

Bengoh RCC Dam, Sarawak

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SYNOPSIS. Bengoh Dam is a 63m high, 267m long RCC dam at present under construction about 40km south of Kuching, Sarawak, Malaysia. It is designed to provide an assured water supply for Kuching and the surrounding area up to 2030, by which time the population it serves is expected to grow to over one million. Despite some 4m annual rainfall, the existing river water source is under pressure and in recent years this resource has been stretched close to its limits with local water demand increasing at 8% year on year. Halcrow Group has been providing technical support to local consultant KTA (Sarawak), starting with review of feasibility in 2003 and progressing through to construction, which is due for completion in December 2010. Specialist aspects of this have included dam design, spillway hydraulic model studies and preparation of Emergency Response Plans. The paper covers the study, investigation, and design of the dam, and touches briefly on a few design revisions during construction.

INTRODUCTION.

Kuching is the state capital of Sarawak, Malaysia. It is located on the north coast of western Borneo near the mouth of the Sarawak River delta to the South China Sea. The Kuching area had a population of over 500,000 in 2003 and this is expected to grow beyond 1 million by 2030. In addition, increased tourism and planned industrial developments are expected to create additional requirements for treated water. Between 1990 and 2002 water demand grew by 8% year-on-year as new areas were connected to the treated water system and individual water consumption increased.

Since 1957 the main water supply for Kuching has been provided by direct river abstraction from the Sarawak Kiri adjacent to the Water Treatment Works at Batu Kitang, immediately upstream of the confluence of Sarawak Kiri and Sarawak Kanan rivers. Water supply in Sarawak is a government function, managed by the Kuching Water Board (KWB) and the Public Works Department (JKR). A series of studies had been carried out since 1980 [2, 3, 4 & 5] culminating in a Master Plan Study in 1997 [1] to develop

MANAGING DAMS: CHALLENGES IN A TIME OF CHANGE

new water resources to meet the projected needs of the growing city. Two major components of this are a weir across the Sarawak Kiri river to prevent backflow and provide in-channel storage at the Batu Kitang intake and the Bengoh Dam to provide long-term river regulation.

The need for these was emphasised in 1997, which was assessed as about a 1:50 dry year. Backflow to the Batu Kitang intake from the lower reaches of the Sarawak River caused saline intrusion and water quality concerns at the intake. The weir to add storage and prevent backflow was constructed in 2004. 2004 was another dry year and, at the peak of the drought, the storage at the weir contained only 10 days supply for the city.

