Consultancy Services for Dokan and Derbendikhan Dam Inspections
Inspection Report (Final)
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Introduction

Background

The Government of Iraq has requested funding from the World Bank (through IDA) for emergency repairs of Dokan and Derbendikhan hydropower plants, both located in the Kurdistan Region of Iraq. A Project Information Document (PID) – Concept Stage was prepared by the World Bank for the proposed ‘Dokan and Derbendikhan Emergency Hydropower Project’ (P099059) at the end of March 2006 and discussed with representatives of the Ministry of Planning and Development Corporation and the Ministry of Electricity of the Central Iraqi Government during the week of 15 April 2006. To continue the preparation of the proposed project, a Preparation Mission was undertaken between 20-25 April 2006, when a team of representatives from the Ministry of Electricity (MoE) of the Kurdistan Regional Government (KRG) met with the World Bank Team to further discuss and agree on the technical and other aspects of project design, initiate procurement documentation preparation, implementation arrangements, environmental and fiduciary requirements.

Dokan and Derbendikhan, with a capacity of 400 MW and 249 MW respectively, are the two largest power stations in the Kurdistan Regional Governorate, and are connected to the national power grid. Each power station is part of a multipurpose scheme for power production and irrigation at each of the locations.

The Dokan Dam is located on the Lesser Zab River, approximately 220km upstream from its confluence with the Tigris River. The site is located adjacent to the town of Dokan and approximately 295km north of Baghdad and 65km northwest of Sulaimaniyah city. The Derbendikhan Dam is located on the Diyala River, immediately upstream of the town of Derbendikhan. It is approximately 150km upstream of the Hemren Dam. The site is approximately 420km by road northeast of Baghdad and 65km southeast of Sulaimaniyah city. It is also within 15km of Iranian border to the southwest.

Dokan Power Station became fully operational in 1979. Repair and maintenance have been substandard because of unavailability of spares and equipment. These factors have contributed to long outages and unreliable performance. Moreover, due to the long operational period (29 years) the power plant is now due for rehabilitation. This would need to be preceded by a detailed assessment of the plant’s condition and the safety of the Dokan Dam. The work would also explore the feasibility of redesign of some of the equipment, in particular the turbine and generator, in order to increase the overall efficiency of the power plant. It would also take into account the unavailability of spares from the original manufacturer.

The construction of Derbendikhan Power Station was completed in 1983 but operation commenced in 1990 due to a delay in construction of the overhead line to connect the power plant to the national grid. Only one unit was commissioned by the contractor, who had to leave the site because of the Second Gulf War. The other two units came into operation without proper commissioning. A combination of this and faulty design of the hydraulic system are considered to have contributed to unsatisfactory performance of this power plant since its commissioning. The plant suffers from severe cavitation of the runners and draft tubes. It also needs complete rehabilitation preceded by investigation of the cause of cavitation and redesign.
The Derbendikhan Dam has also suffered in its early days from a large slope failure on the right bank, approximately 100m upstream of the dam. As a result, subsequent modifications have been done since, and monitoring has indicated that additional slope movement is minimal, but the data record is scarce; and accordingly the operating restriction on the minimum pool level will be maintained during the project.

Due to shortage of power generation it is necessary that both power plants continue to operate. Therefore the rehabilitation work would be implemented in two phases. This project would constitute the first phase, consisting of urgent repairs to keep the two power plants operational, as well as studies and designs for the second phase which would involve rehabilitation.

Project Objective

The objective of the project is to help alleviate the current power supply shortfall through urgent repair works, and prepare for the subsequent rehabilitation of the Dokan and Derbendikhan hydropower plants to restore their original capacity 400 and 249MW respectively.

Details of the proposed project components are presented in 0.

Scope of SMEC Consultancy Assignment

Snowy Mountains Engineering Corporation (SMEC) were engaged by the World Bank\(^1\) to provide a Dam Safety Expert, Mr. Mark Cordell, to update the earlier condition assessments carried out for Dokan and Derbendikhan Dams and recommend works, if any, of an emergency nature, that should be financed under the proposed Dokan and Derbendikhan Emergency Hydropower Project.

The Terms of Reference of the Consultancy Assignment are given in 0.

Consultancy Assignment Programme

Following receipt of the Contract for the Consultancy Assignment on Friday 5 May 2006, SMEC immediately mobilised Mr. Mark Cordell to undertake the inspections of Dokan and Derbendikhan Dams on 8-17 May 2006. A broad outline of Mr. Cordell’s visit to KRG is summarised in Table 1.

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday 8 May 2006</td>
<td>Departed Melbourne to Erbil (via Dubai)</td>
</tr>
<tr>
<td>Tuesday 9 May 2006</td>
<td>Arrived in Erbil and overland transfer to Sulaimaniyah</td>
</tr>
<tr>
<td>Wednesday 10 May 2006</td>
<td>Kick-off Meeting with Mr. Fatih Salih</td>
</tr>
<tr>
<td></td>
<td>Initial Visit to Derbendikhan Dam and discussions with Mr. Abdulrahman Khani, Dam Manager and his staff</td>
</tr>
<tr>
<td>Thursday 11 May 2006</td>
<td>Inspection of Derbendikhan Dam</td>
</tr>
<tr>
<td>Friday 12 May 2006</td>
<td>Inspection of Derbendikhan Dam</td>
</tr>
<tr>
<td>Saturday 13 May 2006</td>
<td>Initial Visit to Dokan Dam and discussions with Mr. Hama Tahir, Dam Manager and his staff</td>
</tr>
<tr>
<td>Sunday 14 May 2006</td>
<td>Inspection of Dokan Dam</td>
</tr>
<tr>
<td>Monday 15 May 2006</td>
<td>Inspection of Dokan Dam Overland transfer to Erbil</td>
</tr>
</tbody>
</table>

\(^1\) Contract 7138546 dated 4 May 2006 and signed by both parties on 5 May 2006. The Consultant contracting entity is SMEC International Pty Ltd.
Format of Report

The Terms of Reference originally envisaged the Consultancy assignment to be carried out in two stages, with the submission of a report at the end of each stage:

1. Inception report advising the World Bank team the conditions that might need emergency attention, based on a desk study review of existing reports; and
2. Visual Inspection report updating the previous condition assessments based on site visits to the dams and categorizing the repair/rehabilitation requirements into those needing immediate attention.

However, due to time constraints and availability of Mr. Cordell, the visual inspections were carried out immediately following award of the Consultancy Assignment Contract. Consequently, the review of previous reports on the condition assessment of each of the two dams has been undertaken in simultaneously with the site visits and assessment of the current repair/rehabilitation requirements. Accordingly, it was no longer considered appropriate to prepare two separate reports as indicated in the Terms of Reference and this single report encompassing all aspects of the Consultancy Assignment has been prepared and submitted for the World Bank’s evaluation.

The general format of this report is as follows:

- Introduction and Background
- Dam Safety Management
- Derbendikhan Dam
  - General Description & History
  - Discussion of Current Conditions
  - Recommendations for Remedial/Rehabilitation Actions
- Dokan Dam
  - General Description & History
  - Discussion of Current Conditions
  - Recommendations Remedial/Rehabilitation Actions
- Proposed Emergency Actions
  - Prioritisation of Activities for Inclusion in Dokan and Derbendikhan Emergency Hydropower Project and beyond

Acknowledgements

We would like to record our appreciation of all the co-operation and assistance that SMEC received from everyone, in particular the following:

1. Mr. Fatih Said Salih, Head of KRG PM team and Technical Manager, General Directorate of Electricity, Sulaimaniyah
2. Mr. Abdulrahman Khani, Dam Manager, Derbendikhan Dam and all of his staff
3. Mr. Hama Tahir, Dam Manager, Dokan Dam and all of his staff
Dam Safety Management

Overview

The consequences of a catastrophic dam failure can be enormous. At stake may not only be the lives and property of the population downstream of the dam, but also the community as a whole; its well being and the natural environment. The latter point is of particular relevance to the dams covered by this Assignment, as they are essential infrastructure components of the region’s hydroelectric power generation. Loss of either of these important assets would have a significant impact on the communities in the region.

In the light of the above, the importance of establishing a dam safety management system to match the appropriate level of hazard potential and likelihood of failure can not be understated. An essential starting point for this Assignment and the assessment of the current condition of Dokan and Derbendikhan Dams was to carry out a preliminary Hazard Category assessment of each dam. Section 0 describes the criteria for determining the Hazard Category of a dam and presents a summary of the preliminary hazard category assigned to each dam.

Dam Safety Standards

In accordance with the World Bank’s Safety of Dams Policy OP 4.37, existing dams on which a Bank-financed project is directly dependent, the borrower is required to arrange for one or more independent dam specialists to:

- Inspect and evaluate the safety status and performance history of the dam;
- Review and evaluate the owner’s operation and maintenance procedures;
- Provide a report of findings and recommendations for any remedial work necessary to upgrade the dam to an acceptable standard of safety.

It is understood that, in Iraq, there is currently no regulatory framework governing dam safety, which would provide the necessary guidance on the acceptable safety standards to be met for Dokan and Derbendikhan dams. Consequently, it has been assumed that the acceptable standard of safety should conform to current international best practice. For the purposes of this Consultancy Assignment, the guidelines published by the Australian National Committee on Large Dams (ANCOLD) have been taken to be the benchmark. It is acknowledged that the guidelines published by corresponding dam safety bodies and organisations in the United Kingdom, United States and other countries could have been applied.

Significance of Hazard and Risk in Dam Safety Management

The amount of effort and resources that a dam owner should put into a dam safety program is determined by each dam’s hazard and risk. In respect to terminology, it is necessary and convenient to distinguish between “hazard” and “risk”.

The Hazard Category, and hence the extent to which the dam poses a potential threat to life or property is fundamental to determining the nature and cost of a dam safety program. It is important to recognise that the Hazard Category of a dam could change from very low to high or extreme during the life of the dam, if there are changes to the downstream environment.

The size of the dam does not necessarily indicate the “Hazard Category” of a dam, although it has long been taken as an initial indicator by the International Commission on Large Dams (ICOLD/CIGB) and some agencies (including the World Bank). Other factors need to be considered and international guidelines such as the ANCOLD Guidelines on the Consequences of Dam Failure describe the current criteria for determining the Hazard Category of a dam. These criteria have been applied in determining the preliminary assessment of hazard categories of Dokan and Derbendikhan Dams.
**Dam Hazard Category**

Whilst Dam Safety Management Guidelines may vary from country to country, it is internationally recognised that the appropriate level of effort and resources that an owner should apply to ensuring the safety of a dam is directly related to the hazard and risk that the dam presents in terms of potential threat to life or property. The ANCOLD Guidelines on the Consequences of Dam Failure describes the current criteria for determining the Hazard Category of a dam and these are reproduced in Table 2.

### TABLE 2. DAM HAZARD CATEGORIES

<table>
<thead>
<tr>
<th>Population at Risk</th>
<th>Negligible</th>
<th>Minor</th>
<th>Medium</th>
<th>Major</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Low</td>
<td>Significant</td>
</tr>
<tr>
<td>1 to 10</td>
<td>Low Notes 1 and 4</td>
<td>Low Notes 4 and 5</td>
<td>Significant Note 5</td>
<td>High C Note 6</td>
</tr>
<tr>
<td>11 to 100</td>
<td>Significant Notes 2 and 5</td>
<td>High C Note 6</td>
<td>High B Note 6</td>
<td></td>
</tr>
<tr>
<td>101 to 1000</td>
<td>Note 1</td>
<td>Note 2</td>
<td>High A Note 6</td>
<td>High A Note 6</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>Note 3</td>
<td></td>
<td>Extreme Note 6</td>
<td></td>
</tr>
</tbody>
</table>

Note 1: With a Population at Risk (PAR) of 5 or more people, it is unlikely that the severity of damage and loss will be “Negligible”

Note 2: “Minor” damage and loss would be unlikely when the PAR exceeds 10

Note 3: “Medium” damage and loss would be unlikely when the PAR exceeds 1000

Note 4: Change to Significant where the potential for one life being lost is recognised

Note 5: Change to High where there is the potential for one or more lives being lost

Note 6: See Section 2.7 and 1.6 of ANCOLD Guidelines on the Consequences of Dam Failure for an explanation of the range of High Hazard Categories.

The Population at Risk (PAR) immediately downstream of Derbendikhan Dam is estimated to be approximately 300 persons living in the former construction camp area and around a further 300 persons are reported to live in another village less than 5km downstream of the dam.

The Population at Risk (PAR) immediately downstream of Dokan Dam within the town of Dokan is estimated to be more than 1,000.

The severity of damage and loss that would be caused by a dam failure is considered to be ‘Major’ in both cases, particularly in light of the strategic importance these dams represent with respect to their hydro-electric power generation, supplying power to the Kurdistan Region in Northern Iraq and the Iraqi national grid.

Accordingly, the preliminary Hazard Category has been determined for each dam, as summarised in Table 3.

### TABLE 3. PRELIMINARY HAZARD CATEGORY

<table>
<thead>
<tr>
<th>Dam Name</th>
<th>Preliminary Hazard Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Derbendikhan Dam</td>
<td>High A</td>
</tr>
<tr>
<td>Dokan</td>
<td>Extreme</td>
</tr>
</tbody>
</table>

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2 Table 2 is a summary of the Incremental Flood Hazard Categories. Details of Severity, Damage and Loss criteria may be found in the ANCOLD Guidelines on Assessment of the Consequences of Dam Failure – May 2000
Dam Safety Management System

The dam safety management system should provide the assurance required by the stakeholders in the dam, that the dams are indeed safe. Assurance involves demonstrating that:

- Adequate resources are committed to dam safety;
- Relevant prevailing technology is used; and
- Sound management practices are in place.

A number of national committees of ICOLD have produced guidelines on dam safety management to assist dam owners and regulators in the discharge of their responsibilities. The Australian national committee, ANCOLD\(^3\), suggests that an adequate dam safety management system should be properly documented, and aim to:

- Ensure that prevailing standards of investigation, design and construction have been used for the dam;
- Cause the dam to be operated within safe procedures;
- Ensure preventative maintenance as programmed;
- Manage incidents with a clear plan and adequate resources;
- Ensure that an owner’s dam’s risk profile remains within tolerable limits;
- Provide a surveillance program to ensure that the owner is aware of the structural and maintenance status of each dam;
- Ensure that dam safety reviews are conducted regularly;
- Provide a system to ensure that all other responsible people are aware of the structural and maintenance status of each dam;
- Provide clearly defined and promulgated responsibilities for dam safety;
- Provide a validation system to ensure systems are operative, and updated;
- Provide training programs to ensure personnel are aware of and practised in dam safety procedures and ready to respond effectively to an incident; and
- Ensure that appropriate personnel and funds are available to conduct the program.

As noted previously, the dam safety management system should be appropriate for the hazard potential and likelihood of failure.

It is understood that there is currently no formal guidelines or legislation in Iraq covering dam safety management. Accordingly, it is recommended that one of the international guidelines, such as ANCOLD’s “Guidelines on Dam Safety Management” is adopted.

Based on the discussions held with the Dam Managers at Dokan and Derbendikhan Dams, it would appear that although Binnie & Partners have been carrying out periodic dam safety reviews at the dams and routine maintenance and surveillance procedures are being followed by the Dam Directorates, a dam safety emergency plan (DESP) does not appear to have been prepared for either dam. DSEPs should exist for all dams where there is the potential for loss of life in the event of dam failure. According to ANCOLD\(^3\), a DSEP is a formal plan that:

- Identifies emergency conditions which could endanger the integrity of the dam and which require immediate action;
- Prescribes procedures which should be followed by the dam owner and operating personnel to respond to, and mitigate, these emergency conditions at the dam; and
- Provides timely warning to appropriate emergency management agencies for their implementation of protection measures for downstream communities.

It is acknowledged that some elements that form part of a DSEP have probably already been recognised and procedures prepared for specific aspects, but it is important that these elements and other pertinent information is collated into a single formal document for each dam - each DSEP must be tailored to the site specific conditions at Dokan and

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3 Australian National Committee on Large Dams Inc., ANCOLD Guidelines on Dam Safety Management, August 2003
Dokan and Derbendikhan dams. The preparation of DSEPs should be included as part of the proposed dam safety actions under the future Dokan and Derbendikhan Emergency Hydropower Project.

Both groups of Dam Directorate staff at Dokan and Derbendikhan are maintaining the condition of their respective dams to a good standard given the limitations that they have with respect to finance and technical resources. Whilst they obviously understand the importance of monitoring and maintaining the dams in a safe condition, it is suggested that there is still credibility in fully assessing the training needs of the Dam Directorate staff at Dokan and Derbendikhan to ensure that they are fully conversant with all the requirements of the dam safety management system and that any training needs are addressed to enable the staff to implement and maintain the adopted dam safety management system.
Derbendikhan Dam

General Description and History

Derbendikhan Dam is located on the Diyala Sirwan river approximately 65km south-east of Sulaimaniyah and 230km north-east of Baghdad. The scheme is a multi-purpose hydro-complex and the main structure is a 128m high embankment dam with a central clay core and rockfill shoulders. The crest length of the dam is 445m. The dam is constructed in a narrow steep-sided gorge on a series of sedimentary rocks including marls, sandstones, limestones and conglomerate.

The reservoir impounded by Derbendikhan Dam had a total design capacity at normal operating level (El. 485.00m ASL) of 3,000 Mm³, of which 2,500 Mm³ is live storage and 500 Mm³ being dead storage. The current storage volumes will be less than this due to 45 years of sedimentation.

The reservoir is controlled by a gated spillway structure located on the right bank and comprises three 15m x 15m tainter gates installed on an ogee shaped overflow section followed by a steep chute terminating in a deflector bucket. Dividing walls separate the discharges from each of the three gate openings. The maximum discharge capacity of the spillway at normal operating level (El. 485.00m ASL) is 5,700m³/s and 11,400m³/s at design flood level (El. 493.50m ASL).

There are two low-level outlet tunnels (6m and 9m diameter) connected to steel conduits which discharge water through three irrigation valves. The conduits also originally supplied water to two small turbines for the service generating station and are now connected to the three large turbines of the new power house (see below). An intake tower for the irrigation outlets is located between the spillway approach channel and dam embankment. The intake tower houses three vertical lift gates, each 4.75m x 9.5m – Gate No.1 serves the 6m diameter tunnel; Gates No.2 and No.3 serve the 9m diameter tunnel.

