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Procedia Engineering 54 (2013) 58 – 68

Procedia Engineering

www.elsevier.com/locate/procedia

The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering

Development of Underground Water Extraction System for Karst Regions with Adapted Technologies and Operating System – Pilot Plant in Java, Indonesia

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Abstract

In many developing countries, despite of much national and international effort to improve the water supply situation, the technical and ecological as well as economical solutions are still insufficient. The situation in karst regions is even more severe due to the extreme climatic and hydrogeological conditions. In karst areas, a large percentage of the precipitation rapidly infiltrates from the surface into the karst rock. The water resources are therefore mainly stored in the karst aquifers as well as in underground river systems. Because of lacking storage possibilities on the surface, bad accessibility of the underground resources and often long running dry seasons, serious water shortages occur. Against this backdrop, an interdisciplinary research group of the Karlsruhe Institute of Technology (KIT), together with industry partners, concentrates intensively on the development and implementation of concepts and technologies for an adapted water resources management in karst regions of Southeast Asia. This paper focuses on the Indonesian-German joint project for the development of an underground hydropower pilot plant in a karst region on Java, Indonesia, which is, from German side, supported by the German Federal Ministry of Education and Research (BMBF). After years of research and construction works facing several setbacks due to earthquakes and flood events, since mid of 2011 the plant is operated continuously under the responsibility of an Indonesian operational team.

Keywords: karst; hydropower; pump as turbine; semi-automatic operation.

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doi:10.1016/j.proeng.2013.03.006

1. Introduction

According to WHO/UNESCO (2002) more than 1.1 billion people throughout the world are affected by water shortages and the vast majority of these people are living in developing countries. This situation of water shortage is even more severe in karst regions. Karst landscapes are formed by the dissolution of soluble rocks, limestone and dolomite. More than 25 % of the world's population either lives or depends on karst aquifers as their source of water. Due to the absence of surface water storage possibilities, people living in karst regions are often suffering from acute water shortage, especially during dry seasons, Scholz et al. 2004. However, in many karst regions large networks of underground rivers exist which lead water continuously. Nevertheless, very often there is limited accessibility to these rivers due to their deep underground location. In addition, high infiltration rates aggravate the situation because of the vulnerability to contamination e.g. from agriculture and urban waste water.

The karst region Gunung Sewu, located in the district of Gunung Kidul, Yogyakarta Special Province, on the southern coast of Java island, is a region facing the above described problems (Figure 1). Over the years the Indonesian government has made a lot of effort to explore the karst aquifers with conventional technologies. However, until now, there are no sustainable solutions in place.

Figure 1. Gunung Sewu during rainy season (left) and dry season (right) [source: IfG – Giessen]

As a consequence, for an exploitation of the underground rivers, adapted and innovative solutions for management, distribution, usage as well as protection of the water are required in order to assure the sustainability of the regional development. Based on this situation, in the year 2002 an interdisciplinary research group from Karlsruhe Institute of Technology (KIT) and University of Giessen (JLU) initiated a German-Indonesian joint project to exploit the underground rivers in a sustainable way associated with the usage of renewable energy. Under the coordination of the Institute for Wa-ter and River Basin Management (IWG/KIT) and in cooperation with German companies as well as Indonesian partners (governmental institutions: e.g. Government of Yogyakarta Special Province, Department of Public Works, National Nuclear Energy Agency - BATAN, universities: e.g. Univer-sitas Gadjah Mada, Universitas Sebelas Maret, enterprises: e.g. PT. Wijaya Karya, NGOs: e.g. ASC speleological club), innovative technologies were developed and implemented.

2. Innovative and Sustainable Technologies for Water Extraction System

Within the frame of feasibility studies, which were conducted by IWG in the year 2000, basic concepts for the sustainable exploitation of underground water resources, had been developed. One of these concepts can be described as “water storage with reinforced concrete dam (barrage)”. Including a barrage to close the whole cave cross section, this concept aims for the storage of the continuously flowing water. Thus, the necessary pressure head is gained to pump the water partially to the surface through a hydropowerdriven conveying system. The advantage of this concept is an appropriate water management depending on the amount of water stored underground. The geological conditions in the target area were analyzed extensively prior to the construction of this hydropower plant. Investigations focused on the risk assessment of water losses due to gaps and porosity of the surrounding rock formation.

