expertise to develop solutions
- Transfer of knowledge so that all members of the community have involvement in prevention of problems arising

Links, contacts, further reading

- *Layout and Lining of Canals* J.Segura, Published by Soluciones Prácticas http://practicalaction.org/layout-and-lining-of-canals
- *Civil Works Guidelines for Micro Hydropower in Nepal* Published by Practical Action Nepal http://practicalaction.org/civil-works-guidelines-for-micro-hydropower-in-nepal
- Villanueva G and Ramírez S (2006) *Obras civiles de bajos costos para microcentrales hidroeléctricas* (Construction and Maintenance of Structures Involved in Micro-hydro Schemes). Hidrored – Red Latinoamerica de Microhidroenergía 3: 18–23 (in Spanish)
- *Impact Of Run-Of-River Hydro-Schemes Upon Fish Populations*
- http://www.solwayenergygateway.co.uk/list_pagereturn_file.asp?idref=%7BA430D795-5266-4F0F-A640-AA94AF92D4FA%7D

Low-Cost Civil Works for Micro-Hydro Schemes was written by Sakthy Selvakumaran for Practical Action in October 2013. Sakthy Selvakurmaran worked with Practical Action on micro-hydroelectric power schemes during 2009 to 2010 as part of her work as an Engineering Masters student at the University of Cambridge. She is now a practising engineer specialising in civil-structural design.
A copy of the Masters' thesis can be downloaded from the EWB-UK website (the link is at the bottom of the page):
http://www.ewb-uk.org/knowledge/energy/hydro
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http://www.ewb-uk.org/filestore/FINAL%20REPORT_Sakthy%20Selvakumaran.pdf

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