The dam was designed by Harza Engineering Company of USA for the Government of Iraq Development Board. Construction of the dam started in 1956 and was completed in summer 1961. The main civil works contractors are shown in Table 4.
### TABLE 4. MAIN CIVIL WORKS CONTRACTORS FOR DERBENDIKHAN DAM

<table>
<thead>
<tr>
<th>Contract</th>
<th>Main Contractor</th>
<th>Sub-Contractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Downstream Part of 6m Diversion Tunnel.</td>
<td>Sainrapt &amp; Brice (France).</td>
<td></td>
</tr>
<tr>
<td>2. Investigation Drilling</td>
<td>Cementation Co. (U.K) and Sondages Injections Forages (France)</td>
<td></td>
</tr>
</tbody>
</table>

Since impounding of the reservoir, the major remedial measures undertaken have included:

- Slope protection above the left and right abutments
- Slope stabilization of the left bank and right bank slide areas
- Additional grouting of the bedrock under the dam
- Reinstatement of the dam crest following settlement in the area adjoining the spillway structure
- Removal of debris produced by the plunge pool development
- Refurbishment of the irrigation valves, caterpillar gates and gantry crane at the Intake Tower
- Riprap protection of the upstream face (1999 and 2000)
- Further slope protection and stabilization measure to the left and right banks (ongoing).

From 1983 to 1985, a new power house (3 x 83MW) was constructed at the toe of the dam. It replaced two smaller generation units (2 x 800kW). Polensky & Zollner of Germany were the main civil works contractor and Mitsubishi Electric Corporation was the turbine and generator supplier. The commissioning of the new power station was delayed due to the political disorders and continuous generator only started in 1990.

The pertinent data of Derbendikhan Dam and its appurtenant structures is summarised in Table 5.

### TABLE 5. PERTINENT DATA OF DERBENDIKHAN DAM

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area</td>
<td>17,850 km²</td>
</tr>
<tr>
<td>Mean Annual Catchment Precipitation</td>
<td>840 mm</td>
</tr>
<tr>
<td>Design Inflow</td>
<td>18,700 m³/s</td>
</tr>
<tr>
<td>Maximum Recorded Inflow</td>
<td>5,816 m³/s</td>
</tr>
<tr>
<td>Peak Outflow (Spillway Design Flood)</td>
<td>11,400 m³/s</td>
</tr>
<tr>
<td>Peak Outflow (Spillway &amp; Irrigation Outlets)</td>
<td>12,000 m³/s</td>
</tr>
<tr>
<td>Maximum Recorded Outflow</td>
<td>2,510 m³/s</td>
</tr>
<tr>
<td>Maximum Recorded Reservoir Level</td>
<td>El. 489.83 m ASL on 24/03/1974</td>
</tr>
<tr>
<td>Minimum Recorded Reservoir Level</td>
<td>El. 439.01 m ASL on 17/01/1967</td>
</tr>
<tr>
<td>Description</td>
<td>Value</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td><strong>DAM</strong></td>
<td></td>
</tr>
<tr>
<td>Dam Type</td>
<td>Embankment dam with central clay core and rockfill shoulders</td>
</tr>
<tr>
<td>Crest Level (Lowest)</td>
<td>El. 495.00 m ASL</td>
</tr>
<tr>
<td>Maximum Height</td>
<td>128.0 m</td>
</tr>
<tr>
<td>Crest Length (including Spillway Width)</td>
<td>535.0 m</td>
</tr>
<tr>
<td>Width of Crest</td>
<td>17.0 m</td>
</tr>
<tr>
<td>Upstream &amp; Downstream Slopes</td>
<td>1 (V) : 1.75 (H)</td>
</tr>
<tr>
<td>Volume of Rockfill</td>
<td>5.2 Mm³</td>
</tr>
<tr>
<td>Volume of Impervious Core</td>
<td>1.3 Mm³</td>
</tr>
<tr>
<td>Volume of Filters</td>
<td>0.6 Mm³</td>
</tr>
<tr>
<td><strong>RESERVOIR (ORIGINAL DESIGN DATA)</strong></td>
<td></td>
</tr>
<tr>
<td>Normal Operation Level</td>
<td>El. 485.00 m ASL</td>
</tr>
<tr>
<td>Reservoir Area and Volume at El. 485.00</td>
<td>113 km² / 3,000 Mm³</td>
</tr>
<tr>
<td>Minimum Drawdown Level</td>
<td>El. 434.00 m ASL</td>
</tr>
<tr>
<td>Live Storage Volume at El. 485.00</td>
<td>2,500 Mm³</td>
</tr>
<tr>
<td>Dead Storage Volume</td>
<td>500 Mm³</td>
</tr>
<tr>
<td><strong>SPILLWAY</strong></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Gated Ogee Overflow Chute terminating in Deflector Buckets and Plunge Pool</td>
</tr>
<tr>
<td>Spillway Gate Size</td>
<td>3 No. 15m x 15m Radial (Tainter) Gates</td>
</tr>
<tr>
<td>Crest Level at Ogee</td>
<td>El. 470.00 m ASL</td>
</tr>
<tr>
<td>Top of Closed Gate</td>
<td>El. 485.00 m ASL</td>
</tr>
<tr>
<td>Discharge Capacity at El. 485.00</td>
<td>5,700 m³/s</td>
</tr>
<tr>
<td>Discharge Capacity at El. 493.50</td>
<td>11,400 m³/s</td>
</tr>
<tr>
<td><strong>INTAKE</strong></td>
<td></td>
</tr>
<tr>
<td>Type and Number of Gates</td>
<td>3 No. Vertical Lift Gates</td>
</tr>
<tr>
<td>Gate Size</td>
<td>4.75 m x 9.50 m</td>
</tr>
<tr>
<td>Capacity of Gantry Crane</td>
<td>135 t</td>
</tr>
<tr>
<td><strong>IRRIGATION OUTLETS</strong></td>
<td></td>
</tr>
<tr>
<td>Diameter of Irrigation Supply Tunnels at Intake</td>
<td>6 m and 9 m</td>
</tr>
<tr>
<td>Diameter of Conduits</td>
<td>4.267 m (14 foot)</td>
</tr>
<tr>
<td>Diameter of Howell Bunger Valves</td>
<td>2.438 m (8 foot)</td>
</tr>
<tr>
<td>Maximum Discharge</td>
<td>3 x 175 m³/s</td>
</tr>
<tr>
<td>Maximum Discharge (without Vibration and Cavitation)</td>
<td>3 x 87 m³/s</td>
</tr>
<tr>
<td><strong>POWER STATION</strong></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Surface Power House at Dam Toe</td>
</tr>
<tr>
<td>Number of Turbine/Generator Units</td>
<td>3 No. Vertical Francis Turbines</td>
</tr>
<tr>
<td>Rated Net Head</td>
<td>80 m</td>
</tr>
<tr>
<td>Rated Discharge</td>
<td>3 x 113 m³/s</td>
</tr>
<tr>
<td>Rated Output</td>
<td>3 x 83 MW</td>
</tr>
<tr>
<td>Turbine Runner Speed</td>
<td>187.5 rpm</td>
</tr>
</tbody>
</table>
Geology

The Derbendikhan Dam is located at the end of a gorge cut through the Baranand Dagh anticline by the Diyala Sirwan River. The anticline is made up of cretaceous rocks which were subsequently folded during the Oligocene to Miocene periods. This folding is associated with the later period of the Alpine-Himalayan orogeny.

The rocks dip downstream towards the south west at about 45° at the dam site. Downstream of the dam, there is evidence of some cross folding of the Qarah Chauq limestone. The strata consist of sedimentary rocks of marine origin, the main units of the sequence may be summarised as Table 6.

<table>
<thead>
<tr>
<th>Main Unit</th>
<th>Approximate Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qarah Chauq Limestone</td>
<td>180 – 525</td>
</tr>
<tr>
<td>Green Marl Formation</td>
<td>60</td>
</tr>
<tr>
<td>Buff Formation</td>
<td>180 – 300</td>
</tr>
<tr>
<td>Bituminous Marl Formation</td>
<td>335</td>
</tr>
</tbody>
</table>

The Buff Formation and Bituminous Marl Foundation make up the dam foundation and these are discussed in more detail in Sections 0 and 0.

Buff Formation

The core and downstream shoulder of the dam are founded on the Buff Formation. In the original site investigations at the time of dam construction, the formation was divided into four zones; Bₐ at the base and Bₐ at the top. The general characteristics of these four zones are summarised in Table 7.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bₐ</td>
<td>Strong grey to brownish grey fine to medium grained slightly to completely weathered calcareous SANDSTONE</td>
</tr>
<tr>
<td>Bₖ</td>
<td>Very weak to weak, grey, thinly bedded to laminated slightly to completely weathered calcareous MUDSTONE/SHALE. Contains beds of moderately strong to strong grey to brownish grey fine to medium grained argillaceous slightly to moderately weathered LIMESTONE. The limestone is frequently nodular (&lt;5mm)</td>
</tr>
<tr>
<td>Bₙ</td>
<td>Moderately strong to strong grey to brownish grey fine to medium grained argillaceous slightly to moderately weathered nodular LIMESTONE interbedded with very weak to weak grey laminated slightly to completely weathered calcareous SHALE</td>
</tr>
<tr>
<td>Bₛ</td>
<td>Strong grey to brownish grey medium to very thickly bedded fine to medium grained slightly weathered LIMESTONE with bands of weak grey fine grained thinly bedded MUDSTONE and laminated SHALE and occasional beds of SANDSTONE and CONGLOMERATE. The calcareous shale/mudstone (marl) weathers very rapidly on exposure. A fresh sample cut from unweathered surface without any apparent discontinuities developed fine cracks within 5 minutes of exposure to atmosphere and after 30 minutes could be broken down easily under light finger pressure to fine gravel</td>
</tr>
</tbody>
</table>

---

Bituminous Marl Formation

The upstream shoulder of the dam is founded on the Bituminous Marl Formation. The marl is generally weak to moderately strong grey to greyish brown fine grained calcareous MUDSTONE/SHALE. The material varies from laminated (<1mm) to medium bedded (<600mm), the surfaces of the bedding and joints are frequently coated in bitumen. The marl varies between fresh slightly weathered to completely weathered residual soil. The examination of exposures during construction indicated that the depth to which a high degree of weathering has occurred in vertical and inclined faces is limited to about 0.5m. A typical weathering profile is given in Table 8.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 – 0.1m</td>
<td>Loose brown silty fine to coarse sandy fine GRAVEL. The gravel comprises dessicated clay which on wetting becomes fine sandy very silty clay with fine gravel of moderately weathered marl</td>
</tr>
<tr>
<td>0.1 – 0.2m</td>
<td>Stiff to very weak, brown, laminated, highly to moderately weathered silty MUDSTONE with some iron staining. The material is easily broken down with light finger pressure but does not soften to silty clay on wetting</td>
</tr>
<tr>
<td>0.2 – 0.3m</td>
<td>Weak to moderately strong, greyish brown, slightly weathered, thickly laminated, calcareous silty MUDSTONE. The material is frequently iron stained with iron rich nodules and has bitumen staining on joints. Fragments produced by excavation are tabular and pieces &gt;20mm thick cannot be broken in the fingers</td>
</tr>
<tr>
<td>0.3 – 0.5m</td>
<td>Moderately weak to moderately strong brownish grey, slightly weathered, calcareous silty MUDSTONE. The material can be marked with a pick, but is very difficult to excavate</td>
</tr>
</tbody>
</table>

The laminations in exposures examined on the right bank during construction, just upstream of the dam, run approximately perpendicular to the strike of the bedding and would therefore appear to be a cleavage feature. Typical dips and dip directions of the cleavage are 75/165. The discontinuities are frequently bitumen stained.

Seismicity

Regional Seismicity

Derbendikhan Dam lies in a folded nappe zone to the southwest of the plate boundary where the Arabian tectonic plate is being subducted beneath the Persian plate. The regional seismicity is described in more detail in Appendix D of the 1987 Binnie Report5.

Maximum Credible Earthquake and Operating Basis Earthquake

The magnitude and peak ground acceleration for the Maximum Credible Earthquake and Operating Basis Earthquake are discussed in Section 5 of the 1987 Binnie Report5 and summarised in Table 9. These parameters were adopted for the stability analysis undertaken by Binnie as part of the Analysis and Safety Evaluation of Derbendikhan Dam carried out in 1987.

---

TABLE 9. MAXIMUM CREDIBLE EARTHQUAKE AND OPERATING BASIS EARTHQUAKE PARAMETERS

<table>
<thead>
<tr>
<th>Event</th>
<th>Magnitude</th>
<th>Estimated Focal Depth</th>
<th>Horizontal Peak Ground Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Credible Earthquake (MCE)</td>
<td>6.5</td>
<td>15km</td>
<td>0.25g</td>
</tr>
<tr>
<td>Operating Basis Earthquake (OBE)</td>
<td>6.5</td>
<td>7.5km</td>
<td>0.10g</td>
</tr>
<tr>
<td>Reservoir Induced Seismicity</td>
<td>6.5</td>
<td>15km</td>
<td>0.25g</td>
</tr>
</tbody>
</table>

The results of the 1987 stability analyses concluded that the dam section is satisfactory under both static and earthquake conditions.

Historically, reservoir-induced earthquakes have generally occurred during first filling of the reservoir or soon after. Since Derbendikhan Dam has been in operation for nearly 45 years, the risk of such an event is considered to be extremely low now or in the future.

Seismic Monitoring

A seismograph was previously installed in Sulaimaniyah, but was destroyed in 1991 and has not been replaced. Consequently, there is no means for monitoring and recording seismic activity at the dam site. As stated in a number of the previous reports, current international design practices indicate that it would be normal for a dam of the size of Derbendikhan to have one or more seismograph stations installed at the dam site for the monitoring and recording of seismic events. To date, no action has been taken to install seismic instruments at the dam and whilst this was previously considered to be a medium-term task by the 1998 Binnie Report⁶, given the importance of being able to monitor and record the seismic response of Derbendikhan Dam, it is proposed that this task is now elevated from the Long-Term to Medium-Term Action List.

Further discussion on the proposed seismic instruments to be procured, supplied and installed is presented in 0.

Hydrology

Historic Reservoir Levels

A near to complete record of daily reservoir level is available for Derbendikhan Dam from the start of impounding in November 1961; only one month of record is incomplete for this 45-year period. Plots of the reservoir level are shown for the past 10 years in Figure 5.

The original reservoir control rule curve is presented in Figure 6 with the drawdown restriction level due to the Right Bank Slip Area shown. Comparing this with Figure 5, it can be seen that the application of the control curve has been over-ruled in a number of these years. It is understood that principal reason for this has principally to meet the demand for hydro-electric power generation.

**Flood Studies**

As part of the Analysis and Safety Evaluation undertaken by Binnie in 1987⁵, a review of the previous flood studies was carried out, including an update of the hydrological studies to incorporate the more recent available data at that time. A summary of the findings of this review is presented in Table 10.

The 1987 studies concluded that the adopted design flood and estimated probable maximum flood (PMF) are appropriate and that provided reservoir operations are in accordance with the rule curve and spillway operation criteria adopted in the flood routing studies are used, Derbendikhan Dam should be safe against overtopping. However, as noted in Section 0, the original reservoir rule curve has not been observed in a number of years due to a change in the emphasis on water use for hydro-electric power generation. It is therefore recommended that the reservoir rule curve is reviewed and updated to suit the current water use demands and conditions. The flood studies should then be updated to confirm that the safety of the dam embankment is not being exposed to a higher than acceptable risk of overtopping as a result of the revised reservoir rule curve.
TABLE 10. SUMMARY OF PREVIOUS FLOOD STUDIES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Reservoir Level m&lt;sub&gt;res&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>489.83</td>
<td>493.50</td>
<td>494.40</td>
<td>494.20 – 494.50</td>
</tr>
<tr>
<td>Min. Reservoir Level m&lt;sub&gt;res&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td></td>
<td>441.91</td>
<td>493.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Inflow m³/s&lt;sub&gt;in&lt;/sub&gt;</td>
<td></td>
<td>-</td>
<td>18,700</td>
<td>25,000</td>
<td>24,400</td>
</tr>
<tr>
<td>Freeboard&lt;sup&gt;[5]&lt;/sup&gt;</td>
<td></td>
<td>5.17</td>
<td>1.50</td>
<td>0.60</td>
<td>0.50 – 0.80</td>
</tr>
<tr>
<td>Max. Total Outflow m³/s&lt;sub&gt;out&lt;/sub&gt;</td>
<td></td>
<td>2,510</td>
<td>11,400</td>
<td>12,800</td>
<td>12,500</td>
</tr>
<tr>
<td>Max. Spillway Outflow m³/s&lt;sub&gt;sp&lt;/sub&gt;</td>
<td></td>
<td>2,280</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Date</td>
<td></td>
<td>24/03/1974</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Date of Study</td>
<td></td>
<td>mid 1950s</td>
<td>late 1950s</td>
<td>mid 1970s</td>
<td>1986</td>
</tr>
</tbody>
</table>

Notes:

[1] Reportedly excludes any irrigation outlet discharges
[2] Maximum reservoir level estimated from reported maximum outflow. Irrigation outlets operating (400m³/s)
[3] Maximum reservoir level uncertainty due to whether irrigation outlets operating or not.
[4] Energo-projekt flood with revised spillway operating rules
[5] Based on dam crest level of 495.00 mASL (minimum design value)

As stated in Section 0, the preliminary Hazard Category of Derbendikhan Dam has been assessed as ‘Extreme’ and accordingly, the dam should have sufficient dry freeboard to protect the dam from being overtopped by a flood event with an annually exceedance probability (AEP) equivalent to the PMF<sup>[7]</sup>. Furthermore, the pre-flood reservoir level should be taken to be the normal full supply level.

Derbendikhan Dam has been constructed with a gated spillway structure that is capable of passing a maximum flow of 11,400m³/s. Based on the 1987 Binnie calculations, the spillway capacity is sufficient to safely pass the PMF event, as required for a dam with an Extreme hazard category. However, given that the last evaluation of the PMF was in 1986, it would be prudent for the hydrology to be updated and re-evaluated.