For the build-up of the conveying system, reverse driven centrifugal pumps (widely known as “Pump as Turbine” – PaT) were used instead of complex turbines due to their positive properties which are: high availability, low investment costs, good maintainability and good operating efficiency at peak load. The generated mechanical energy is transmitted via a gearbox to the feed pumps for water transport to a high-elevated reservoir. Optimization studies for various pump types had been conducted by IWG in cooperation with German pump manufacturer KSB AG. The results show that a suitable pump selection can lead to an efficiency of the PaT of over 80 % (Singh, 2005).

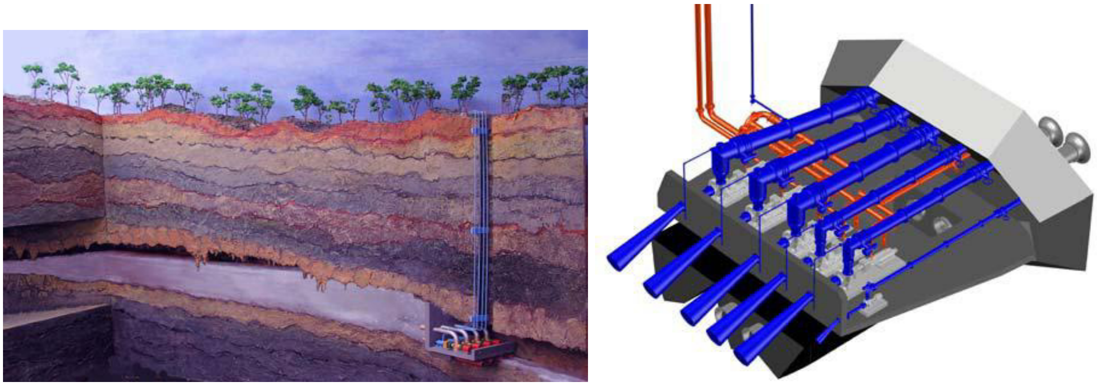

Figure 2. Basic outline of the underground hydropower plant for water supply (left) [source: Batan / IWG-KIT]. Modular layout of the hydropower plant (right) [source: KSB / IWG-KIT]

A substantial disadvantage of a PaT compared to the common "turbine" is the absence of an adjustable mechanism for adjusting the PaT according to discharge variations. However, this can be solved by parallel installation of multiple modules which can be operated independently. Therefore, a broad discharge spectrum can be covered in order to achieve a high overall efficiency of the facility. In case of high discharge (e.g. during rainy seasons), which cannot be managed by the PaTs and feed pumps, the flow will additionally be controlled and discharged through two flood relief lines.

3. Gua Bribin as Pilot Plant and Cave Laboratory

For the implementation of the proposed concept in a pilotplant, a cave named "Gua Bribin" was found to be particularly suitable regarding its geometry, geology and geomorphology. Based on the study of Sir MacDonald and Partners (1984) as well as on initial field studies of the KIT in the early 2000s, the discharge during dry seasons can still be higher than 1.0 m^3/s. During the rainy seasons this value increases dramatically. A current study which is conducted by the KIT shows, that the discharge conditions within 2000 – 2009 have temporarily slightly changed, among others, affected by the changes of the precipitation characteristics in the region (Brunsch et al. 2011).

The dimensioning and design work of Bribin hydropower plant was carried out based on the hydrologic and geodetic boundary conditions in Gua Bribin. In cooperation with KSB AG standard machines for innovative use were selected as system components to underline the advantages of the PaT technology (Nestmann et al. 2009). Through parallel operation of 5 modules, each consisting of PaT, gearbox and feed pump, the optimal efficiency of the entire plant can be achieved. The design discharge for full operation of the entire plant is defined at 1.9 m^3/s. One PaT possesses a flow capacity of 375 l/s with 15 m pressure height and an efficiency of 81 %. The rotation speed for PaT and feed pump are 1200 rpm and 2200 rpm, respectively, synchronized through the gearing. These operational conditions empower each feed pump to deliver 15 l/s to the 220 m elevated reservoir and at full capacity 65 l/s of water can be supplied. From this reservoir the water will be distributed to the communities mainly by the impact of gravity. Due to the fact that cost intensive external energy will not be needed, this facility can be operated 24 hours a day and able to supply 80.000 inhabitants with 70 litres per person per day (lpcd).

4. Construction Phase: Short Overview

Shaft construction :

For the construction of the plant, the establishment of a shaft as a vertical entrance was necessary to bring building materials, pipes, pumps, etc. into the cave. Furthermore, it is also needed as entryway for operation and maintenance works. For the development of this shaft, the German company Herrenknecht AG had developed an appropriate drilling machine, which can be operated under the local conditions with can quickly sink shaft in mixed geology, rock and especially under groundwater conditions with low vibration and emissions [Meyer, 2005]. With this drilling machine, a shaft was drilled to a depth of approx. 100 m with a diameter of about 2.5 m (Figure 3).