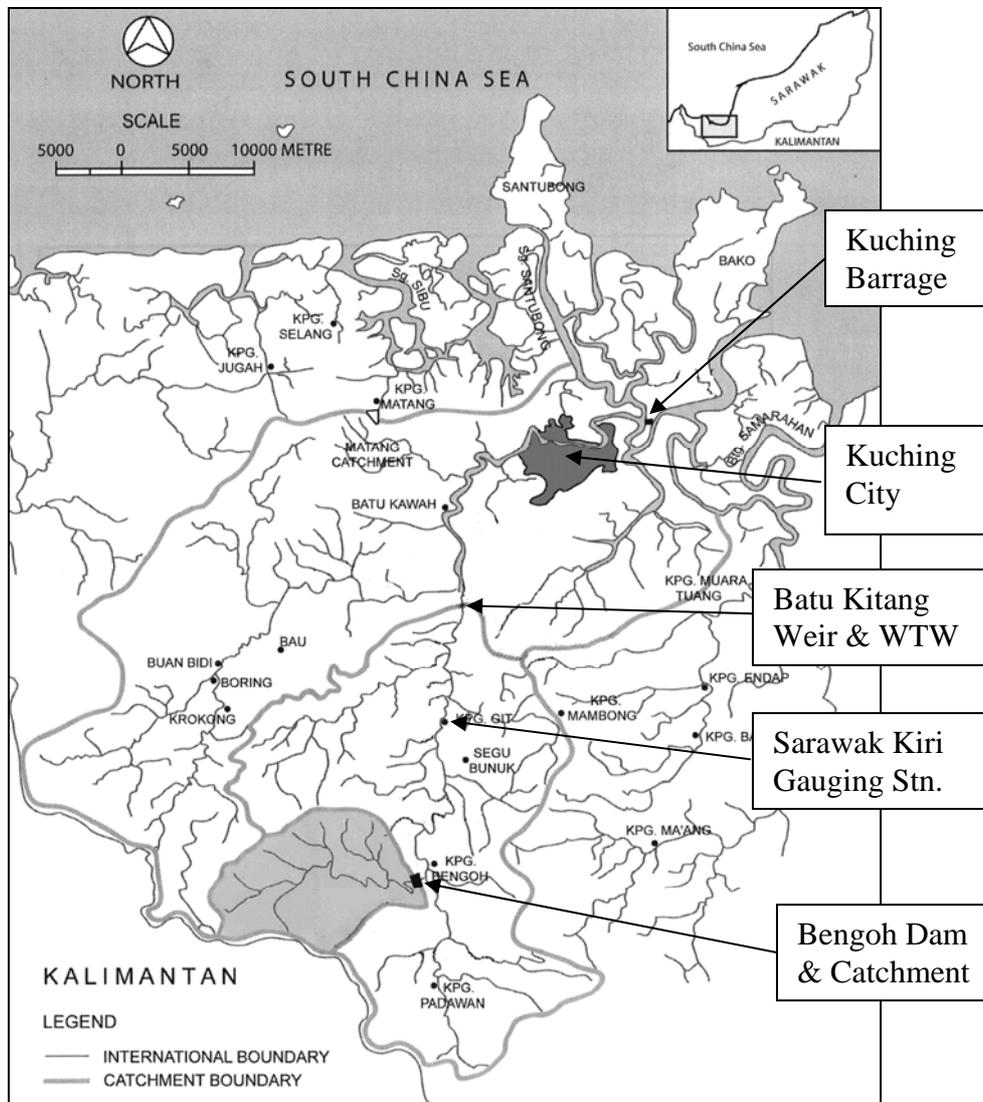


Figure 1. Map showing the main river basins and key locations.

MORISON AND YEOH

Further consideration was given to development of the Sarawak Kanan as a resource [6], but was not adopted because of water quality concerns over historic use of cyanide at gold mines in the catchment. In 2003 JKR awarded a contract for an assessment study, outline and detailed design of Bengoh Dam to KTA (Sarawak) with support from Halcrow Group. The terms of reference were for a development to meet water demand requirements for Kuching to 2030, with the project to be completed by the end of 2010.

SARAWAK KIRI WATER RESOURCES.

The Sarawak Kiri has a catchment area of 633km² to the Batu Kitang intake. Most of the catchment area is rural, and much of it is steeply sloping and densely vegetated, with shifting agriculture, tree crops and forest rather than settled agriculture. Rainfall records from the whole Sarawak River catchment indicate an average annual rainfall of about 4000mm, dropping to around 3000mm in a 1: 50 dry year. The main source of flow data on the Sarawak Kiri is a gauging station at Kg Git, which has some 28 years of useable record from a catchment area of 440km². The records from this show an average annual runoff of 2222mm. The Bengoh is a tributary of the Sarawak Kiri upstream of Kg Git with a catchment area of 127km².

Analysis of the flow record transposed to Batu Kitang gave a 7-day 1:50 dry year flow (the recommended Malaysian standard for direct abstraction water supply sources) of about 400 MI/d (4.5m³/s). This is increased by the presence of the storage weir downstream of the intake.

The flow data from Kg Git was scaled on an area basis to provide synthetic flows for the Bengoh and remaining catchments to Batu Kitang and a conjunctive resource model developed to assess the storage volume required to provide the projected raw water demand of 2050 MI/d (23.7m³/s) at Batu Kitang in 2030 in a 1:50 dry year. The required storage was found to be 133Mm³. The peak outflow from the dam, ignoring demand reduction measures and transmission losses in the river, was 20m³/s.

A stage storage curve for a reservoir at the Bengoh dam site was developed from the contours of available 1:10,000 scale mapping. With river bed level at the dam site about 24m aSL and a minimum operating level of about 53m aSL (about 10Mm³ or 7% of dead storage) the required volume for flow regulation is provided with a reservoir Full Supply Level (FSL) of 80m aSL, providing a gross storage of 144Mm³ and a surface area at FSL of 8.87km².