Previous Studies and Reports

The depth of information pertaining to the dam design, construction, operation and maintenance is to be commended, particularly given the degree of conflict and war experienced in the region over the past two decades. A summary of the reports and documents that were made available during the Inspection are listed in 0.

With respect to Dam Safety inspections and evaluations, the following reports are of particular relevance for Derbendikhan Dam:


The previous assessments and recommendations regarding aspects of dam safety made in the above reports are discussed in Section 0, together with an update of the current conditions.

Aspects Relating to Dam Safety

Risk Assessment and Emergency Action Plans

As noted in Section 0, it is considered appropriate that a full Risk Assessment is undertaken for Derbendikhan Dam and an Emergency Action Plan prepared. Due to the limited time of this mission, it was not possible to fully evaluate the existing information and procedures that are currently held by the Dam Directorate. These need to be reviewed and any information gaps resolved to enable a formal Dam Safety Action Plan to be prepared.

Dam Instrumentation and Monitoring System

Central to any dam safety management system is the monitoring of the dam’s performance; any sign of abnormal behaviour could represent a threat to dam safety. External loads acting on the dam and its foundations, together with their response, need to be carefully monitored so that any abnormality can be identified as soon as possible and the necessary action taken promptly before the abnormality becomes a serious dam safety issue.

Dam monitoring consists of two major tasks:

- Review / checking of the structural safety of the dam (= Dam Condition)
- Detection of any abnormal event (= Dam Behaviour)

The Dam Condition is assessed through periodic inspections of the dam, ranging from the daily routine observations by the Dam Directorate staff to comprehensive dam safety reviews undertaken by a dam safety specialist at 5-yearly intervals.\(^8\) With the last comprehensive dam safety review undertaken by Binnie & Partners in 1987 (and updated in 1998), it is strongly recommended that a comprehensive dam safety review is undertaken by a competent Engineering Company as part of the proposed Dokan and Derbendikhan Emergency Hydropower Project.

The dam instrumentation installed at Derbendikhan to monitor the dam’s behaviour was partly rehabilitated in 1986 and at that time comprised the following installations:

- Two reservoir level indicator equipment (dam operations and power station operations)
- Survey reference points (benchmarks) forming a triangulation network
- 23 survey measuring points installed along the dam grouting galleries
- Observation points on the dam surface
- Some 100 observation points along the spillway and on the intake structure
- 10 standpipe piezometers in the Right Bank Grouting Gallery
- 12 standpipe piezometers in the Left Bank Grouting Gallery
- 2 measuring weirs installed at the bottom end of the two dam grouting galleries
- 9 pore-pressure cells installed in the dam core near the spillway structure
- Crack monitoring instruments

Over the past twenty years, the piezometers and the seepage flows have been recorded by the Dam Directorate staff and a number of surveys carried out on the settlement reference points.

\(^8\) Table 5.2 of ANCOLD’s ‘Guidelines on Dam Safety Management’ recommends that comprehensive inspections are carried out at 5-yearly intervals following first filling of the reservoir, with annual intermediate inspections by a competent Dam Engineer. However, it is acknowledged that other international dam safety guidelines/legislation, such as the UK Reservoirs Act, requires annual intermediate inspections and comprehensive inspections at intervals not greater than 10 years. Given the strategic importance of Derbendikhan Dam, it is recommended that the ANCOLD guidelines are applied.
points on the dam crest. However, the behaviour of the dam and possible signs of abnormalities have not been possible to monitor properly. This has largely been due to a number of the above mentioned installations becoming inoperable, but is also related to the Dam Directorate’s staff capability in interpreting the measurements obtained.

Part III of Mr. Wermelinger’s Mission Report provided a detailed review of the monitoring system at Derbendikhan Dam to observe and report on the dam’s behaviour. Recommendations were made for the rehabilitation and upgrade of the instrumentation; these are reproduced in 0 with some additional comments based on observations made during this assignment.

Mr. Wermelinger commented in his report that the dam monitoring installations, after its rehabilitation and reinstatement, is based on the instrumentation layout established in 1979 or earlier. This layout does not fully comply with present international standards for a dam of the size and hazard category of Derbendikhan. Accordingly, the reestablishment of an appropriate dam instrumentation monitoring system is urgently required and a detailed study to review and design the required rehabilitation and extension of instrumentation for Derbendikhan Dam is necessary. It is recommended that this task is incorporated in the terms of reference for the comprehensive dam safety review to be undertaken, as recommended above.

As part of the detailed study to assess the future instrumentation requirements for Derbendikhan Dam, it is suggested that consideration may be given to the establishment of a central control room from which all of the dam monitoring systems can be observed. It is further suggested that this be combined with a remote control facility for the dam operating systems (spillway gates, intake gates and irrigation outlet valves). Such an arrangement would enhance the dam safety monitoring and operation of the dam.

Mr. Wermelinger also commented in his report that some training and transfer of knowledge regarding dam safety was provided to the Dam Directorate staff during his visits. This seems to have been primarily focussed on the reading, checking and recording of the dam monitoring data, including the establishment of spreadsheets to record and plot the hydrological data and piezometer readings. Further training is now required to extend the Dam Directorate’s capability in interpreting the instrumentation data, so that

1. the envelope of normal dam behaviour is recognised, and
2. what action should be taken if abnormal behaviour is identified?

It is not suggested that the Dam Directorate staff need to become dam safety specialists, but it is considered important for them to be able to recognise the early signs of abnormal behaviour so that appropriate specialist advice can be sought to assess the dam behaviour before an issue of dam safety develops to critical levels. It is suggested that this should be tied into a reporting procedure linked to the program of intermediate and comprehensive dam safety inspections adopted as part of the overall Dam Safety Management System.

Right Bank Slip Area

Five years after first impounding of the reservoir, slip failure of an area of the right bank some 300m upstream of Derbendikhan Dam was identified in November 1967. The affected area, consisting of about 2 Mm³ of material approximately 350m in length and 200m wide, moved 1.5m downwards at reservoir elevation 455m following 126mm of rainfall over a period of 7 days. Additional settlement of the right bank slip area occurred between November 1969 and January 1970.
The historical background of the right bank is presented in Figure 8, which has been taken from Coyne et Bellier’s most recent report. Coyne et Bellier, in association with Dar Baghdad Consulting Engineers, has been involved in the assessment, design and remedial works supervision since 1975.

A further failure of this slip mass represents a threat to the safety of Derbendikhan Dam as it could potentially:
1. block the area immediately in front of the inlets and the spillway, restricting the volume of water that could be safely passed through the irrigation outlets, hydropower tunnel intake and over the spillway in the event of an extreme flood
2. water displaced by the slip mass could cause a flood wave to overtop the dam crest, if the slip failure occurred at its highest reservoir level.

It is therefore extremely important that a long-term solution for the stabilisation of the right bank is achieved in the interests of dam safety.

Remedial works for the stabilisation of the slip area proposed by Coyne et Bellier consisted of:

- unloading of the slip area by excavation and removal of slip material above elevation 488m;
- surface protection of the slip area by a drainage system and by landscaping to minimize the infiltration of rain water
- construction of 9 wells with horizontal drains, equipped with pumps to control (lower) the phreatic surface within the sliding zone (deep drainage)
- restriction of the reservoir drawdown to a minimum level of 460m

These remedial works commenced in 1979, but the remedial works remain incomplete as they were halted in October 1980 due to the Iran-Iraq war affecting activities at the site.

The status of the remedial work at that time was reported to be:

- excavation of 120,000m³ above elevation 488m nearly completed, but not assessed by topographic survey
- placement of topsoil for landscaping not started
- excavation of 7 wells started; well P-2 collapsed and was replaced by well P-56; wells P-3 and P-7 were completed including the sub-horizontal drains;
- installation of 12 piezometers completed.

In January 1981, complementary stability analyses by Coyne et Bellier indicated that the minimum reservoir level could be revised to 455m.

The dam inspection carried out by Binnie & Partners in January 1998 suggested that no significant movement of the right bank slip area had occurred since 1986, despite drawdown of the reservoir to level 442m in 1988. New cracks on the ground were observed in April 1998, possibly indicating further movement of the slip mass, but the development of these cracks could also be partially attributed to surface run-off erosion during several days of high intensity rainfall.

In September 1999, the reservoir level was once more drawn down below the recommended safe level of 455m and Coyne et Bellier was engaged to assess the risk of movements. The following recommendations were given in December 1999:

- Installation of pumps in the completed wells and starting draining the wells
- Cleaning of the sub-horizontal wells

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• Collection of rainfall runoff by installing surface drainage
• Cleaning of existing piezometers
• Survey of all existing beacons to monitor movements
• Underwater survey of the concrete slabs installed at the toe of the slip slope (these were last surveyed in November 1978)
• Improve/complete the landscaping of the slip area.
Figure 8. Historical Background of Right Bank Slip Area
The current status of the wells installed in the right bank slip area is summarized in Table 11 and discussed in Coyne et Bellier’s 2006 report, which includes analyses carried out to examine the behaviour of the slip area. The report makes further recommendations for the continued monitoring of the slip area and short-term measures. The main recommendations can be summarized by:

- The allowable minimum drawdown level of the reservoir may be reduced to elevation 450m, provided that a maximum drawdown rate of 10cm/day is not exceeded
- Urgent attention to reinstating/establishing an effective network of surface drains to intercept surface run-off and protect the slip area from surface run-off erosion.
- Urgent attention to the cleaning of the sub-horizontal drains in existing wells to maximize their drainage efficiency
- Continue monitoring installed drainage wells, in particular, collection of pumping data to assess the performance of the existing well installations

The conclusions of Coyne et Bellier’s report end by stating that in order to achieve the minimum drawdown level of 435m (original design) and restore the full operating capacity of the reservoir, the current data suggests that the sub-horizontal drains in wells P-1, P-6 and P56 should be installed, a seventh well (P-15) installed and the surface drainage/landscaping of the slip area completed. The report also suggests a two stage approach towards the realisation of the long-term aim of the remedial works (i.e. a safe minimum drawdown level of 435m):

1. Immediate (short-term) implementation of the main recommendations indicated above; and
2. Reassessment of the slip area behaviour after a further period of monitoring to determine whether all or part of the outstanding remedial works (as defined in Coyne et Bellier’s original remedial works design) is necessary to secure satisfactory conditions within the slip area for the safe drawdown of the reservoir level to 435m.

However, as noted in Part IV of Mr. Wermelinger’s report, there is still no firm evidence which confirms that the Coyne et Bellier’s proposed deep drainage system will achieve its final objective and keep the phreatic surface in the slip mass below or at the limits required for safe conditions with the reservoir drawdown to its intended minimum operating level of 435m. Coyne et Bellier’s 2006 analysis yields factors of safety against a deep sliding failure (down to elevation 405m) of only \( F_s=1.13 \) to 1.14 (reservoir level 455m) and \( F_s=1.10 \) to 1.11 (reservoir level 450m). These results are below the normally accepted minimum factors of safety required by international standards for load cases without earthquake load. There is therefore a real concern that the proposed deep drainage system will not be able to achieve its objective and satisfy international standards for slope stability.

Furthermore, the design concept of the deep drainage system relies on the continuous reduction of the water table in the right bank area by pumping water from the well installations. This will require maintaining a continuous power supply to the pumps, ensuring that the pumps are regularly maintained and adequate spare parts are readily available; failure to keep up the required level of maintenance will result in an increased risk to the safety of Derbendikhan Dam. Whilst alternatives for a permanent solution may require a greater capital investment (since significant investment in the deep drainage system has already be made), the ongoing maintenance costs of the deep drainage system may also mean that an alternative solution with no associated maintenance costs could be economically advantageous. A ‘no/low ongoing maintenance’ solution would also present a lower risk to the safety of Derbendikhan Dam.

Mr. Wermelinger’s statement that “the design concept based on deep drainage of the sliding mass can only be considered as a temporary solution” is supported. It is therefore recommended that an alternative permanent solution for the stabilisation of the right bank slip area is thoroughly investigated and assessed economically against the deep drainage system prior to any further capital investment in extending the deep drainage system.

In the meantime, it is proposed that Coyne et Bellier’s recommended short-term measures given above are implemented immediately so that the stability of the Right Bank Slip Area.
can be enhanced (and hence risk to dam safety lowered) until a permanent solution can be implemented.
### TABLE 11. CURRENT STATUS OF RIGHT BANK SLIP AREA WELL INSTALLATIONS

<table>
<thead>
<tr>
<th>Well No</th>
<th>Top Elevation (mASL)</th>
<th>Depth</th>
<th>Bell No</th>
<th>No. of Drains</th>
<th>Total Length</th>
<th>No. of Drains</th>
<th>Total Length</th>
<th>Length of Each Drain</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-1</td>
<td>490.766</td>
<td>50</td>
<td>1</td>
<td>6</td>
<td>310</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>4” Flygt submersible pump installed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>7</td>
<td>350</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>P-2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Well collapsed and abandoned - replaced by P-56</td>
</tr>
<tr>
<td>P-3</td>
<td>519.144</td>
<td>31</td>
<td>1</td>
<td>12</td>
<td>480</td>
<td>12</td>
<td>480</td>
<td>12 x 40</td>
<td>4” Flygt submersible pump installed</td>
</tr>
<tr>
<td>P-4</td>
<td>514.393</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Well Not Installed</td>
</tr>
<tr>
<td>P-5</td>
<td>506.068</td>
<td>35</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>P-6</td>
<td>492.596</td>
<td>36</td>
<td>1</td>
<td>8</td>
<td>370</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>4” Flygt submersible pump installed</td>
</tr>
<tr>
<td>P-7</td>
<td>510.731</td>
<td>31</td>
<td>1</td>
<td>16</td>
<td>458</td>
<td>16</td>
<td>485</td>
<td>6 x 40</td>
<td>4” Flygt submersible pump installed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>9</td>
<td>310</td>
<td>9</td>
<td>310</td>
<td>5 x 40</td>
<td></td>
</tr>
<tr>
<td>P-8</td>
<td>515.610</td>
<td>35</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Well Not Installed</td>
</tr>
<tr>
<td>P-9</td>
<td>503.893</td>
<td>28</td>
<td>1</td>
<td>7</td>
<td>310</td>
<td>6</td>
<td>260</td>
<td>3 x 50</td>
<td>4” Flygt submersible pump installed</td>
</tr>
<tr>
<td>P-15</td>
<td>488.000</td>
<td>43</td>
<td>1</td>
<td>14</td>
<td>700</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Well Not Installed</td>
</tr>
<tr>
<td>P-56</td>
<td>498.120</td>
<td>38</td>
<td>1</td>
<td>10</td>
<td>281</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>4” Flygt submersible pump installed</td>
</tr>
<tr>
<td>P-57</td>
<td>488.200</td>
<td>43</td>
<td>1</td>
<td>7</td>
<td>380</td>
<td>-</td>
<td>-</td>
<td>2 x 40</td>
<td></td>
</tr>
</tbody>
</table>

*Remarks:* 4” Flygt submersible pump installed
A common solution for the long-term stabilisation of a slip area is to load the toe of the slope. Given the close proximity of the slip area to the power intake structure, irrigation outlets and spillway, consideration may be given to the placement of interlocking pre-cast concrete blocks to load the toe area. Whatever the design of the permanent solution, the impact that any proposed remedial works will have on the performance of the intakes and the spillway needs to be evaluated and properly accounted for.

**Riprap Protection at the Upstream Dam Slope**

The reinstatement of the protection of the upstream face of the dam was carried out by the Dam Directorate in 1999. According to the 1987 and 1998 Binnie inspection reports, appropriately sized riprap material had not been provided to protect the upstream face from wave attack and displaced material had rolled down the face and accumulated at the berms. The 1999 remedial works only provided riprap protection to the slopes and not the berms or upstream face access road. The riprap protection was completed in 2002 following the riprap design prepared by Mr. Wermelinger and detailed in his report.

The present condition of the upstream dam face is satisfactory and no longer represents an issue affecting safety of the dam.

**Settlement of Dam Crest / Dam Crest Reconstruction**

Unexpected large crest settlements in the contact zone with the concrete intake/spillway structure developed soon after first filling of the reservoir. The remedial works undertaken in 1980 are discussed in Mr. Wermelinger’s report and further reconstruction works were required in 2001 to rectify the uneven dam crest surface, which allowed the formation of puddles and ponds of accumulated rain water that promote erosion. This reconstruction of the crest was undertaken by the Dam Directorate included the construction of an asphalt crest road with kerbs and safety barriers. The current condition of the dam crest is more than satisfactory and this represents an issue affecting safety of the dam.

**Right Bank Grouting Gallery**

The main part of the Right Grouting Gallery was constructed in an excavation trench following the bedrock surface at the base of the central clay core along the dam axis. The upper section of the gallery is incorporated into the spillway structure. Two accesses are
available to the gallery; one from the spillway crest on the right abutment and the other from the downstream face berm at elevation 415m via an access gallery within the left spillway wall. The grouting gallery ends at about elevation 366m and extends for a horizontal plan distance of 175m from the right abutment. There is no connection to the left bank grouting gallery; approximately 75m length of the dam remains without a gallery at the middle.

The inspection of the Right Bank Grouting Gallery was made on 12 May 2006 and the reservoir level was reported at elevation 482.90m.

The gallery was found generally to be in good condition; some minor seepage could be observed at some construction joints in the concrete walls and vault. All of the water ingress is collected in a sump at the base of the gallery and measure by a weir. A submersible pump discharges the water through pipework to the tailrace area.

A total of 10 standpipe piezometers are installed in the gallery to the downstream side of the dam foundation at the levels shown in Table 12. Most of the piezometers are equipped with Bourdon gauges; pressure readings from the others are read by temporarily fitting a gauge. Valves and drain outlets are provided for all pipes.