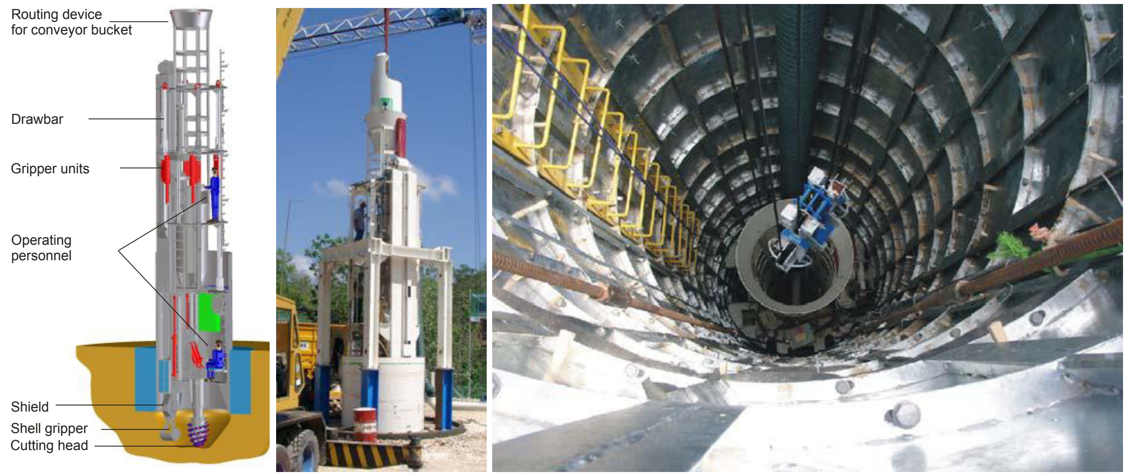

Figure 3. Application of the vertical drilling machine (left) and view into the developed shaft with a depth of 100 m (right)

Dewatering, excavation works and platform construction :

After finishing the shaft, the construction works in the cave began with the implementation of the two flood relief lines with a length of 18.6 m, each to convey water from upstream to downstream (DN800; DN600/900). 250 m³ rock materials were excavated with pneumatic chisel tools in order to expand the cavern and the rock abutment area. Furthermore, 150 m³ of mud and rubble deposits were removed. A total of 310 rock anchor drillings for the platform foundation were accomplished, drainage pipes were installed and concrete reinforcements were prepared. At the beginning of November 2005 the construction of the platform and the valve chamber was finished (Figure 4).

At the beginning of December 2005, several intense rainfall events occurred. These high amounts of rainfall caused a flooding of the underground construction site due to a flood wave with a peak flow of >10 m³/s. Due to safety reasons, all project partners agreed that the construction works should be postponed until end of rainy season 2005/2006.

Figure 4. Flood relief lines (left) and status of the construction site in November 2005 (right)

Severe earthquake in May 2006 :

The construction activities were planned to be continued at the beginning of the dry season 2006 (April-May). Unfortunately, in May 2006, a severe earthquake with an intensity of 6.3 Richter scale hit Yogyakarta region. This earthquake caused 6.000 casualties and had ruined more than 100.000 houses. Moreover, after the earthquake it was detected that the water level at the construction site rose by 1.5 m. Explorations to the downstream area had been carried out by German professional divers in July 2006 to determine the causes of the high water level. They found a rock fall of more than 1.000 m^3 which had been released by the earthquake. This rock fall partially blocked the river and caused the backwater to the construction site (Figure 5).

Figure 5. Rock fall after downstream siphon (left) and open channel after blasting (right)

In the 2nd half of 2006, most of the activities were concentrated on the blasting activities with the objective to remove the rock fall partly for a reduction of the backwater at the construction site. With a cooperation between German professional divers and Indonesian partners, in November 2006 and April 2007 the blasting activities were carried out successfully so a sufficient part of the rock fall could have been removed (Figure 5).

Construction of the barrage :

The construction activities were continued in June 2007. In order to improve the establishment of the barrage foundation, multiple micro piles were installed to reinforce the anchoring into the cave walls. This reinforcement leads up to a maximum bearable load of the barrage of approx. 30 m pressure head. The construction work of the monolithic barrage was divided into six sections with several days' intervals for the forming, reinforcement and concreting works. After finishing the construction works in January 2008, the contact injection between the barrage and the rock had been carried out in July 2008. A detailed description of construction material and technologies as well as the related construction processes can be seen in (Bohner et al. 2009) and (Mutschler et al. 2009).