MANAGING DAMS: CHALLENGES IN A TIME OF CHANGE

DESCRIPTION OF THE BENGOH CATCHMENT.

The Bengoh and the Semadang join at Kg Bengoh to form the Sarawak Kiri. The river bed level at the confluence is about 18m aSL, about 70km from the sea. From the confluence, the bed level of the Bengoh rises to about 30m aSL over a distance of 2km. This section of the Bengoh is in a steep-sided, deep V-shaped valley or gorge with the river characterised by alternating pools and rapids, with rock outcrops visible on the river banks and bed, typical of a mountain terrain. Upstream of this section, the terrain becomes much flatter and opens out into a less deeply incised basin before rising to the high ground which forms the international border with Indonesia. The steep section of valley is located where the river cuts through harder geological strata which form a rim around the drainage basin forming the catchment. Figure 2 shows this diagrammatically. The reservoir area and the area around the existing kampungs are covered in secondary forest from shifting cultivation, but the higher ground is mostly primary rain forest.

The combination of a narrow dam site and a more open basin upstream provide a very economic site in that a large storage volume can be provided for a relatively small dam.

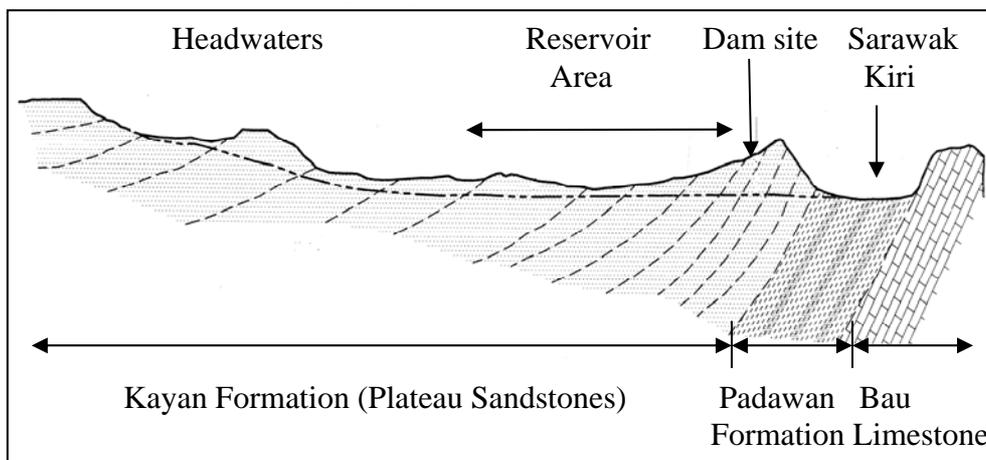


Figure 2. Indicative section through the Bengoh basin.

ACCESS

Access is a particular problem for the project. While there is public road access to Kg Bengoh, further road access to the dam was initially blocked by the river. All early access to the site, including for site investigation, was on foot. Access to the dam site has been a major aspect of the project design, including a new bridge and approximately 1.95km of access road,

MORISON AND YEOH

some crossing very steep valley slopes requiring extensive slope support. There are still no access roads into the catchment or reservoir area.

GEOLOGY

The gorge section of the Bengoh valley cuts through the lower Kayan formation, consisting of inter-bedded and cross-bedded sedimentary sandstones, pebble conglomerates and mudstones. Around the dam sites these dip in an upstream direction at angles of between about 45° and 65° skewed about 45° from the selected dam axis. The thickness of individual horizons varies from a few millimetres to tens of metres. The sandstone is the hardest of the layers and sandstone outcrops form the steepest sections of the river. The mudstone or soft shale layers tend to weather quickly and control the sliding properties of the rock mass. The upper valley slopes are weathered to depths of typically 15m to 20m. The predominantly sandstone areas form a suitable foundation for most types of dam.

Geological investigations consisted of surface mapping, borehole investigations and laboratory testing at two sites, including some 12 boreholes to a depth of up to 80m at the selected dam site. These confirmed the suitability of the selected site for a concrete gravity dam and provide data for the dam foundation design.

SEISMICITY

The seismic record shows the area to be of very low seismicity. A nominal 0.1g peak ground acceleration was adopted for dam design, but proved not to be the critical design criterion.