<table>
<thead>
<tr>
<th>Piezometer Station</th>
<th>Top Elevation (m ASL)</th>
<th>Inclination</th>
<th>Piezometer Depth (m)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>242</td>
<td>425.50</td>
<td>30º d/s</td>
<td>50</td>
<td>No pressure at gauge</td>
</tr>
<tr>
<td>260</td>
<td>410.30</td>
<td>30º d/s</td>
<td>10</td>
<td>No pressure at gauge</td>
</tr>
<tr>
<td>280</td>
<td>394.20</td>
<td>30º d/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>295</td>
<td>382.00</td>
<td>30º d/s</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>310</td>
<td>373.00</td>
<td>30º d/s</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>323</td>
<td>365.80</td>
<td>30º d/s</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>328</td>
<td>366.60</td>
<td>30º d/s</td>
<td>60</td>
<td>Grouted</td>
</tr>
<tr>
<td>340</td>
<td>365.95</td>
<td>30º d/s</td>
<td>25</td>
<td>Blackish water observed on opening of relief valve. Strong hydrogen sulphide aroma</td>
</tr>
<tr>
<td>341</td>
<td>366.50</td>
<td>30º d/s</td>
<td>5</td>
<td>Grouted</td>
</tr>
<tr>
<td>342</td>
<td>365.00</td>
<td>30º d/s</td>
<td>10</td>
<td>Grouted</td>
</tr>
</tbody>
</table>

As noted in Table 12, on opening the valve to piezometer at Station 340 dirty water containing fine blackish sediment was observed. It was reported that the presence of the blackish water was first observed in 2002. In addition to the sediment, a strong hydrogen sulphide smell was clearly recognisable. The presence of the hydrogen sulphide is not recent and was commented upon in the 1987 Binnie inspection report. A ventilation system has been installed, but its effectiveness is poor and requires attention to achieve a safe working environment for the Dam Directorate staff monitoring the instrumentation in the grouting gallery. It might be prudent for the Dam Directorate staff to be provided with a hand-held gas detection instrument, so that the air quality can be tested prior to entry and monitored whilst working in the gallery.

The emergence of the black sediment material from the piezometer would appear to be a matter of concern and within the time available for this assignment it has not been possible to examine this in further detail. However, it is noted that grey clay sediments and sulphuric odours have previously been observed from the Right Bank Grouting Gallery piezometers. The Coyne et Bellier 1975 report concluded that no erosion phenomena had developed during the first 10 years of dam operation (up to January 1973). However, over twenty more years has passed since then and this should be investigated as a matter of

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10 Section A – Complementary Grouting in Dam, Derbendikhan Dam Main Remedial Works (Phase 1), Analysis of Dam Behaviour, Review of Previous Reports Recommendations, Coyne et Bellier, May 1975
extreme urgency. As a starting point, it is suggested that samples of the sediment material is collected and analysed to verify whether it is traces of the central clay core material or emanates from an alternate source. It could be an indication that a ‘pipe’ may be developing within the dam core or foundation, which would be a clear threat to the safety of Derbendikhan Dam.

In the zone between Station 310 and 340, a white slimy residue was observed in large quantities. This also started to appear in 2002. Samples of the residue should be taken and analysed to determine its possible origin, although it is suspected that testing will confirm this to be deposits of the chemical grouting that was used to treat the fault zone between Stations 310 and 345. The chemical grout mix used comprised 50% cement and bentonite and 50% sodium silicate and aluminium silicate.

Figure 11. Blackish Water Observed from Piezometer Station 340

An explanation why these deposits have started to emerge is not immediately clear and should be investigated fully. If the deposits are confirmed to be the chemical grout, then there is the suggestion that the grout curtain in this area may be compromised and the implications of this may present a direct threat to dam safety if the grout curtain is compromised. It is not clear whether this problem is directly related to the blackish sediments observed from piezometer Station 340.

Figure 12. White residue emerging in Right Bank Grouting Gallery between Station 310 - 345

From an occupational health and safety perspective, the provision of new handrails would enhance safe access for the Dam Directorate staff and other authorised personnel on the narrow and steep steps.

Left Bank Grouting Gallery

The Left Bank Grouting Gallery was constructed in an excavation trench following the bedrock surface at the base of the central clay core along the dam axis. There is a single access to the gallery from the left dam abutment platform via a short vertical shaft. The grouting gallery ends at about elevation 373m and extends for a horizontal plan distance of about 250m from the left abutment. There is no connection to the right bank grouting gallery; approximately 75m length of the dam remains without a gallery at the middle. The inspection of the Left Bank Grouting Gallery was made on 12 May 2006 and the reservoir level was reported at elevation 482.90m.

The gallery was found generally to be in good condition; seepage flows into the gallery were mainly observed at construction joints in the concrete walls and vault, although some leakage water was also observed at points where no joint is located. Figure 13 shows such a leakage point at approximate elevation 398m (close to Station 500) and the brown deposits appeared to have similar characteristics to clay. The amount of seepage observed was minor on the day of inspection. It is recommended that this leakage hole be carefully broken out to inspect the conditions beneath the gallery invert to check for loss of fines and repaired to make good and seal the leakage. All of the water ingress is collected in a sump at the base of the gallery and measured by a weir. A submersible pump discharges the water through pipework to the tailrace area.
A total of 12 standpipe piezometers are installed in the gallery to the downstream side of the dam foundation at the levels shown in Table 13. Most of the piezometers are equipped with Bourdon gauges; pressure readings from the others are read by temporarily fitting a gauge. Valves and drain outlets are provided for all pipes.

**TABLE 13. LEFT BANK GROUTING GALLERY PIEZOMETERS**

<table>
<thead>
<tr>
<th>Piezometer Station</th>
<th>Top Elevation (m ASL)</th>
<th>Inclination</th>
<th>Piezometer Depth (m)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>420</td>
<td>373.85</td>
<td>30° d/s</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>440</td>
<td>379.88</td>
<td>30° d/s</td>
<td>10</td>
<td>No pressure</td>
</tr>
<tr>
<td>460</td>
<td>386.42</td>
<td>30° d/s</td>
<td>10</td>
<td>Slight odour of hydrogen sulphide</td>
</tr>
<tr>
<td>480</td>
<td>391.71</td>
<td>30° d/s</td>
<td>50</td>
<td>Clear water; no odour of hydrogen sulphide</td>
</tr>
<tr>
<td>500</td>
<td>397.37</td>
<td>30° d/s</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>520</td>
<td>405.82</td>
<td>30° d/s</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>540</td>
<td>418.63</td>
<td>30° d/s</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>560</td>
<td>428.24</td>
<td>30° d/s</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>580</td>
<td>436.84</td>
<td>30° d/s</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>600</td>
<td>445.86</td>
<td>30° d/s</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>620</td>
<td>455.45</td>
<td>30° d/s</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>640</td>
<td>465.66</td>
<td>30° d/s</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Improvements could be made to the shaft access to the Left Bank Grouting Gallery, particularly in terms of the access ladder, in the interests of occupational health and safety.

**Security Screen in Front of Spillway Gate No.3**

As previously reported, a security screen was installed in front of spillway gate No.3 as a military security measure. The screen bears potential risk for:

(a) initiating vibrations during spillway operation resulting in damaging the screen and its anchorage,
(b) clogging by floating debris, and
(c) affecting the discharge capacity of the spillway.

The screen should therefore be removed as soon as possible.

*Figure 14. Spillway Gate No.3*
It can be seen from Figure 14 that there is a considerable volume of floating debris that has already accumulated in front of the security screen and the remainder of the spillway approach channel. This should be cleared and removed to a suitable disposal area to avoid the operation and discharge capacity of the spillway from being adversely affected.

**Intake Gates to Power / Irrigation Outlet Tunnels**

It was reported in the 1998 Binnie inspection report that the intake gates to the power/irrigation outlet tunnels had been replaced with hydraulically operated emergency gated supplied and installed by Metalna Maribor of Slovenia. One gate is provided for the 6m diameter tunnel and two gates for the 9m diameter tunnel, all gates normally being held in their open position immediately above the intake openings. Metalna left the site in 1990 before these gates could be commissioned and this is still an outstanding action that should be remedied as soon as possible. Without commissioning, the proper operation of the intake gates can not be assured. It was reported during the inspection that there is a degree of leakage into the tunnels when the gates are closed. The cause of this leakage is not known, although it is suspected that the cause is either damage to the gate seal or debris trapped in the gate guide recess. The cause of this leakage should be investigated and rectified during the commissioning program of the gates.

**Aspects Relating to Operational Efficiency**

**Plunge Pool Rock Bar**

It was previously recommended in the 1998 Binnie inspection report that the plunge pool is surveyed to check how it is developing and to verify whether any corrective action to prevent undermining of the end of the spillway or tailrace structure is required. It was also noted that a rock bar has been formed at the downstream end of the plunge pool and this appears to have had the affect of increasing the tailwater level at higher discharges (i.e. when more than one turbine is in use simultaneously). A survey of the plunge pool and the downstream rock bar would enable the extent of this problem to be fully assessed. Removal of the rock bar, whether completely or in part, would help reduce the tailwater levels and increase the net head; a higher net head would enable more electricity to be generated from the volume of water available. However, a word of caution is made; removal of the downstream rock bar and lowering of the tailwater level will also have the effect of decreasing the depth of water available to cushion and absorb the energy of the spillway flows. This may cause further erosion of the plunge pool and potentially threaten the security of the end of the spillway or tailrace structures. It is therefore important that the energy dissipation of spillway flows is fully examined in conjunction with the survey of the plunge pool and the decision as to whether the downstream rock bar can be safely removed.

**Right Bank Access Road**

There are two accesses available to Derbendikhan Dam; one from downstream via an access tunnel that passes beneath the spillway chute structure to reach the power station and downstream toe of the dam, and the other from the dam crest going upstream along the right bank of the reservoir to meet with the Derbendikhan – Sulaimaniyah main road near the entrance to the tunnel on that road. The access road along the right bank is in need of remedial works to stabilise the steep cut slopes and prevent further landslides and erosion from undermining the access road (Figure 15).
Previous stabilisation measures have been undertaken in areas immediately adjacent to the area identified in Figure 15 and a similar approach to the measures illustrated in Figure 16 is required. It is understood that documentation for these works has previously been prepared by the Dam Directorate.

Whilst this issue does not have a direct impact in terms of dam safety, failure of the right bank slopes in this area would result in the loss of access to the dam crest from upstream. Consequently it would have an impact on the operational efficiency of maintaining the dam, albeit more of a hindrance rather than a critical issue.

**Maintenance Issues**

**Left Bank Slip Area**

On the left bank, some 400m upstream of the dam axis, a landslide was detected in the early 1970s. The movements occurred in a disposal area comprising spoil material from the dam excavation. The affected area extends up to elevation 520m and investigations carried out in 1976/77 concluded that the settlements were the result of consolidation of disposal material dumped below the reservoir level; the movement at the higher levels were in response to this consolidation. A series of 26 sub-horizontal drains was proposed and installed in 1980 to stabilise the water table in the upper part of the affected area and a surface drainage system was implemented. These remedial works appear to have been successful, as it is understood that no further movement has been observed in the upper part of the slip area (above the service road – elevation 485m).

However, in 2000 a new scarp developed near elevation 470m and extended for a length of about 500m. It is understood that this slip failure is shallow in nature and may have been the result of drawdown of the reservoir level and surface erosion arising from periods of heavy rainfall. A further slip approximately 40m in length occurred in October 2005 approximately 275m upstream of the dam axis just below the service road (elevation 485m). Again this slip appears to be a shallow surface failure, probably arising from drawdown of the reservoir level below elevation 455m and at a drawdown rate in excess of 30cm/day. Whilst the stability of the left bank should continue to be monitored as part of the Dam Directorate’s routine inspections, there is no evidence to suggest that these recent localised slips present a threat to the safety of Derbendikhan Dam.
Left Bank Rock Fall Area

A gabion wall constructed behind the security buildings located on the left abutment platform of the dam crest retains falling rock debris from a zone of instability above the left abutment of the dam. As reported in Mr. Wermelinger’s report, behind several sections of the wall the debris has now accumulated to the top and further falling material has started to cause some minor damage to the buildings. As far as possible, material should be cleared from behind the gabion wall to restore sufficient space to capture future falling material. There has also been the suggestion that the gabion wall be extended or heightened. If the latter is proposed, careful consideration should be given to the condition of the existing gabion elements and the stability of the higher wall.

Right Bank Rock Falls

Rocks which have fallen from the cliffs above the right abutment and the right side of the spillway chute should be cleared as far as reasonably practicable, so that further rock falls can be easily identified and appropriate stabilisation measures undertaken if considered necessary. Significant areas of the right abutment have already had rock stabilisation measures applied.

There were no specific issues identified with the right abutment cliffs during the inspection, however, this should be kept under constant review as part of the routine maintenance inspections carried out by the Dam Directorate staff.

Spillway Gates

One of the principal recommendations in the interests of dam safety in the 1998 Binnie inspection report was the immediate commissioning of the spillway radial (tainter) gates and reinstatement of the spillway gate anchorages. The commissioning of the gates was completed by the original supplier Metalna Maribor of Slovenia in 1998 and stand-by power was also installed to the spillway gates in 2004.

The spillway gates appeared to be in good condition, although comments were made by the Dam Directorate staff that the protective coating to the upstream face of the spillway gates requires attention. The full face of the spillway gates could not be viewed during the visit and it is recommended that an inspection is undertaken at the next reservoir drawdown and any areas of damage made good, as part of the routine maintenance program.

There were also comments that the bottom seal needed to be replaced on each of the spillway gates, however, the absence of visible leakage at the time of inspection casts some doubt on the necessity of this task at this point in time, except perhaps spillway gate No.1.
which showed some signs of minor leakage. It is recommended that the bottom seals are inspected during the next reservoir drawdown period as part of an annual (intermediate) inspection.

**Spillway Flip Bucket Drainage**

The drainage outlets to the flip buckets are partially blocked and are causing water to accumulate in the trough of the flip buckets. These outlets should be cleared to enable free draining of the flip buckets. This is considered a routine maintenance issue and does not constitute a threat to the safety of the dam. It will however affect the efficiency of the spillway at low flows, until there is sufficient depth of flow to wash the accumulated water out from the bucket deflector.

**Other Issues**

There are no other issues identified relating to the safety of Derbendikhan Dam during the site inspection to report.
Dokan Dam

General Description and History

Dokan Dam is located on the Lesser Zab river approximately 295km north of Baghdad and 65km southeast of Sulaimaniyah city. The dam is a concrete arch with gravity abutment blocks located in a narrow steep sided gorge incised in the limestone and dolomite bedrock. The crest length of the dam is 350m and has a maximum height of 116m.

The reservoir impounded by Dokan Dam had a total design capacity at normal operating level (El. 511.00m ASL) of 6,870 Mm³, of which 6,140 Mm³ is live storage and 730 Mm³ being dead storage. The current storages will be less than this due to over 45 years of sedimentation.

The reservoir is controlled by two spillways, both sited on left bank of the reservoir. The service spillway, referred to as the gated spillway, has three vertical gates, each closing an orifice with a clear opening of 10m high by 6.8m wide. The orifices discharge into a short steep chute connecting to an 11m diameter tunnel with a free outlet set about 50m above the river in the gorge downstream of the dam. The gated spillway crest is set 14.5m below the normal top water level of the reservoir. The maximum capacity of the gated spillway is 2,450m³/s.

The emergency spillway is a circular 40.26m diameter bellmouth (Morning Glory) spillway with its crest set at the normal top water level of the reservoir. The bellmouth discharges via a vertical 12.5m diameter drop shaft into a 10.2m diameter tunnel. At its downstream end, the tunnel is steel lined, reducing in diameter to 9.9m and inclined both 30° upwards and 47° in a downstream direction for a free discharge into the river gorge. The maximum capacity of the emergency spillway is 1,860m³/s.

In addition, releases can be made through two irrigation outlets that are fed by a tunnel passing beneath the dam on the right bank. This tunnel bifurcates below the crest of the dam, where each 2.29m diameter steel lined tunnels can be closed by emergency gates lowered from the dam crest. Each of these tunnels connect to a steel conduit with a
butterfly guard valve and flow is regulated by a hollow-jet discharge valve with a maximum capacity of 120m³/s each at full reservoir level.

Five further steel conduits of 3.65m diameter were constructed through the arch section of the dam. Each of these can be closed by an emergency gate lowered from the dam crest and each conduit leads to a guard valve and 80m turbine unit in the main power station located at the dam toe.

Two emergency gates have been provided for closing off the irrigation tunnels and power conduits, and a travelling gantry crane with a hydraulically operated lifting beam is installed at the crest of the dam for handling these gates.

The dam was designed by Binnie, Deacon & Gourley of the UK for the Republic of Iraq. Construction of the dam was started in 1954 and was completed in 1959. The main civil works contractor was Dumez-Balloz of France and the gates and associated E&M equipment was supplied by Nerpic of Grenoble, France. Construction of the powerhouse at the toe of the dam did not commence until 1975 and the last of the five 80MW turbine units was commissioned in 1979.

The pertinent data of Dokan Dam and its appurtenant structures is summarised in Table 14.