Figure 6. Construction of the barrage with wall pipes (left), transportation of concrete in the cave (right)

Installation of the machinery :

The first KSB pump module was installed directly after the finishing of the barrage construction in order to prepare for the first test storage and test run. Subsequently, the installation of the controlling valves at the flood relief lines provided by VAG GmbH was accomplished (Figure 7). In total both relief lines have a maximum capacity of approx. 10 m³/s (maximum monitored peak discharge during flooding) at a pressure head of 20 m. In order to avoid solid-waste materials flowing through the flood relief lines, wire cages have been installed at the inlet of the flood relief lines.

Test storage and first operational test :

In August 2008 the first test storage with a river discharge of 1.2 m³/s was carried out. Fortunately the storage level of 16 m was reached within two and a half days. These results, obtained by years of intensive investigations and implementation works, show that damming water in karst caves is possible. As part of this successful test storage, the first KSB module was taken into operational test: a water flow of approx. 20 l/s was pumped to the surface through a 100 m vertical pipeline (Figure 8). Based on these positive test results the final selection was done and installation of four identically constructed modules was carried out (Figure 8).

Figure 7. First installed KSB-Module (left), Installation of VAG-valves at flood relief lines (right)

Due to high water pressure from the upstream side of the barrage, seepage water penetrates through the rocks onto the platform. In order to reduce the amount of seepage water as well as to avoid hydraulic breakthroughs, grouting injections around the barrage were carried out in 2009 and 2010. Detailed description of the grouting injection activities can be seen in (Breiner et al. 2011).

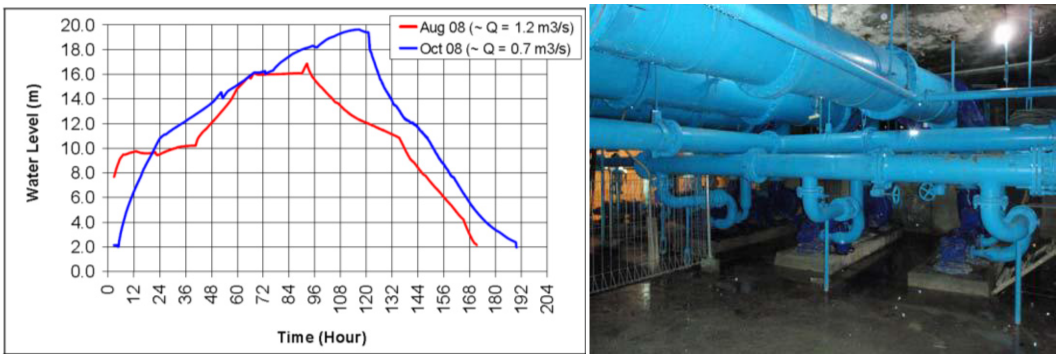

Figure 8. Storage curve during initial test (left) - note: for monitoring purposes, the water level had constantly been held at several heights through partial opening of the controlling valves. Parallel KSB - modules in Gua Bribin (right).

5. Continuous Operation Through Adapted Control System

A current study from Adji [2010] shows that in approximately 5.5 hours the rainfall within Bribin catchment area reacts on the Bribin karst aquifer. Although a full correlation between the discharge and the precipitation was not possible at that point in time, but the results clarify the relation between the precipitation and discharge. This relation causes the discharge fluctuation in the underground river, especially during rainy season where the fluctuation intensifies dramatically. As a result, for the operation of the plant continuous supervision and readjustment of the plant, either by man or by an automated electronic control system, is required to keep the plant in an optimal operating condition at any time. While operating the plant fully-automatically, the causes of malfunctions would be hard to detect for the operating personnel due to the complex structure of the associated electronic control system (“black box”). Therefore, based on the experiences during the implementation of the project as well as looking at the local boundary conditions, instead of full-automatic system, the plant was equipped for a semi-automatic operation which includes:

- An adapted electronic control system which constantly monitors the most important operating parameters (e.g. upstream/downstream water level, amount of seepage water, etc.).
- An alarm function which will be actuated as soon as previously set limiting values of the operating parameters are exceeded.
- Manual readjustment of the plant (number of operated conveying modules, adjustment of the flood relief lines) through the operating personnel by using electrical driven valves.

- Storage of all measured parameters for a subsequent evaluation of the operating conditions.