TOPOGRAPHIC SURVEY

Detailed topographic surveys were carried out for the dam and access road sites. In addition, contour surveys at FSL and Design Flood Level for the reservoir were carried out to define the reservoir area, together with a series of selected cross sections within the reservoir area. The dam site and reservoir area surveys were done by ground survey techniques and required cutting sight lines through the dense secondary vegetation. The survey confirmed that a saddle dam was not required at a low point, probably a historic river capture channel, on the reservoir rim.

The survey showed the FSL surface area of the reservoir to be 10.2km², an increase of about 15% on the surface area from the map contours. The storage volume is thought to be increased by a similar amount, although insufficient survey work was carried out to confirm the exact volume. This will be rechecked after clearance of vegetation from the reservoir area. It was decided not to reduce the FSL of the reservoir, but to leave the expected additional storage volume as a margin for environmental releases and

MANAGING DAMS: CHALLENGES IN A TIME OF CHANGE

transmission losses in the river between the dam site and Batu Kitang, which were not included in the resource model.

ENVIRONMENTAL

An independent Environmental Impact Assessment (EIA) [8] was carried out for the project by the University Malaysia Sarawak, and reported in March 2007. Based on this, environmental approval was given for the project in February 2008, subject to conditions on: Dam design and safety, Soil erosion and sedimentation, Control of air and water pollution, Waste management, Protection of biological resources, Reservoir preparation, Socio-economic, health and safety aspects, Environmental monitoring and audit and Site clearance.

Biomass clearance and disposal and erosion control before reservoir filling were particular requirements, as were the preparation of a dambreak impact assessment and emergency response plan for the area downstream of the dam. Halcrow and KTA are preparing a dambreak and consequence study, an on-site plan and an outline off-site plan. The major impacts of a dambreak are on the villages along the Sarawak Kiri, which would suffer major damage and loss of life. Kuching is less badly affected, with at least 2 hours warning of flooding similar to the natural 1:100 year flood.

RESETTLEMENT

Resettlement was recognised as a significant issue for the project. Four kampungs were identified in the catchment, two of which are substantially within the reservoir, and one of which is partially within the reservoir and flood rise. These three would all lose low-level agricultural land to the reservoir, making them potentially unsustainable. The fourth kampung is remote from the reservoir and largely unaffected. Estimates are that some 1,100 people need to be resettled. None of these kampungs have road access, only footpath access. They do, however, have primary schools, churches and other community services.

Resettlement is the responsibility of the Sarawak Government. Extensive discussions and negotiations on resettlement and compensation have been going on during development of the project. A resettlement site has now been agreed on land in an adjacent catchment and work is in progress on construction of access roads and housing. However, it seems likely that resettlement will now be the controlling factor in the programme for filling the reservoir. Additional river diversion capacity has been added through the dam to reduce the risk of flooding of the upstream kampungs by backwater once the main dam rises above cofferdam level.

HYDROPOWER

It was originally envisaged that hydropower would form part of the Bengoh Dam development. The Assessment Study [7] concluded that a 3MW installation would give a 95% reliable 24 hour power output initially, but that as the water supply demand developed towards that projected, the hydropower reliability would drop towards 50% in dry years, as flow would not be available for hydropower while the reservoir was refilling after deep drawdown. A new HV transmission line would be required to carry the power produced to the Kuching system. During the design stages of the project no potential organisation (KWB, JKR or the Sarawak Electricity Supply Corporation (SESCO)) was interested in developing or managing the hydropower aspects of the project, and so this was not included in the project detailed design. However an outline scheme to retro-fit the original 3MW installation to the draw-off pipework was developed, and this remains an option.

A recent review identified significant advantages in a 6MW, 12 hour peaking development from the same resource, with water supply regulation provide by the Batu Kitang intake weir. This would be better able to use the larger regulating flows envisaged as water demand grows, but requires a larger intake and outlet pipework than was required for water supply releases. A costing was obtained from the dam contractor to construct the additional intake to keep this option open, but this was not economically attractive and was not taken up.