TABLE 14. PERTINENT DATA FOR DOKAN DAM

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area</td>
<td>11,690 km²</td>
</tr>
<tr>
<td>Mean Annual Catchment Precipitation</td>
<td>850 mm</td>
</tr>
<tr>
<td>Design Inflow</td>
<td>13,300 m³/s</td>
</tr>
<tr>
<td>Maximum Recorded Inflow</td>
<td>4,698 m³/s</td>
</tr>
<tr>
<td>Peak Outflow (Design Flood)</td>
<td>4,180 m³/s</td>
</tr>
<tr>
<td>Maximum Recorded Outflow</td>
<td>2,260 m³/s</td>
</tr>
<tr>
<td>Maximum Recorded Reservoir Level</td>
<td>El. 512.56 m ASL on 04/05/1988</td>
</tr>
<tr>
<td>Minimum Recorded Reservoir Level</td>
<td>El. 430.95 m ASL on 25/12/1960</td>
</tr>
<tr>
<td>Dam Type</td>
<td>Cylindrical Arch with Gravity Abutments</td>
</tr>
<tr>
<td>Crest Level (Lowest)</td>
<td>El. 516.07 m ASL</td>
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<tr>
<td>Maximum Height</td>
<td>116.5 m</td>
</tr>
<tr>
<td>Crest Length</td>
<td>Total 345.0 m</td>
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<td></td>
<td>Left Gravity Abutment 41.0 m</td>
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<tr>
<td></td>
<td>Arch 240.0 m</td>
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<td></td>
<td>Right Gravity Abutment 64.0 m</td>
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<tr>
<td>Width</td>
<td>At Crest 6.2 m</td>
</tr>
<tr>
<td></td>
<td>At Base</td>
</tr>
<tr>
<td></td>
<td>Including Foundation Socle 65.0 m</td>
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<td></td>
<td>Without Foundation Socle 34.3 m</td>
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<td>Radius of Upstream Face Cylinder</td>
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<td>Concrete Volume</td>
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<td>Arch 325,000 m³</td>
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<td>Gravity Abutments 45,000 m³</td>
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<td>Excavation Volume</td>
<td>160,000 m³</td>
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<td>Normal Operation Level</td>
<td>El. 511.00 m ASL</td>
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<td>Reservoir Area and Volume at El. 511.00</td>
<td>270 km² / 6.8 Mm³</td>
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<td>Minimum Drawdown Level</td>
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<td>Live Storage Volume at El. 511.00</td>
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<td>Dead Storage Volume</td>
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<td>Description</td>
<td>Value</td>
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</tr>
<tr>
<td><strong>Type</strong></td>
<td>Gated Service Spillway</td>
</tr>
<tr>
<td></td>
<td>Each gate orifice discharges into common short steep chute connecting to tunnel</td>
</tr>
<tr>
<td>Spillway Gate Size</td>
<td>3 No. 10.00m x 6.80m Vertical Lift Gates</td>
</tr>
<tr>
<td>Crest Level at Ogee</td>
<td>El. 496.50 m ASL</td>
</tr>
<tr>
<td>Top of Closed Gate</td>
<td>El. 506.50 m ASL</td>
</tr>
<tr>
<td>Discharge Capacity at El. 515.10</td>
<td>2,450 m³/s</td>
</tr>
<tr>
<td>Internal Diameter of Shaft</td>
<td>-</td>
</tr>
<tr>
<td>Internal Diameter of Tunnel</td>
<td>11.00 m</td>
</tr>
<tr>
<td>Outlet Details</td>
<td>Free Outlet approx 50m above river gorge</td>
</tr>
<tr>
<td><strong>Type and Number of Gates</strong></td>
<td>2 No. Emergency Gates to serve both Irrigation Tunnels and the Power Conduits lowered from Dam Crest by travelling Gantry Crane</td>
</tr>
<tr>
<td>Gate Size</td>
<td>4.75 m x 9.50 m</td>
</tr>
<tr>
<td>Capacity of Gantry Crane</td>
<td>160 t</td>
</tr>
<tr>
<td><strong>Irrigation Supply Tunnels</strong></td>
<td>2 No. through right abutment rock</td>
</tr>
<tr>
<td></td>
<td>□ Upstream part internal diameter 4.85 m</td>
</tr>
<tr>
<td></td>
<td>□ Downstream part internal diameter 2.29 m</td>
</tr>
<tr>
<td>Diameter of Butterfly Guard Valve</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Diameter of Howell Bungers Valves</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Maximum Discharge</td>
<td>2 x 110 m³/s</td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td>Surface Power House at Dam Toe</td>
</tr>
<tr>
<td>Number of Turbine/Generator Units</td>
<td>5 No. Vertical Francis Turbines</td>
</tr>
<tr>
<td>Steel Penstocks</td>
<td>5 x 3.65 m diameter</td>
</tr>
<tr>
<td>Rated Head</td>
<td>95 m</td>
</tr>
<tr>
<td>Rated Discharge</td>
<td>5 x 110 m³/s</td>
</tr>
<tr>
<td>Rated Output</td>
<td>5 x 80 MW</td>
</tr>
</tbody>
</table>
Geology

Dokan Dam lies within a gorge cut by the Lesser Zab river through the axis of an anticline formed by sedimentary rocks of the Cretaceous age. The rocks in the anticline are predominantly calcareous, being made up of marls, limestones and dolomites. The anticline was formed during folding associated with the latter stages of the Alpine-Himalayan orogeny during the Oligocene and Miocene periods. The anticline at Dokan is part of a series of greatly elongated anticlinal domes which extend to the north-east and south-west.

The foundations and abutments of the dam lie within the Quamchuga formation and the Shiranish formation. The local succession at the dam site is given in Table 15.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Presumed Formation</th>
<th>System</th>
<th>Approx. Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stylolitic Limestone</td>
<td>Shiranish</td>
<td>Upper Cretaceous</td>
<td>123</td>
</tr>
<tr>
<td>Calcareous Shale</td>
<td>Shiranish</td>
<td>Upper Cretaceous</td>
<td>1</td>
</tr>
<tr>
<td>Limestone</td>
<td>Shiranish</td>
<td>Upper Cretaceous</td>
<td>3</td>
</tr>
<tr>
<td>Dolomite</td>
<td>Quamchuga</td>
<td>Mid Cretaceous</td>
<td>120</td>
</tr>
</tbody>
</table>

The Quamchuga Dolomite forms the sides of the lower 60m of the gorge. These are near vertical and overlain by steep slopes formed of the Shiranish limestones and shales. Details of the lithology are provided in Appendix A of the 1987 Binnie report and can be summarised as given in Table 16.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td><strong>Stylolitic Shiranish Limestone</strong></td>
</tr>
<tr>
<td></td>
<td>The Shiranish Limestone is typically strong to very strong, light grey, fine grained, thin to medium bedded, fresh to slightly weathered siliceous limestone, containing many foraminiferal traces</td>
</tr>
<tr>
<td>(ii)</td>
<td><strong>Bituminous Calcareous Shiranish Shale</strong></td>
</tr>
<tr>
<td></td>
<td>The Shiranish Shale appears at exposure as weal to moderately weak black to dark grey, fine grained, slightly to moderately weathered, laminated, bituminous shale</td>
</tr>
<tr>
<td>(iii)</td>
<td><strong>Base Shiranish Limestone</strong></td>
</tr>
<tr>
<td></td>
<td>The Shiranish Limestone is typically strong to very strong, light brown, fine grained, thin to medium bedded, fresh to slightly weathered siliceous limestone</td>
</tr>
<tr>
<td>(iv)</td>
<td><strong>Bituminous Quamchuga Dolomite</strong></td>
</tr>
<tr>
<td></td>
<td>The Quamchuga Dolomite is typically strong to very strong, brownish grey to dark grey, fine grained, medium to thickly bedded, fresh to slightly weathered bituminous dolomite. The dolomite shows evidence of extensive solution caverning. The effects appear to be associated with all of the major discontinuity sets. The resulting cavities are frequently filled with silty clay. Adjacent to the gorge, the cavities have been enlarged to caves up to 30m in length</td>
</tr>
</tbody>
</table>

Seismicity

Regional Seismicity

Dokan Dam lies in a folded nappe zone to the southwest of the plate boundary where the Arabian tectonic plate is being subducted beneath the Persian plate. The regional seismicity is described in more detail in Appendix D of the 1987 Binnie Report.

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Maximum Credible Earthquake and Operating Basis Earthquake

The magnitude and peak ground acceleration for the Maximum Credible Earthquake and Operating Basis Earthquake are discussed in Section 5 of the 1987 Binnie Report and summarised in Table 17. These parameters were adopted for the stability analysis undertaken by Binnie & Partners as part of the Analysis and Safety Evaluation of Dokan Dam carried out in 1987.

TABLE 17. MAXIMUM CREDIBLE EARTHQUAKE AND OPERATING BASIS EARTHQUAKE PARAMETERS

<table>
<thead>
<tr>
<th>Event</th>
<th>Magnitude</th>
<th>Estimated Focal Depth</th>
<th>Horizontal Peak Ground Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Credible Earthquake (MCE)</td>
<td>6.5</td>
<td>15km</td>
<td>0.25g</td>
</tr>
<tr>
<td>Operating Basis Earthquake (OBE)</td>
<td>6.5</td>
<td>7.5km</td>
<td>0.10g</td>
</tr>
<tr>
<td>Reservoir Induced Seismicity</td>
<td>6.5</td>
<td>15km</td>
<td>0.25g</td>
</tr>
</tbody>
</table>

The results of the 1987 stability analyses concluded that the dam section is satisfactory under both static and earthquake conditions. Historically, reservoir-induced earthquakes have generally occurred during first filling of the reservoir or soon after. Since Dokan Dam has been in operation for over 45 years, the risk of such an event is considered to be extremely low now or in the future.

Seismic Monitoring

A seismograph was previously installed in Sulaimaniyah, but was destroyed in 1991 and has not been replaced. Consequently, there is no means for monitoring and recording seismic activity at the dam site. As stated in a number of the previous reports, current international design practices indicate that it would be normal for a dam of the size of Dokan to have one or more seismograph stations installed at the dam site for the monitoring and recording of seismic events. To date, no action has been taken to install seismic instruments at the dam and whilst this was previously considered to be a medium-term task by the 1998 Binnie Report, given the importance of being able to monitor and record the seismic response of Dokan Dam, it is proposed that this task is now elevated from the Long-Term to Medium-Term Action List. Further discussion on the proposed seismic instruments to be procured, supplied and installed is presented in 0.

Hydrology

Historic Reservoir Levels

It is understood that a near to complete record of daily reservoir level is available for Dokan Dam from the start of impounding in the beginning of 1959; only one month of record is incomplete for this 45-year period. A plot of the reservoir level for the period September 1990 to June 2002 is shown in Figure 21.
The original reservoir control rule curve is presented in Figure 21. Comparing this with Figure 22, it can be seen that the application of the control curve is considered to be unworkable in recent years. It is understood that principal reason for this has principally to meet the demand for hydro-electric power generation, rather than irrigation supply which was the original primary purpose of the dam.

**Flood Studies**

As part of the Analysis and Safety Evaluation undertaken by Binnie & Partners in 1987\(^5\), a review of the previous flood studies was carried out, including an update of the hydrological studies to incorporate the more recent available data at that time. A summary of the findings of this review is presented in Table 10.

The 1987 studies concluded that the adopted design flood and estimated probable maximum flood (PMF) are appropriate and that provided reservoir operations are in accordance with the rule curve and spillway operation criteria adopted in the flood routing studies are used, Derbendikhan Dam should be safe against overtopping.

However, as noted in Section 0, the original reservoir rule curve has not been observed in a number of years due to a change in the emphasis on water use for hydro-electric power generation. It is therefore recommended that the reservoir rule curve is reviewed and updated to suit the current water use demands and conditions. The flood studies should then be updated to confirm that the safety of the dam embankment is not being exposed to a higher than acceptable risk of overtopping as a result of the revised reservoir rule curve.
TABLE 18. SUMMARY OF PREVIOUS FLOOD STUDIES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Reservoir Level</td>
<td>m</td>
<td>510.77</td>
<td>514.70</td>
</tr>
<tr>
<td>Date</td>
<td>28-29/04/1974</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. Reservoir Level</td>
<td>m</td>
<td>441.91</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>15,16/12/1988</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Inflow</td>
<td>m³/s</td>
<td></td>
<td>18,700</td>
</tr>
<tr>
<td>Freeboard[^5]</td>
<td></td>
<td>5.23</td>
<td>1.30</td>
</tr>
<tr>
<td>Max. Total Outflow</td>
<td>m³/s</td>
<td>1,800</td>
<td>4,180</td>
</tr>
<tr>
<td>Date</td>
<td>10-12/04/1969</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Spillway Outflow</td>
<td>m³/s</td>
<td>1,500-1,800</td>
<td>4,180</td>
</tr>
<tr>
<td>Date</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
[^1]: The dam crest elevation is 516m ASL.
[^2]: Design values do not include any discharge from the power station or irrigation outlets.

As stated in Section 0, the preliminary Hazard Category of Dokan Dam has been assessed as ‘Extreme’ and accordingly, the dam should have sufficient dry freeboard to protect the dam from being overtopped by a flood event with an annually exceedance probability (AEP) equivalent to the PMF[^5]. Furthermore, the pre-flood reservoir level should be taken to be the normal full supply level.

Dokan Dam has been constructed with gated (service) spillway and bellmouth (emergency) spillway structures that are capable of passing a maximum combined flow of 4,310m³/s. The 1987 Binnie calculations showed that the combined spillway capacity is sufficient to safely pass the PMF event, as required for a dam with an Extreme hazard category. Furthermore, 1987 studies showed that neither the design flood nor PMF would cause overtopping of the dam with the central spillway gate closed (inoperable) and without any irrigation or hydropower releases being made.

However, these results are only valid if the reservoir operations are in accordance with the rule curve and spillway operation criteria. As the historical records show, the rule curve has not been applied and consequently the flood studies should be reviewed for an updated rule curve that matches the current reservoir operations more closely.

It is also noted that the flood studies are also only valid and Dokan Dam safe against overtopping provided that the bellmouth spillway tunnel is kept clear of any accumulated debris.

Previous Studies and Reports

The depth of information pertaining to the dam design, construction, operation and maintenance is to be commended, particularly given the degree of conflict and war experienced in the region over the past two decades. A summary of the reports and documents that were made available during the Inspection are listed in 0.

With respect to Dam Safety inspections and evaluations, the following reports are of particular relevance for Derbendikhan Dam:


Aspects Relating to Dam Safety

Risk Assessment and Emergency Action Plans

As noted in Section 0, it is considered appropriate that a full Risk Assessment is undertaken for Dokan Dam and an Emergency Action Plan prepared. Due to the limited time of this mission, it was not possible to fully evaluate the existing information and procedures that are currently held by the Dam Directorate. These need to be reviewed and any information gaps resolved to enable a formal Dam Safety Action Plan to be prepared.

Dam Instrumentation and Monitoring System

Central to any dam safety management system is the monitoring of the dam’s performance; any sign of abnormal behaviour could represent a threat to dam safety. External loads acting on the dam and its foundations, together with their response, need to be carefully monitored so that any abnormality can be identified as soon as possible and the necessary action taken promptly before the abnormality becomes a serious dam safety issue.

Dam monitoring consists of two major tasks:

- Review / checking of the structural safety of the dam (= Dam Condition)
- Detection of any abnormal event (= Dam Behaviour)

The Dam Condition is assessed through periodic inspections of the dam, ranging from the daily routine observations by the Dam Directorate staff to comprehensive dam safety reviews undertaken by a dam safety specialist at 5-yearly intervals. With the last comprehensive dam safety review undertaken by Binnie & Partners in 1987 (and updated in 1998), it is strongly recommended that a comprehensive dam safety review is undertaken by a competent Engineering Company as part of the proposed Dokan and Derbendikhan Emergency Hydropower Project.

The dam instrumentation installed at Dokan to monitor the dam’s behaviour was partly rehabilitated in 1986 and at that time comprised the following installations:

- A reservoir level indicator and one staff level
- 3 Plumb lines (plumb bobs) with micrometer microscopes
- Survey monuments constituting a triangulation network
- 12 survey target points fixed to the downstream face of the dam at approximate crest elevation
- Survey equipment consisting of a Wild T2000 theodolite and a WILD D15 distomat
- 10 standpipe piezometers at the downstream toe of the dam
- 7 standpipe piezometers installed from the surface at the left dam abutment and 3 sets of 2 piezometers at the Left Bank Grouting Gallery
- 4 sets of 2 piezometers at the Right Bank Grouting Gallery

Table 5.2 of ANCOLD’s ‘Guidelines on Dam Safety Management’ recommends that comprehensive inspections are carried out at 5-yearly intervals following first filling of the reservoir, with annual intermediate inspections by a competent Dam Engineer. However, it is acknowledged that other international dam safety guidelines/legislation, such as the UK Reservoirs Act, requires annual intermediate inspections and comprehensive inspections at intervals not greater than 10 years. Given the strategic importance of Derbendikhan Dam, it is recommended that the ANCOLD guidelines are applied.
• Series of V-notch measuring weirs in both abutment galleries and at the left tailrace river bank
• Crack monitoring instruments

Over the past twenty years, the piezometers and the seepage flows have been recorded by the Dam Directorate staff and a number of surveys carried out on the settlement reference points on the dam crest. However, the behaviour of the dam and possible signs of abnormalities have not been possible to monitor properly. This has largely been due to a number of the above mentioned installations becoming inoperable, but is also related to the Dam Directorate’s staff capability in interpreting the measurements obtained.

Part II of Mr. Wermelinger’s Mission Report provided a detailed review of the monitoring system at Dokan Dam to observe and report on the dam’s behaviour. Recommendations were made for the rehabilitation and upgrade of the instrumentation; these are reproduced in 0 with some additional comments based on observations made during this assignment.

Mr. Wermelinger commented in his report that the structural safety of an arch dam is mainly determined by its stress and deformation pattern – including foundation and abutments – and the periodic comparison of the analytical data with the measurement records. At Dokan Dam, the dam monitoring installations, after its rehabilitation and reinstatement, is based on the instrumentation layout established in 1986. This layout does not fully comply with present international standards for a dam of the type, size and hazard category of Dokan. The following deficiencies on dam monitoring can be identified:

• Dam displacement
• Displacement of the foundation and the abutments
• Uplift gradient
• Joint displacements
• Concrete temperature
• Water temperature.

Accordingly, the establishment of an appropriate dam instrumentation monitoring system is urgently required and the possible extension of the instrumentation may comprise of the following:

1. For monitoring dam displacements: additional polygonal traverses at different elevations on the downstream dam face
2. For monitoring displacements of the foundation and the abutments: inverted pendulums and/or rock meters
3. Monitoring of uplift gradient: additional piezometers (pore-pressure cells) in drillings for measuring water pressure upstream and downstream of the grout curtain.
4. For monitoring joint displacements: dilatometers, jointmeters, etc.
5. For monitoring concrete temperature: concrete thermometers (Note: the temperature, next to the water load, has a prominent influence on the deflection of an arch dam)
6. For monitoring water temperature: water thermometer (see also 0, 0)

A detailed study to review and design the required extension of instrumentation for Dokan Dam is necessary. It is recommended that this task is incorporated in the terms of reference for the comprehensive dam safety review to be undertaken, as recommended above.

Mr. Wermelinger also commented in his report that some training and transfer of knowledge regarding dam safety was provided to the Dam Directorate staff during his visits. This seems to have been primarily focussed on the reading, checking and recording of the dam monitoring data, including the establishment of spreadsheets to record and plot the hydrological data and piezometer readings. Further training is now required to extend the Dam Directorate’s capability in interpreting the instrumentation data, so that

1. the envelope of normal dam behaviour is recognised, and
2. what action should be taken if abnormal behaviour is identified?