The objective for the design of the adapted electronic control system was the implementation of a lean, thus robust system which can be handled by local electricians (Figure 9). Furthermore, through the usage of standard components the trouble shooting as well as related maintenance works should be simplified. Besides monitoring the relevant operating parameters, the control system automatically transfers the seepage water from the valve chamber to downstream to avoid a flooding of the plant.

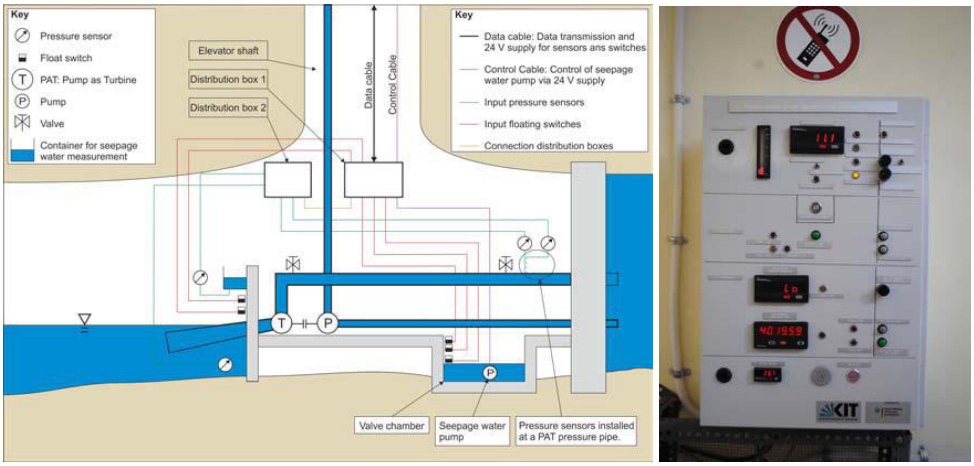

Figure 9. Scheme of the adapted electronic control system (left). Switching cabinet of the control system with visual displays showing the operating parameters (right)

To prepare the operating personnel for a self-reliant operation of the plant, multiple comprehensive training courses were carried out prior to the start-up. Using manuals and posters, which were especially designed for this purpose, a transfer of knowledge regarding the tasks during regular operation as well as a code of conduct for cases of malfunctions was accomplished.

By checking the operating parameters routinely, the operating personnel are instructed to react prior to the actuation of the alarm function. Thus, especially discharge variations should be determined at an early stage for keeping the plant in optimal operating conditions. This will enable a continuous conveyance of water as well as a minimum of malfunctions due to few load changes.

Figure 10. Temperature checks during regular operation (left). Maintenance works of the conveying modules (middle). Posters as training materials as well as operational instructions (right)

6. Outlook

Currently the hydro power plant Bribin is running 24/7, operated by a well-trained staff of local technicians. Continuous monitoring of the plant is still of high interest for all related sub-projects, to gain comprehensive knowledge about the behaviour of all machines, concrete buildings as well as the cave itself under the operational load. As continuation of the water resources management in the project area, in 2008 both Indonesian and German sides agreed to extend the cooperation with the follow-on project "Integrated Water Resources Management (IWRM) in Gunung Kidul". The main objective of IWRM is not only to explore the underground water resources, but also to manage the water resources (including wastewater and sanitation) in order to increase the life quality of the communities (Oberle et al., 2005). The IWRM should focus on all aspects of research and development of technologies to handle water resources, covering infrastructure (civil works), water distribution, water quality regulations and wastewater treatment and disposal. Additional to operational and economical aspects, the hydrological, hygienic, ecological, social and cultural boundary conditions must be taken into consideration.

Within the IWRM project, the development of second water extraction concepts using wood-stave pipeline as well PaT technologies is being planned. Instead of directly construct these concepts and technologies in a cave named "Gua Seropan", construction of model-scale (prototype) on the surface had been proposed and will be implemented in cooperation with Gadjah Mada University, Yogyakarta - Indonesia. This prototype will support the learning process from both sides prior to implementation of the new concept in the cave environment. Additionally, this prototype could be used as a learning object for e.g. Indonesian students both during construction and operation. Therefore, these students can become potential multiplicators for the future development.

Actual information regarding the state of the development and the activities in Gunung Kidul can be found in: www.iwrm-indonesien.de

Acknowlegement

This research was funded by Federal Ministry of Education and Research (BMBF), Germany as part of the Indonesian-German joint project “Water Resources Management of an Underground River in a Karst area, Yogyakarta Special Province” and “Integrated Water Resources Management in Gunung Kidul, Java, Indonesia”. This financial support is gratefully acknowledged by the authors.

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