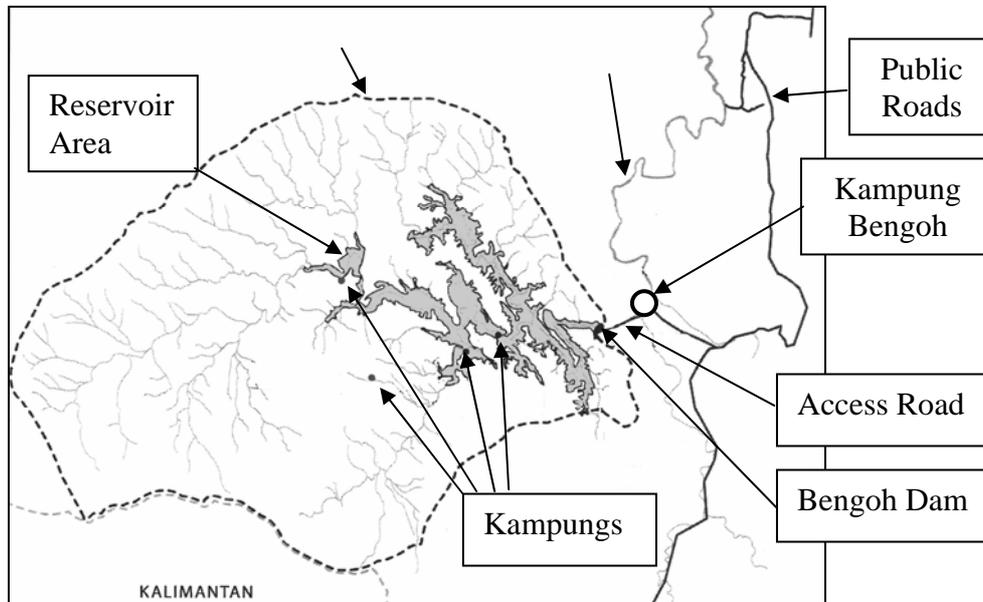


Figure 3. Plan of the Bengoh Catchment showing reservoir development.

MANAGING DAMS: CHALLENGES IN A TIME OF CHANGE

DAM TYPE AND LOCATION OPTIONS

Options for RCC gravity, earthfill, clay core rockfill and concrete face rockfill dams were considered on four different dam sites within the Bengoh gorge. Two of these sites were located where spillways, outlets and diversions could be constructed at bends in the river, more suited to embankment dams. The cost of access to the dam was taken into account in assessing the options. The furthest upstream site offered a lower and slightly cheaper dam, but with significantly higher access road costs and delay while this was constructed. The selected site is about 250m upstream of that identified in the Feasibility Study. The cheapest option at this site was an RCC gravity dam. Lowest foundation level for the dam is 23.0m aSL. Spillway crest level is 80.0m aSL and dam crest level is 86.2m aSL, giving a maximum dam height of 63.2m and a dam crest 267m long.

RIVER DIVERSION

The original design of the river diversion included a twin box culvert, each barrel 4m wide by 4.5m high, located on a rock shelf on the dam left abutment. These can pass the 1:10 year flood of 365m³/s with an upstream cofferdam level of 42m aSL, about 15m high. Pipework is to be installed in the diversion culverts when the river diversion is closed to form the outlets.

During construction, a third similar sized opening has been added in the dam body to prevent backwater flooding of the existing kampungs upstream of the dam up to the 1:100 year flood once the dam body rises above cofferdam level.

SPILLWAY

An overflow spillway on the dam crest with a stepped downstream face was adopted, designed to pass the Probable Maximum Flood (PMF) without overtopping the dam crest. The PMF peak inflow was determined as 2,420m³/s. Routing this over the 62m long ogee crest, the routed outflow is 1,800m³/s with a flood rise of 5.8m. The stepped spillway is expected to dissipate around 75% of the head at the 1:10 year flow, reducing to about 45% at PMF.

The valley is asymmetric, and the spillway is longer than the width of the downstream river channel. The stepped spillway design therefore included asymmetric side channels on the abutments downstream of the dam to carry the discharge to the river channel. The final arrangement of this was determined by physical model testing at a scale of 1:35 [Ref 11] carried out in UK by BHR Group. The final spillway arrangement has a shorter crest length than the initial design to reduce the asymmetric flow on the apron. Baffle blocks were included on the downstream concrete side channels and

MORISON AND YEOH

apron to reduce depth of flow against the training walls and initiate a stable hydraulic jump at the toe of the dam. The downstream training walls heights were selected to fully contain flows and provide freeboard for splash up to the 1:1000 year return period and to just contain the PMF.