It is not suggested that the Dam Directorate staff need to become dam safety specialists, but it is considered important for them to be able to recognise the early signs of abnormal behaviour so that appropriate specialist advice can be sought to assess the dam behaviour before an issue of dam safety develops to critical levels. It is suggested that this should be
tied into a reporting procedure linked to the program of intermediate and comprehensive dam safety inspections adopted as part of the overall Dam Safety Management System.

**Bellmouth Spillway and Tunnel**

The concrete lining of the bellmouth spillway shaft leaks and an inspection was carried out on 26 July 2000 by lowering an engineer into the spillway shaft using a mobile crane and inspection cabin. The reservoir level on this day was about elevation 488m. Approximately 40 minutes of video footage of the inspection has been transferred from VHS format to digital format and this was made available on a CD. Examination of the video shows that the principal points of leakage are located around the construction joint between the lower shaft lining and the collar incorporating the air shaft opening (elevation c. 479m – arrow 1). The main leakage is characterised as three closely grouped orifices on the west side of the shaft. General seepage can be observed around the remainder of the construction joint at this level. Addition seepage was observed at the next construction joint at the base of the pre-cast blocks (elevation c. 488m – arrow 2) on the east side of the bellmouth. The quantity of leakage from the main points of ingress appeared to be in the order of 5 l/min, which would correlate with the level of the reservoir.

The leakage needs to be treated in order to prevent further deterioration of the bellmouth shaft lining and a possible solution may be to inject a radial pattern of grout around the circumference if the shaft at the construction joints (elevations 479m and 488m). This would need to be carried out during a period when the reservoir is drawn down, preferably below 480m.

It is recommended that the remedial works be designed by a competent Engineering Company and implemented within the next six months to take advantage of the lower reservoir levels at the end of the year.

**Right Bank Grouting Gallery**

An inspection of the Right Bank Grouting Gallery was carried out on 14 May 2006 and the reservoir water level was at elevation 501.34m on this day. Access to the gallery is via an access adit; approximately 250m long, separating the grouting gallery in a c.420m long North drive heading towards the dam and a c.300m long South drive (see Figure 25). The elevation of the galleries is approximately 450m with a slope towards the access adit. The Access Adit has a concrete invert, but is otherwise unlined. The adit was essentially dry during the inspection, with the exception of seepage flows collected from the North and South drives being conveyed out to the river downstream of the dam. It is estimated that approximately 25 l/min was flowing through the V-notch weir.
The North Drive is generally a d-shaped profile, fully lined with shotcrete and a concrete invert. A pattern of short drain holes through the shotcrete provides protection against the development of severe water pressure behind the lining. There are a number of short sections of the gallery that fully concrete lined.

The gallery provides access to the measuring point of the plumb-line installed in Block 13 of the arch dam. The gallery has no contact with the dam and ends underneath Block 11. Pressure groutings were carried out from the gallery; vertically to the ground surface as well as into bedrock below the gallery. A further unlined adit connects the grouting gallery with the surface in the vicinity of the dam abutment (see Figure 26). This adit provides natural through ventilation for the North Drive and Access Adit.

Two sets of piezometers are installed in the North Drive; both sets are understood to be operable. Close to the dam, several areas of leakage were observed and the ingress of water was estimated to be in the order of 3-4 l/min each; sections of the gallery invert were under a centimetre or more depth of ponded water. The water ingress was running clear. This seepage water is collected by the drain within the galley and measured by a V-notch weir located at the junction with the Access Adit.

Like the North, the South Drive is a fully shotcrete-lined gallery with a concrete invert. This gallery exhibited similar conditions to the North with a few sections of the gallery subject to ponding. A couple of leaks were observed in the South Drive and these contributed to the balance of flow observed in the Access Adit V-notch.

A lighting system is provided to the South Drive, but no ventilation system exists to circulate air in the dead end. The working conditions would be improved for the reading of the piezometer sets located at the end of the South Drive if a blower system mounted in front of the access adit portal and a ducted system was installed to deliver fresh air to the South end of the gallery.

There were no observations in the Right Bank Grouting Gallery that gave any cause for concern and it is understood that the leakage flows were not unusual for the corresponding water level in the reservoir.
Left Bank Grouting Gallery

The Left Bank Gallery was excavated during the construction of the dam to provide access for grouting works to the left abutment. The main part of the gallery, with a length of some 450m, runs along approximate elevation 434m. At the end of this section, the gallery climbs up an estimated 50m in the direction of the reservoir and the gated spillway. This last section of the gallery is not properly documented on the available drawings. The working adit driven from the left bank on the upstream side was plugged with concrete after completion of the grouting work. A break-through occurred in the gallery in March 1959, which was brought successfully under control by the construction of a “Dumez-Plug”. However, in 1962, the plug was removed and a steel gate installed in order to provide some protection against flooding of the powerhouse and dam adits in the event of a sudden change in leakage flows. A new plug was formed (“Skew Plug”) further into the hillside. A further break-through occurred in the gallery in 1965 and it was decided to provide a complete concrete lining throughout the gallery and together with high pressure grouting to control leakage. These works were implemented between 1979 and 1980.

An inspection of the Right Bank Grouting Gallery was carried out on 14 May 2006 and the reservoir water level was at elevation 501.34m on this day.

The overall condition of the Left Bank Grouting Gallery is generally satisfactory now that it is fully concrete lined, including the ascending part leading to the area of the gated spillway. The last section of the gallery at higher elevation is still unlined; Dam Directorate staff report that considerable leakage flow from this unlined section is observed when the reservoir level is high. At the time of the inspection, a leakage of around 2 l/min was observed from the crown of the gallery (Figure 28).

The steel ‘safety’ gate is now installed at the “Skew Plug”, approximately 170m from the “Dumez-Plug” and was reported to be in poor condition and unable to be closed. Remedial works were undertaken to restore the hinges to good working condition. Whilst the gate can now be closed, there is a reluctance by the Dam Directorate staff to keep it closed because it is heavy to open when they need to read the 3 sets of piezometers installed in the gallery. In his report, Mr. Wermelinger discussed the location of the potential high risks.
relative to the location of the safety gate. For instance, the Boundary Fault system which caused the first break-through is on the dam side of the gate. The unlined end section of the gallery may present a risk for sudden increased inflow, but only at high reservoir pool levels. Seepage readings indicate that there is increased inflow when the pool level reaches elevation 492m. It would be good practice to ensure that the safety gate is kept closed at all times to ensure that the protection that is was installed to provide can be realised in event of a sudden increase of leakage flow. However, the regular reading of the piezometers behind the safety gate must not be interrupted, particularly during periods of high reservoir pool levels.

The piezometers installed in the grouting gallery are in pairs; one on the upstream side of the grout curtain and the other downstream. Pressure gauges of the pair L (upstream) and H (downstream), showed approximate readings of 4.5 bar and 3.6 bar respectively. The upstream reading would appear to be a little low with the reservoir pool level at elevation 501.34m (some 67m above the gallery), but it has not been possible within the scope of this assignment to confirm the correlation between the reservoir pool level and piezometer readings. It is understood that these readings are within the normal range. The other observation made was that water released from the upstream piezometer ‘N’ was discoloured and odourless. However, although the corresponding downstream piezometer ‘J’ ran clear, hydrogen sulphide odours could be recognised. It is not clear whether this has any significance based on a single observation. The significance of these observations and any correlation to recorded data should be assessed during the Comprehensive Dam Safety Review.

A total of four V-notch weirs are installed in the gallery to measure the leakage flows.

**Left Abutment Drives**

In addition to the main Left Bank Grouting Gallery discussed in Section 0 above, there are additional drives that were excavated during construction of the dam within the left abutment at elevation 480.5m and 465m. The can be accessed via the lift.

In Drive No.4 which extends in a north-easterly direction towards the left bank of the reservoir at elevation 480.5m, significant leakage can be observed with an inflow of some 5 l/sec. An attempt has been made to control this leakage by the installation of a pipe to capture the leakage and direct the water to the appropriate drain. However, at high reservoir pool levels, the inflow exceeds the capacity of the pipe and overflows. A sheet of corrugated metal has been placed against the pipe to deflect the water away from the water supply pipes that occupy the end of this drive.

**Irrigation Outlets**

Two irrigation outlets are provided below the right dam abutment. A common intake and feeder tunnel delivers water to just upstream of the dam, where it bifurcates into the two irrigation outlet tunnels. Each of these tunnels is provided with an emergency closure gate shaft to allow the lowering of the gate from the dam crest. The tunnels are steel lined
downstream of the gate shafts to the valve chambers. Downstream of the gate shafts, only the first 18m of the tunnels have been fully backfilled with concrete around the steel linings and the drawings indicate that grouting was carried out from inside the linings to form a plug. Downstream of the plug, the tunnel excavation profiles were only partly backfilled to provide inspection adits above the irrigation pipes.

A third irrigation outlet was originally installed and connected to the penstock embedded in Block 9 of the dam. This outlet had to be abandoned when the powerhouse was constructed.

**Inspection Adits**

In 1988, during a period of very high reservoir levels (the emergency spillway was in operation), leakage flow from Inspection Adit No.1 (adit at hillside) was first observed. Leakage was soon detected in Inspection Adit No.2 as well. Initially these inflows were small and could be drained by gravity from Adit No.2 and discharged by a pump from Adit No.1. The leakage flows significantly increased in 1994 and pipe systems were installed to collect the concentrated inflows at the rock surface and drain the water directly to the tailrace area.

The leakage in Adit No.1 is confined to a single point on the riverside of the adit some 15m downstream of the plug. The concentrated inflow to Adit No.2 is divided between three points on the hillside of the adit. The 1998 Binnie Inspection Report suggests that the leakage may be fed by the reservoir, possibly through joints in the rock that were flushed out by the high reservoir level during 1988. If confirmed, then this could be resolved by grouting to seal the inspection adits using services of a specialist contractor. However, analysis of the data already collected by the Dam Directorate staff, and further monitoring if necessary, is required to confirm that the leakage is fed by the reservoir and not an alternate source.

Access to these inspection adits is rather precarious with loose wooden planks laid above the irrigation pipes. In the interests of occupational health and safety, proper safe access should be established with open mesh type staging. Due consideration will be required for maintaining ready access to the irrigation pipes and associated fittings when designing the access platforms.

**Irrigation Conduit Steel Liners**

The steel liners to the irrigation outlets were inspected by UNDP engineers in July 2000 and the internal surfaces were found to be in reasonable condition considering their age; the corrosion pitting was minimal and light (less than 0.5mm). At that time, it was recommended that the internal surfaces are blast cleaned and repairs to the protective coating scheduled within the next five years.

The steel liners were not inspected as part of this assignment and it is recommended that the internal condition is re-assessed as part of the next comprehensive dam safety inspection/review.
Hollow Cone Valves

The Hollow Cone Valves were also inspected in July 2000 and were found to be in reasonable condition with only minor touch-up painting with an epoxy coating. The rear sliding seal of Hollow Cone Valve No.2 was observed to have an undesirable level of leakage, but adjustment of the seal tightness using set screws in the areas was recommended to address this issue. It is understood that this matter has been resolved as the Hollow Cone Valves appeared to be in satisfactory working order during this assignment’s visit - both hollow cone valves were opened for several minutes each to demonstrate their operation.

Figure 31. Hollow Cone Valve No. 2

Aspects Relating to Operational Efficiency

Control Room at Control Tower

The control room for dam operation is located at the control tower on the dam crest near the left abutment. The original control and monitoring equipment panel for the gated spillway and irrigation outlets was installed at the time of dam construction, but was never commissioned. Consequently, operation of any of the gates or valves has never been possible from the control room and the room does not appear to have been used as a control room.

The original water level monitor has been upgraded and the new readout unit fitted within the panel. There would be distinct operational advantages if the control and monitoring panel was commissioned and the control room renovated to provide adequate lighting and air-conditioning. However, as the gates and valves are operable from their respective local control panels, the completion of the control room to enable it to fulfil its intended purpose is not really a matter affecting the safety of Dokan Dam.

Bellmouth Spillway Plunge Pool

The operation of the gated spillway, as well as the bellmouth spillway, has formed two plunge pools in the river gorge downstream of the dam. These are several hundreds of metres downstream of the dam and therefore would not constitute a threat to the safety of the dam. In his report, Mr. Wermelinger stated that no evidence of instabilities could be found on the lateral river banks resulting from scouring action. Rock bars have been formed at the boundary of the pools. It is thought that the rock bar to the bellmouth spillway plunge pool may be of sufficient height to affect the tailwater level at the powerhouse.

It was not possible to check the elevation of this rock bar to draw an opinion on whether it does increase the tailwater level and reduce the net available head for power generation. If this is the case, then there would be an operational benefit for removing the rock bar, either fully or in part. However, in addition to restoring the tailwater levels at the powerhouse, such action would also reduce the plunge pool level below the bellmouth spillway exit. Reduction of the plunge pool level will decrease the depth of water available to cushion and absorb the energy of the spillway flows. This may cause further erosion of the plunge pool and lead to the development of instabilities in the river banks.
Accordingly, it is recommended that a survey is undertaken to determine whether the rock bar is of sufficient elevation to influence the tailwater level at the powerhouse. If so, the survey should be extended to include the plunge pool area, so that the effect of any changes to the rock bar and plunge pool level can be evaluated. The results of these studies should enable a decision on whether the plunge pool rock bar can be safely removed.

**Irrigation Outlet Butterfly Guard Valves**

The main purpose of the 2.5m butterfly guard valves is to provide a ready emergency closure facility for the irrigation conduits if the Hollow Cone Valves should develop a problem and/or fail to close. Accordingly, these valves are required to be capable of closing into the full discharge flow of the Hollow Cone Valves (i.e. 120m³/s).

The internal condition of these valves were found to be poor by the UNDP engineer in July 2000 and urgent complete rehabilitation or replacement of the valve disc, rubber seals and valve body internals was recommended to restore these valves to a reasonable working order. It was further recommended that the original valve supplier, Neyrpic, be contacted to advice on the scope and detail of the restoration work.

Although it is important for the operational effectiveness of these valves that this restoration work is undertaken as soon as possible, it is not considered essential in the specific interests of dam safety. This is because the worst scenario that could result from failure of both the Butterfly Guard Valve and Hollow Cone Valve on either of the irrigation outlets would be drawdown of the reservoir pool area until the upstream emergency gate could be lowered into position from the dam crest. Given the maximum discharge capacity of the Hollow Cone Valve is 120m³/s; the rate of drawdown would be in the order of 40mm/day, which would not cause an issue for dam safety.

**Water Supply Pipework**

A major concern of the Dam Directorate staff is the condition of the pipework and valves that extract water from the penstocks for water supply to Dokan town. Offtakes were originally installed to penstocks No.2 thru No.5 and the supply pipeline ran across the back of the toe of the dam. When the powerhouse was constructed in 1978, it was built over the top of the water supply pipe and valves. The offtake valves to penstocks No.2 and No.5 were accommodated within small valve pits, but access into and around the pipework in the pits is extremely limited. At penstocks No.3 and No.4, the offtake valves have been concreted in leaving only the operating spindles exposed. The offtakes feed a 300mm diameter main supply pipeline which is partly embedded before emerging in the gallery and underground pumping station located near the dam lift.

The current condition of the offtake valves is summarised in Table 19.

<table>
<thead>
<tr>
<th>Offtake from Penstock</th>
<th>Access to Valve</th>
<th>Valve Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.2</td>
<td>Located in small valve pit with limited access</td>
<td>Operable</td>
</tr>
<tr>
<td>No.3</td>
<td>Embedded – only operating spindle exposed</td>
<td>Operable</td>
</tr>
<tr>
<td>No.4</td>
<td>Embedded – only operating spindle exposed</td>
<td>Can only be opened by force – currently kept closed</td>
</tr>
<tr>
<td>No.5</td>
<td>Located in small valve pit with limited access</td>
<td>Inoperable – reported to be jammed closed</td>
</tr>
</tbody>
</table>

In 1999, the 300mm main supply pipe was reported to have been leaking within the concrete near the pipe bends before emerging in the gallery. The leakage water was running out along an adjacent pipe duct carrying a large (50mm dia) electrical cable leading to the irrigation outlet valves. Pipe pits at the generator floor level needed regular

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15 Ignores any other releases of water from, and any inflows to, the reservoir.
manual dewatering to control the leakage. The cable duct near the reported leakage point was concreted in at both ends and this appeared to temporarily stop the leakage. This issue continues to be a major concern for the Dam Directorate staff, as there is the potential that increased leakage and failure of the offtake valves to isolate the main supply pipe could cause flooding in the powerhouse. This is obviously a concern for the operation of the powerhouse and generation of hydro-electric power, but is not an issue affecting safety of the dam which is the mandate of this assignment.

It is suggested that detailed investigations be made to determine the condition of the existing pipework and valves using a remote closed circuit television camera system that can be introduced into the main supply pipeline. From the results of such an internal inspection, it should be able to determine whether the pipe can be economically renovated or needs to be replaced. Water companies in the UK have extensive experience of upgrading old pipework by applying an internal epoxy lining. A similar approach may be appropriate, if renovation is feasible.

It is noted that a UNDP letter on the subject dated 15 November 1999, comments that the capacity of the current water supply system is much greater than the apparent demand. The letter suggests that there is a need to re-evaluate the water supply arrangements and investigate whether there is a more economical way of delivering water to the hillside communities of Dokan town.

Maintenance Issues

Dam Lift

The Otis lift providing access from the dam crest on the left abutment down to the left bank grouting gallery and powerhouse is dated and not in good condition. Spare parts are required and these are not available locally. Consideration may be given to the complete replacement of the lift with a new one of local/regional manufacture. This may be an appropriate approach with respect to future maintenance and availability of spare parts.

Gated Spillway Stoplog Hoists

Whilst the hoists for the stoplogs are understood to be operable, they show signs of leaking oil and are in need of refurbishment.

Gated Spillway Building

Structural cracks in the spillway building noted in the 1987 Binnie report do not appear to have deteriorated, although it is recommended that these cracks continue to be monitored as part of the Dam Directorate’s routine inspection program.