OUTLETS

The draw-off system is designed to discharge up to 21m³/s down to minimum operating level of 55m aSL from a multi-level intake, discharging to the river downstream of the dam. The intake comprises a dry well with inlets at five levels feeding a single 1.6m diameter pipe stack above one of the diversion culverts. The pipe discharges to the downstream culvert through a 1.4m diameter hooded fixed-jet cone (Howell-Bunger) valve. Each inlet is controlled by a gate valve with provision for an upstream maintenance gate. A lifting D-shaped trash screen is placed in the gate track of the operating intake.

In addition to the draw-off, a 1.6m diameter bottom outlet is included in the second diversion culvert, discharging with a similar arrangement as the drawoff. This also has a 1.6m upstream gate valve and provision for a maintenance gate. The opening to this is located in the side of the diversion culvert downstream of the cofferdam and includes a fixed trash screen. Environmental flow outlets are provided on the drawoff and outlet pipework, each capable of discharging 1m³/s at Minimum Operating Level through needle valves.

The draw-off and bottom outlet, acting together, are capable of discharging about 70m³/s with the reservoir at FSL. They would draw down the reservoir by initially about 0.4m/day and drain 90% of the reservoir volume to minimum operating level in 45 days against the highest (January) average monthly inflow.

DAM STRUCTURAL DESIGN

The dam is designed as a gravity section to be stable under normal, extreme floods and seismic loads. The dam body has a vertical upstream face. The upper part of the downstream face above 40m aSL has a slope of 0.78:1, and the lower at 0.9:1 to limit tensile stress at the foundation contact. The non-spillway crest section was made 8m wide for ease of RCC construction. Stresses and deflection of the section were checked by finite element analysis using ANSYS. Consolidation grouting is specified at the upstream heel and downstream toe and an inclined grout curtain is included to about 40m below foundation level beneath the upstream face of the dam, subject to further testing during installation. A drainage curtain in the foundation and dam body, connected to a system of galleries in the dam section

MANAGING DAMS: CHALLENGES IN A TIME OF CHANGE

The total volume of the dam and associated structures is about 160,000m³ of mass concrete and RCC, with an additional 15,000m³ of reinforced concrete in the river diversion, outlet structures and spillway.

PROJECT IMPLEMENTATION

A turnkey contract for implementation of the project was awarded by JKR to Nain Cendera Sdn Bhd (NCSB) in August 2007. Work started on site on the bridge and access road in September 2007. NCSB awarded the dam construction contract to Sinohydro, and clearing of the dam site started in March 2008. KTA (Sarawak) is providing engineering and construction supervision. Forestry Department approval for the Biomass Removal Plan is awaited before clearing and disposal of vegetation from the reservoir area can commence.

Construction was over 55% complete in December 2009, with about 50% of the RCC placed in the dam body. Figure 4 shows the dam in December 2009.



Figure 4. Bengoh Dam in December 2009.

The selected aggregate for the RCC is Bau Limestone, and a new quarry and aggregate plant were set up within 3km of the dam site to provide and process the aggregate for dam construction. Trial mixes for the RCC using cement and flyash from sources in Kuching were used to develop an RCC design mix containing 60kg of cement, 120kg of flyash, 0.6% of water

MORISON AND YEOH

reducing admixture and a water cementitious ration of around 0.5. This has a modified VeBe time of between 8 and 15 seconds, little segregation and an average compressive strength of about 35MPa (N/mm²) at the specified 91 days. This is significantly more than the specified 15MPa characteristic strength, but since reducing the cement content and increasing the flyash content to maintain the cementitious content provides little cost saving and thermal aspects are within specification, the Contractor has chosen not to change the approved design mix. Initial set time is between 10 to 14 hours, and final set between 24 and 36 hours, allowing most layers to be placed with “hot” or “warm” joints. The maximum recorded temperature rise from the 30⁰C specified placing temperature is about 14⁰C. The average RCC density is about 2450kg/m³.

Substantial completion of the project construction is scheduled for December 2010, but impounding is likely to be delayed by reservoir area clearing and finishing works which cannot be completed until resettlement takes place.

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