Other Issues

Downstream Development

The town of Dokan downstream of the dam is under-going a phase of development and this has included a number of developments along the river banks. Whilst none of these developments pose a threat to dam safety, the encroachment of some of these developments on the river channel will be affecting the river morphology. Evidence of this was noticed on the right bank of river adjacent to the main highway bridge, where spoil had been dozed over the river bank to extend the property area for car parking by several metres.

The consequence of such action is that the river section is reduced and in times of flood, the level of the flood waters will be higher due to the restriction to flow caused by the encroachments. It is understood that the last flood event only just passed beneath the soffit of the bridge. Now that the river section has been reduced, a flood event of the same
magnitude may now flow over the bridge deck and potentially displace it from its abutments, or even wash it downstream.
It is suggested that this matter is raised with the appropriate authorities responsible for development in the town of Dokan, so that river course can be ‘protected’ against any encroachments that would impact the flood levels in the town.
Proposed Emergency Actions

Prioritisation of Required Actions

Throughout the proceeding sections of the report, there have been a number of recommendations made for studies or remedial works to be undertaken. The Preparatory Mission Aide Memoire defined the assignment task as ‘provide an update on critical dam safety issues’. It is with this in mind that the emphasis on issues affecting dam safety has been applied to prioritise the measures to be taken into the following categories:

(a) Emergency Actions: immediate/serious threat to dam safety and should to be implemented as soon as possible (i.e. within 2 months)
(b) Urgent Actions: pose threat the dam safety and should be implemented within the next 6 months
(c) Medium-Term Actions: implications for dam safety and the continued safe operation and monitoring of the dam. These actions should be implemented within next 18 months.
(d) Long-Term Actions: improvements for dam safety and safe operation and monitoring of the dam. The actions should be scheduled for implementation within the next 3 years.

The order of the actions listed within these categories follow the order of discussion in the text, rather than further prioritisation within each category.

Derbendikhan Dam

Emergency Actions Required in the Interests of Dam Safety

<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Remedial Works to Right Bank Slip Area</td>
<td>Reconstate-establish effective network of surface drainage, Cleaning of existing sub-horizontal drains, Continue monitoring of Slip Area</td>
</tr>
<tr>
<td>2</td>
<td>Analysis of Samples to Investigate Possible Piping Mechanism and/or Deterioration of Grout Curtain</td>
<td>Samples to be collected from Grouting Galleries and analysed at a reputable test laboratory facility</td>
</tr>
<tr>
<td>3</td>
<td>Personal Gas Detection Equipment</td>
<td>To enhance safe working conditions in the Dam Grouting Galleries – recommend provision of 2No. units</td>
</tr>
</tbody>
</table>

Urgent Actions Required in the Interests of Dam Safety

<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Undertake a comprehensive Dam Safety Review, including Risk Assessment</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Preparation of Emergency Action Plan</td>
<td>Included in proposed Terms of Reference for Comprehensive Dam Safety Review</td>
</tr>
<tr>
<td>3</td>
<td>Detailed Review of Dam Monitoring System</td>
<td>Included in proposed Terms of Reference for Comprehensive Dam Safety Review</td>
</tr>
</tbody>
</table>
### Medium-Term Actions Required

<table>
<thead>
<tr>
<th>Action Ref</th>
<th>Description</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Supply and install seismic accelerograph at Derbendikhan Dam</td>
<td>Technical Specifications previously prepared by Mr. Wermelinger (no copy available)</td>
</tr>
<tr>
<td>2</td>
<td>Reestablishment of appropriate dam instrumentation monitoring</td>
<td>To follow recommended design for instrumentation system determined by Urgent Action No.3.</td>
</tr>
<tr>
<td>3</td>
<td>Training for Dam Directorate Staff</td>
<td>Training to cover:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✡ Dam Safety Management System</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✡ Instrumentation &amp; Monitoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✡ Interpretation of Readings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✡ Dam Safety Emergency Plan</td>
</tr>
<tr>
<td>4</td>
<td>Improvement of ventilation in Grouting Galleries</td>
<td>Consideration of overseas training?</td>
</tr>
<tr>
<td>5</td>
<td>Survey Plunge Pool and Assess Impact of Rock Bar on Tailwater</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Levels</td>
<td></td>
</tr>
</tbody>
</table>
## Long-Term Actions Required

<table>
<thead>
<tr>
<th>Action Ref</th>
<th>Description</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Improved safe access to the Left Bank Grouting Gallery and safety handrails in Right Bank Grouting Gallery</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Investigate Leakage and Soil Deposits for hole in invert of Left Bank Grouting Gallery</td>
<td>Repair hole and make good after investigations</td>
</tr>
<tr>
<td>3</td>
<td>Remove Security Screen from in front of Spillway Gate No.3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Remove floating debris from spillway approach channel and upstream face of dam</td>
<td>Establish long-term procedures for regular clearance of floating debris – purchase/rehabilitation of new/existing floating barge</td>
</tr>
<tr>
<td>5</td>
<td>Remove rock bar, complete or in part, as necessary</td>
<td>Action dependent on results of survey</td>
</tr>
<tr>
<td>6</td>
<td>Install slope stabilisation measures below Right Bank Access Road</td>
<td>Suitably qualified Engineering Contractor to be engaged.</td>
</tr>
<tr>
<td>7</td>
<td>Clear accumulated rock fall material from behind gabion wall on Left Abutment</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Clear accumulated rock fall material from right wall of spillway chute</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Inspection of Spillway Gate bottom seals</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Inspection of Spillway Gate upstream face</td>
<td>Repair areas of damage to protective coating, as necessary</td>
</tr>
<tr>
<td>11</td>
<td>Clear blockage to Spillway Deflector Bucket drains</td>
<td></td>
</tr>
</tbody>
</table>
Dokan Dam

Emergency Actions Required in the Interests of Dam Safety

There are no required actions that are considered to fall under the Emergency Actions category.

Urgent Actions Required in the Interests of Dam Safety

<table>
<thead>
<tr>
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<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Undertake a comprehensive Dam Safety Review, including Risk Assessment</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Preparation of Emergency Action Plan</td>
<td>Included in proposed Terms of Reference for Comprehensive Dam Safety Review</td>
</tr>
<tr>
<td>3</td>
<td>Detailed Review of Dam Monitoring System</td>
<td>Included in proposed Terms of Reference for Comprehensive Dam Safety Review</td>
</tr>
<tr>
<td>4</td>
<td>Design of Remedial Measures for Bellmouth Spillway Leakage</td>
<td>Suitably qualified Engineering Company to be engaged.</td>
</tr>
<tr>
<td>5</td>
<td>Re-inspection of Steel Liners and</td>
<td>Included in proposed Terms of Reference for Comprehensive Dam Safety Review</td>
</tr>
</tbody>
</table>

Medium-Term Actions Required

<table>
<thead>
<tr>
<th>Action Ref</th>
<th>Description</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Supply and install seismic accelerograph at Dokan Dam site</td>
<td>Technical Specifications previously prepared by Mr. Wermelinger (no copy available)</td>
</tr>
<tr>
<td>2</td>
<td>Reestablishment of appropriate dam instrumentation monitoring system</td>
<td>To follow recommended design for instrumentation system determined by Urgent Action 3.</td>
</tr>
</tbody>
</table>
| 3          | Training for Dam Directorate Staff                                           | Training to cover:  
• Dam Safety Management System  
• Instrumentation & Monitoring  
• Interpretation of Readings  
• Dam Safety Emergency Plan  
Consideration of overseas training? |
<p>| 4          | Implementation of Remedial Measures for Bellmouth Spillway Leakage           | To follow design of remedial measures                                                |
| 5          | Installation of Ventilation system to South Drive of Right Bank Grouting Gallery |                                                                                        |
| 6          | Renovation of Irrigation Outlet Butterfly Guard Valves                        | Neypric to provide guidance on renovation                                            |</p>
<table>
<thead>
<tr>
<th>Action Ref</th>
<th>Description</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Investigative studies to confirm source of leakage in Irrigation Outlet</td>
<td>Suitably qualified Engineering Company to be engaged.</td>
</tr>
<tr>
<td></td>
<td>Inspection Adits and design remedial measures as appropriate</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Provision of safe access to Irrigation Outlet Inspection Adits, including</td>
<td></td>
</tr>
<tr>
<td></td>
<td>staging platforms</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Survey Bellmouth Spillway Plunge Pool and Assess Impact of Rock Bar on</td>
<td>Suitably qualified Engineering Company to be engaged.</td>
</tr>
<tr>
<td></td>
<td>Tailwater Levels</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Assess economics of renovation vs. complete replacement of Dam Access</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shaft Lift</td>
<td></td>
</tr>
</tbody>
</table>

**Long-Term Actions Required**

<table>
<thead>
<tr>
<th>Action Ref</th>
<th>Description</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Renovation of Control Room including commissioning of Control and Monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equipment Panel</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Remove rock bar, complete or in part, as necessary</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Investigate Leakage to Water Supply Pipework</td>
<td>Suitably qualified Engineering Company to be engaged.</td>
</tr>
<tr>
<td>4</td>
<td>Re-evaluate water supply arrangements and investigate possible economic</td>
<td>Suitably qualified Engineering Company to be engaged.</td>
</tr>
<tr>
<td></td>
<td>alternatives</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Refurbishment of Gated Spillway Stoplog Hoists</td>
<td></td>
</tr>
</tbody>
</table>
Dokan and Derbendikhan Emergency Hydropower Project Description

The objective of the Dokan and Derbendikhan Emergency Hydropower Project is to help alleviate the current power supply shortfall through urgent repair works, and prepare for the subsequent rehabilitation of the Dokan and Derbendikhan hydropower plants to restore their original capacity 400MW and 249MW respectively.

The proposed project components, as discussed and agreed with the KRG team\textsuperscript{16}, are:

**Repairs for Dokan (US$ 8.15 million)\textsuperscript{17}**

**Replacement of the excitation systems**

The equipment for this work was supplied by ABB (Italy) under the UN OFFP and is in storage at the site. ABB would be contracted to install, test and commission the systems, and provide training for operation and maintenance staff of the power plant.\textsuperscript{18}

**Spare parts for four compressors**

The equipment for this work was supplied by CompAir (France) under the OFFP and installed by Ministry staff. CompAir would be contracted to provide spare parts and to provide training for operation and maintenance staff.

**Repair of GIS for Unit No.1**

This will involve the repair of the GIS for Unit No.1 and the provision of training for operation and maintenance staff. The work will be carried out by Siemens who have already supplied the equipment.

**Completion of Installation of Synchronous Condenser**

The equipment was also supplied under the UN OFFP, by Technopromexport (Russia) and is on site. The same contractor would install, test and commission the synchronous condenser system, as well as provide training for operation and maintenance staff. The status of the existing contract is unclear, but this will be clarified during further preparation.

**Replacement of control systems**

This will involve the design, supply, installation and commissioning of a new control system at each of the power plants, as well as training for operation and maintenance staff. KRG will require the services of a consultant to assist with design and other pre-award activities, as well as in supervision of the work. Procurement will be through International Competitive Bidding (ICB) for Supply and Installation. This will be tendered as one contract together with the control system for Derbendikhan (0).

**Repairs for Derbendikhan (US$20.75 million)**

**Replacement of the excitation systems**

The equipment for this work was supplied by ABB (Italy) under the UN OFFP and is in storage at the site. ABB would be contracted to install, test and commission the systems, and provide training for operation and maintenance staff of the power plant.


\textsuperscript{17} Project cost estimates are indicative and are subject to further review.

\textsuperscript{18} (Note: For this and other contracts to be awarded on a sole-source basis, KRG should ensure that corresponding OFFP contracts which had a supply, installation and commissioning part are terminated, prior to award of a new contract for installation, testing and commissioning. This also applies to Sub-Component 2.1 for Derbendikhan).
Derbendikhan Switchyard

This will consist of replacement of 11kV vacuum switchgear, 33kV SF6 switchgear, metering, control and protection equipment for the 132kV GIS, a 63MVA, 132/33/11kV transformer, and 132kV cables between the GIS circuit breaker and the 132 kV gantries, and the provision of spare parts for the GIS switchgear. It will be procured through ICB for Supply and Installation.

Replacement of control systems

This will involve the design, supply, installation and commissioning of a new control system at each of the power plants, as well as training for operation and maintenance staff. KRG will require the services of a consultant to assist with design and other pre-award activities, as well as in supervision of the work. Procurement will be through International Competitive Bidding (ICB) for Supply and Installation. This will be tendered as one contract together with the control system for Dokan (0).

Dam Safety Emergency Repairs

To be further defined after visit of Dam Safety Expert (repair of landslide on embankment upstream of Derbendikhan Dam)

Assessment of Rehabilitation Needs, Environmental Assessment and Dam Safety and Engineering and Other Support (US$11.1 million)

Engineering Services

This will include:
(i) The provision of pre-contract award services for the emergency repairs;
(ii) Supervision of supply, installation and commissioning of the emergency activities;
(iii) Review and update previous assessments of rehabilitation needs carried out for the Dokan and Derbendikhan hydropower plants (including the cavitation problem for Derbendikhan), in order to extend their operational lives by at least 20 years;
(iv) Carry out hydrographic surveys to assess the current capacities of the two reservoirs; and
(v) Prepare designs and bid documents for the rehabilitation, which shall be implemented a separate project or under the current project if funds are available. Selection will be in accordance with the World Bank Guidelines for Selection of Consultants, using QCBS.

Environmental Impact Assessment

This will include a full Environmental Impact Assessment for the Dokan and Derbendikhan hydropower stations, including a complete assessment of the safety of the two dams. Selection will be in accordance with the World Bank Guidelines for Selection of Consultants

Other Urgent Repairs

This work could involve the repair of spillway and power intake gates, and instrumentation for monitoring the condition of the dams or other urgent repairs at the power stations identified as part of the assessment of rehabilitation needs. For example, at Derbendikhan, the work could comprise urgent repair to the main inlet valves and the generator cooling system. At Dokan, the work could comprise the replacement of spillway gate gauges, installation of an accelerometer to monitor seismic activity and provision of mechanical means of cleaning piezometers, drains, etc.
Support to the Project Management Team

Operating and travel costs of the PMT, excluding salaries, but including office equipment and fiduciary requirements such as audits and consultancy related to the Environment Management Plan.
Terms of Reference

REHABILITATION OF DERBANDIKHAN AND DOKAN HYDRO-ELECTRIC POWER STATIONS

Update of the Condition of the Derbendikhan and Dokan Dams

Terms of Reference

Background
The Derbendikhan dam is located on the Diyala River, whereas Dokan is on the Lesser Zab River. Both are in the Kurdistan Region of Iraq. The two dams store water used for two multi-purpose schemes, for irrigation and power supply.

The Government of Iraq has requested funding from the World Bank (through IDA) for emergency repairs of the two power plants. Part of the funding is earmarked for a full assessment of the condition of the two power plants, including the two dams, in preparation for complete rehabilitation.

Binnie and Partners assessed the condition of the dams and submitted several reports between 1999 and 2000, including a report on remedial works to the spillway. Other reports were prepared by: (i) Kurt Wermelinger, Dams Engineer of Colenco Power Engineering, on the condition, sedimentation and monitoring of both dams in 2000; and (ii) Coyne and Bellier, on the Derbendikhan spillage area.

Objective
The objective of the consultancy assignment is to update the earlier assessments and recommend works, if any, of an emergency nature, that should be financed out of the emergency credit.

Scope of Services
1. Review the previous reports on assessment of the conditions of Dokan and Derbendikhan dams and prepare an inception report, advising the Bank team the conditions that might need emergency attention. This part of the work should be conducted as a desk study (5 days).
2. Carry out a visual inspection of the two dams, update the previous assessments, and confirm the desk study findings. Thereafter, submit an updated report categorizing the repair/rehabilitation requirements into those needing immediate attention (with cost estimates) and those that could be delayed, providing the relevant justification for each category. Also recommend the necessary follow-up work and estimated costs for carrying out detailed investigations during the emergency project (5 days at site).

Reports Submission
1. A draft of the first (desk study) report should be submitted 4 days after commencement of the work, and the final report, two days after the receipt of comments from the World Bank.
2. A draft of the final report should be submitted 4 days after completion of the site visit, and the final report, two days after receipt of comments from the World Bank.

Timing and Payment Schedule
The assignment will commence on or about May 15, 2005 and will be for a period of 17 man-days, including a trip to Derbendikhan and Dokan dams. An advance of 10% of the total amount will be paid on contract signature; 25% on submission of the final first report and 65% on submission of the final report, following the site visit.
Available Reports and Documents

Derbendikhan Dam

The following documents are held at the Dam Directorate Office in Derbendikhan and were made available during the visit:

1. As Constructed Drawings, Derbendikhan Dam, Harza Engineering Company, October 1956
5. Derbendikhan Dam Main Remedial Works (Phase 1), Analysis of Dam Behaviour, Review of Previous Reports Recommendations, Coyne et Bellier, May 1975

It should be noted that this is not an exhaustive list of all the documents and reports held by the Dam Directorate.
Dokan Dam

The following documents are held at the Dam Directorate Office in Dokan and were made available during the visit:

1. As Constructed Drawings, Dokan Dam, Binnie, Deacon & Gourley, November 1959
3. Analysis and Safety Evaluation of Dokan Dam, Final Report, Volumes 1, 2a, 2b and 3, Binnie & Partners (Overseas) Ltd, August 1987
7. Inspection of Bellmouth Spillway Shaft and Tunnel – Photo Documentation, UNDP, July/August 2000
8. Inspection of Bellmouth Spillway Shaft and Tunnel – Video Footage on CD, UNDP, July/August 2000

It should be noted that this is not an exhaustive list of all the documents and reports held by the Dam Directorate.
Scope and State of Instrumentation

General

The dam instrumentation comprises the following monitoring installations:

- Two reservoir level indicator equipment (one for the dam operation and one for the operation of the power station);
- Survey reference points (benchmarks) forming a triangulation network;
- 23 survey measuring points installed along the dam grouting galleries;
- Observation points on the dam surface;
- Some 100 observation points along the spillway and on the intake structure;
- 10 standpipe piezometers in the Right Bank Grouting Gallery;
- 12 standpipe piezometers in the Left Bank Grouting Gallery;
- 2 measuring weirs installed at the bottom end of the two dam grouting galleries;
- 9 pore-pressure cells installed in the dam core near the spillway structure;
- Crack monitoring instruments (mechanical strain gauges and pocket driller)

Only some of the surface observation points at the crest and most of the piezometers are dating from the construction of the dam. All other installations were established or re-established later during the operation of the dam.

The current state of the equipment is documented in the following subsections. The monitoring installations for the Right Bank Slippage Area are covered by Part IV of Mr. Wermelinger’s 2000 Mission Report.

Reservoir Water Level Monitoring Equipment

A mechanical type of water level monitoring device is installed in the stilling shaft at the intake structure. The device is driven by a float and a synthetic tape. A mechanical reading unit is mounted on the device indicating the water level to 1 cm. Access for readings is via a manhole. The dam personnel reported that the equipment was installed during the construction of the dam.

A second measuring device was established for the control system of the new power station. The equipment is installed in the same shaft and consists of two electrical pressure sensors and a reading unit mounted in the access chamber of the stilling shaft. The device is connected to the control room of the powerhouse. However, the transmitter is reported to be out of order and the protective equipment missing.

The arrangement of the stilling shaft is given in Appendix 111-3.1 of Mr. Wermelinger’s Report and copies of the drawings from the electrical level indicators are included in Appendices 111-3.2 and 111-3.3 of the same report.

A staff gauge is located on the upstream face of the dam, alongside the spillway/intake structure.

Survey Reference Points and Triangulation Network

A complex survey network was established covering an area from approx. 600 m upstream of the dam to approx. 1 km downstream of the dam. The time of the installation is unknown. However, some of the reference monuments must have been established during the dam construction.

Nine check surveys of the triangulation network, carried out by an international company, were documented\(^\text{19}\). The last of these checks took place in 1983. Further, calculation print-outs of check surveys, prepared by the Organisation of Survey (Iraq

\(^{19}\) Derbendikhan Dam – Dam Deformation Measurements, Final Report, Polservice, May 1983

Government Agency), are also available at the Dam Project Office. It is understood that the last check of the net took place recently in 2005, but the readings are still to be evaluated. It was reported that there are some concerns regarding the reliability of some reference monuments being taken as the reference baseline and it is understood that the baseline has been changed recently. There is the need for the survey results to be reviewed and correlation to a common baseline to enable trends to be identified and monitored. The detailed inspection report on the triangulation network and a location map prepared by Mr. Wermelinger may be found in Appendices 111-3.4 and 111-3.5 of his 2000 Mission Report.

Survey Measuring Points along the Dam Galleries

Optical alignments with reference points on concrete monuments are established in both dam galleries (in 1979?). These alignments allow for monitoring displacements by the method of triangulation. Connecting sightlines to the triangulation net are also established. All survey monuments are in good condition. The centring plates are safely secured and protected by steel covers.

Measurements were taken by an international survey team and by a team of the State Organisation of Survey during several survey campaigns (see Section 0).

Reports of several survey campaigns are available at the Dam Project Office.

Observation Points on the Dam Surface

Measuring points were established on the dam surface to monitor displacements of the dam. In particular the rate and the range of settlements are of interest. Thus, these points are also known as settlement gauges. However, spatial displacements of these points can and should be measured.

Reference points were provided on the upstream shoulder, along the dam crest, and on the downstream shoulder in 1979. Many of the points were destroyed during maintenance works since then. In fact, the crest points A to F are only dating from the construction of the dam. The other existing points were reinstated in the last years. These include the crest points H to M and the points 23, 24, 25, and 30 at the downstream shoulder of the dam.

The location of the dam crest points can be given with the stationing of the dam chainage:

<table>
<thead>
<tr>
<th>Point</th>
<th>Dam Chainage</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>616.7 m</td>
<td>Original point from dam construction.</td>
</tr>
<tr>
<td>B</td>
<td>566.6 m</td>
<td>Original point from dam construction.</td>
</tr>
<tr>
<td>C</td>
<td>516.6 m</td>
<td>Original point from dam construction.</td>
</tr>
<tr>
<td>D</td>
<td>466.7 m</td>
<td>Original point from dam construction.</td>
</tr>
<tr>
<td>E</td>
<td>417.0 m</td>
<td>Original point from dam construction.</td>
</tr>
<tr>
<td>F</td>
<td>367.0 m</td>
<td>Original point from dam construction.</td>
</tr>
<tr>
<td>G</td>
<td>Approx. 317 m</td>
<td>Point reinstalled.</td>
</tr>
<tr>
<td>H</td>
<td>Approx. 267 m</td>
<td>Point reinstalled.</td>
</tr>
<tr>
<td>I</td>
<td>Approx. 255.4m</td>
<td>New point.</td>
</tr>
<tr>
<td>J</td>
<td>Approx. 244.4m</td>
<td>New point.</td>
</tr>
<tr>
<td>K</td>
<td>Aoorox-239.4m</td>
<td>New point.</td>
</tr>
<tr>
<td>L</td>
<td>Approx. 236.4 m</td>
<td>New point.</td>
</tr>
<tr>
<td>M</td>
<td>Approx. 235.4 m</td>
<td>New point.</td>
</tr>
</tbody>
</table>

Dam chainage of the points A to F are taken from the 1987 Binnie Report; dam chainage from other points are calculated according to information received from the Dam Project Office.

An inspection report of the survey monuments prepared by Mr. Wermelinger is given in Appendix 111-3.6 of his 2000 Mission Report.
Observation Points for the Concrete Structures

Some 100 observation points are established on the concrete structures of the spillway and the intake tower. A few points are also installed on the ground in close vicinity of these structures. The reference points allows for monitoring any displacement of the structures by optical survey method. No specific inspection on these reference points was carried out. However, the Dam Personnel will check the points and provide an inventory of these reference points.

Several survey measurements were carried out by an international survey team and by a team of the State Organization of Survey. Some report and print-outs of the results are available at the Dam Project Office (see Section 0).

Piezometers in the Dam Galleries

Standpipe piezometers are provided in the left and the right bank grout galleries located at the base of the central clay core. The piezometers extend to various depths into the bedrock. The horizontal spacing between the piezometer pipes is approximately 10m. Most of the pipes are permanently equipped with Bourdon gauges. Pressure readings from the others are taken by installing temporarily a gauge. Valves and drain outlets are provided for all pipes.

The following table lists the information of piezometers installed in the dam grouting galleries as provided by the Dam Project Office:

**TABLE 20. PIEZOMETERS IN THE DAM GALLERIES**

<table>
<thead>
<tr>
<th>PZ ID</th>
<th>Top Elevation</th>
<th>Inclination</th>
<th>Depth</th>
<th>Bottom Elevation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sta</td>
<td>?</td>
<td>?</td>
<td>28 m</td>
<td>?</td>
<td>Not in use</td>
</tr>
<tr>
<td>Sta 242</td>
<td>425.50 m</td>
<td>30° d/s</td>
<td>50 m</td>
<td>375.50 m</td>
<td>No pressure</td>
</tr>
<tr>
<td>Sta 260</td>
<td>410.30 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>400.30 m</td>
<td>No pressure</td>
</tr>
<tr>
<td>Sta 280</td>
<td>394.20 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>384.20 m</td>
<td></td>
</tr>
<tr>
<td>Sta 295</td>
<td>382.00 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>372.00 m</td>
<td></td>
</tr>
<tr>
<td>Sta 310</td>
<td>373.00 m</td>
<td>30° d/s</td>
<td>50 m</td>
<td>323.00 m</td>
<td>Leakage of surface seal</td>
</tr>
<tr>
<td>Sta 323</td>
<td>365.80 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>355.80 m</td>
<td></td>
</tr>
<tr>
<td>Sta 328</td>
<td>366.60 m</td>
<td>30° d/s</td>
<td>60 m</td>
<td>306.60 m</td>
<td>Grouted</td>
</tr>
<tr>
<td>Sta 340</td>
<td>365.95 m</td>
<td>30° d/s</td>
<td>25 m</td>
<td>340.95 m</td>
<td></td>
</tr>
<tr>
<td>Sta 341</td>
<td>366.50 m</td>
<td>30° d/s</td>
<td>5 m</td>
<td>361.50 m</td>
<td>Grouted</td>
</tr>
<tr>
<td>Sta 342</td>
<td>365.00 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>355.00 m</td>
<td>Grouted</td>
</tr>
<tr>
<td>Sta 420</td>
<td>373.85 m</td>
<td>30° d/s</td>
<td>25 m</td>
<td>348.85 m</td>
<td></td>
</tr>
<tr>
<td>Sta 440</td>
<td>379.88 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>369.88 m</td>
<td></td>
</tr>
<tr>
<td>Sta 460</td>
<td>386.42 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>376.42 m</td>
<td></td>
</tr>
<tr>
<td>Sta 480</td>
<td>391.71 m</td>
<td>30° d/s</td>
<td>50 m</td>
<td>341.71 m</td>
<td></td>
</tr>
<tr>
<td>Sta 500</td>
<td>397.37 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>387.37 m</td>
<td></td>
</tr>
<tr>
<td>Sta 520</td>
<td>405.82 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>495.82 m</td>
<td></td>
</tr>
<tr>
<td>Sta 540</td>
<td>418.63 m</td>
<td>30° d/s</td>
<td>25 m</td>
<td>393.63 m</td>
<td></td>
</tr>
<tr>
<td>Sta 560</td>
<td>428.24 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>418.24 m</td>
<td></td>
</tr>
<tr>
<td>Sta 580</td>
<td>436.84 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>426.84 m</td>
<td></td>
</tr>
<tr>
<td>Sta 600</td>
<td>445.86 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>435.86 m</td>
<td></td>
</tr>
<tr>
<td>Sta 620</td>
<td>455.45 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>445.45 m</td>
<td>Leakage of surface seal</td>
</tr>
<tr>
<td>Sta 640</td>
<td>465.66 m</td>
<td>30° d/s</td>
<td>10 m</td>
<td>455.66 m</td>
<td></td>
</tr>
</tbody>
</table>
The piezometers were inspected in 1980 and it was concluded to replace all of them\(^{20}\). However, these works had not been started before the contractor left the site in October 1980.

### Seepage

Seepage flows in the dam galleries are measured regularly. A small weir is arranged at the bottom of each gallery to collect the water and to allow for measuring the flows by a measuring container.

### Pore-Pressure Cells

Since the construction, the dam crest has settled in the contact zone with the spillway structure. A report of the commission of experts from 1973 indicates settlement of 1.08m\(^ {21}\). A further report of experts from December 1976 concluded that the settlements resulted from the consolidation process of the core material in that zone. An investigation program consisted of the drillings of 8 boreholes and installation of 9 pressure-cell piezometers in the dam core. Reinstatement of the dam core, the filters and the dam crest was undertaken in 1980. The above mentioned expert’s report from 1976 further concluded that there is no danger for safety of the dam and that further treatment appears unnecessary\(^ {22}\).

The pressure cells were read from November 1976 until January 1978 and from January 1980 until May 1981. During Binnie & Partner’s dam safety inspection of 1987, the readings confirmed satisfactory behaviour of the dam core. It was recommended to continue with the readings at monthly intervals\(^ {23}\).

Presently four of the nine piezometers originally installed are still working and readings are still taken. The following table summarises the information available from the pore-pressure cells:

<table>
<thead>
<tr>
<th>Pressure Cell ID</th>
<th>Elevation</th>
<th>Status / Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>462.70m</td>
<td>In operation</td>
</tr>
<tr>
<td>B2</td>
<td>465.20m</td>
<td>Out of order; last readings from 1981.</td>
</tr>
<tr>
<td>B3</td>
<td>440.70m</td>
<td>Out of order; last readings from April 1996.</td>
</tr>
<tr>
<td>B4</td>
<td>450.30m</td>
<td>Out of order; last readings from Dec. 1997.</td>
</tr>
<tr>
<td>B5</td>
<td>440.70m</td>
<td>Out of order; last readings from Aug. 1986.</td>
</tr>
<tr>
<td>B6</td>
<td>476.00m</td>
<td>Out of order; last readings from Jan. 1991.</td>
</tr>
<tr>
<td>B7</td>
<td>464.00m</td>
<td>In operation</td>
</tr>
<tr>
<td>B8</td>
<td>454.10m</td>
<td>In operation</td>
</tr>
<tr>
<td>B9</td>
<td>473.40m</td>
<td>In operation</td>
</tr>
</tbody>
</table>

The location of the pressure cells in a plan view is provided in Plate 1 of the 1978 Coyne et Bellier Design Report. The readings, taken from the Dam Personnel, need to be converted to differential pressure.

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\(^{20}\) Derbendikhan Dam Main Remedial Works (Phase 4), Interim Report about Works Performed between October 1979 and October 1980, Volume 1, Coyne et Bellier, February 1983  
\(^{21}\) Derbendikhan Dam Main Remedial Works (Phase 1), Analysis of Dam Behaviour, Review of Previous Reports Recommendations, Section C, Coyne et Bellier, May 1975  
\(^{22}\) Derbendikhan Dam Main Remedial Works (Phase 3), Design Report, Coyne et Bellier, August 1978  
\(^{23}\) Analysis and Safety Evaluation of Derbendikhan Dam, Final Report, Volumes 1, 2 and 3, Binnie & Partners (Overseas) Ltd, August 1987
Rehabilitation

General

A basic dam monitoring system was in operation from 1979 to 1983 consisting of a triangulation network, survey reference points on the dam body and in the dam galleries, as well as piezometers installed in the dam galleries. Regular readings were taken. The data were evaluated to a limited extent only. A few of such information is available only. This monitoring system, after its reinstatement, provides appropriate data to assess in general the state of the structural integrity and safety of the dam. Better measurement techniques are now available and experience in dam engineering was grown in the meantime. Thus, the monitoring system dating from the 70's may require an extension of the instrumentation to comply with dam engineering standards from today. However, priority shall be given to the rehabilitation of the existing instrumentation. The following sub-chapters provide the requirements for the rehabilitation of the dam monitoring system. Additionally, design concept and specifications for supply and installation of seismic instruments to be installed at the dam site are included. These instruments are considered as a replacement for the seismograph, which was installed before in Sulaimaniyah. But, the seismic instruments provide also essential information of the effective input motion on the dam and its response to an earthquake. Further comments on possible upgrading of the dam monitoring system are given in Section 0.

Reservoir-Water Level Monitoring Equipment

The reservoir water level is one of the main loads acting on a dam. Also seepage rates depend essentially on the reservoir water level. Therefore, regular and accurate readings of the reservoir water level and its presentation provides necessary information for evaluation and interpretation of most of the monitoring data. Because of the importance of these readings, redundancy is absolutely necessary. The mechanical float device installed at Derbendikhan Dam is a simple and reliable instrument. It needs to be checked regularly by using, for instance, a dip meter. The Dam Project Office is requesting to replace the instrument by a modern type including a remote reading unit at the new dam site office. The other measuring device, installed by the Power Generation Directorate, can provide, if repaired, the reading signal to a remote indicator. The combination of both of these instruments is an optimal arrangement for cross checking the readings. The installation of a third item of equipment for the same purpose appears to be excessive. It is recommended to repair the electrical water level recorder and to provide the reading to powerhouse as well as to the Dam Directorate's office.

Survey Measuring Points along the Dam Galleries

Displacements of the dam grouting galleries are monitored by determination of the spatial coordinates of the measuring points established inside the galleries. Any displacement of the galleries suggests also a movement of the dam foundation and of the dam. The measuring is based on the principle of triangulation. Connecting sightlines to the triangulation network are essential to determine the absolute displacement of the control points. As mentioned in Section 0, all reference monuments are in good condition. The very precise and redundant observations as well as the evaluation using special computer programmes must be carried out by a well experienced International Surveyor Engineer. The survey campaign for the check of the triangulation network shall also include these survey works.
Observation Points on the Dam Surface

Measuring points were established on the dam surface to monitor displacements of the dam. Dam deformations are mainly caused by the reservoir water level and the self-weight of the fill of the dam. Earth pressure at the foundation and/or the conditions at the foundation respectively may also be a decisive factor. Mainly permanent deformations are expected for an embankment dam. The analyses of the rate of the displacements and their total amount permits to monitor the behaviour of the dam.

Spatial displacements of the points are measured by optical alignments and levelling. Redundancy in combination with the triangulation net is absolutely necessary.

Sufficient reference points have been established along the crest of Derbendikhan Dam (points A to M). However, new points on the upstream shoulder of the dam and additional points on the downstream shoulder are required to complete the net of points necessary to cover the dam sufficiently. The location of the additional points is given in Appendix 111-4.1 of Mr. Wermelinger’s Report. Appendix 111-4.2 of the same report provides the design for the monuments prepared by Mr. Wermelinger.

The Dam Personnel should survey the reference points at the dam surface at least twice a year. The survey equipment necessary for this work is listed in Appendix 111-4.3 of Mr. Wermelinger’s Report and is based on the following survey requirements for Derbendikhan Dam:

- Accuracy of survey results in Hz and V: +/- 3 mm
- Accuracy of level survey: less than +/- 1 mm

The absolute displacements of the observation points shall be determined by the International Survey Engineer to be engaged for checking the triangulation network.

Observation Points for the Concrete Structures

Reference points were established on the concrete structure and their vicinity to monitor any movement and settlement of these structures. The relevance of these observations could not be assessed based on the information available. A further review during the proposed comprehensive Dam Safety Review shall clarify whether or not these observations are necessary.

Piezometers in the Dam Galleries

A few readings from the piezometers installed at the two dam galleries have been made available in MS-Excel format. The review of those and discussions with the Dam Office Personnel indicate that a detail review of all data and a further detailed inspection of the piezometer pipes are necessary.

The reported leakage of surface seals of some of the piezometer pipes shall be checked. The piezometers at Sta 242 and Sta 260 have no pressure at the gauges, since years. The possibility to remove the covers of these pipes shall be studied to allow for watertable monitoring by dip meter.

Piezometer readings shall be taken regularly, once a month.

Seepage

Seepage flows in the dam galleries shall be regularly measured once a month. Records and graphs shall be prepared in the same MS-Excel format as prepared for the V-notch weirs measurement at Dokan Dam.

Pore-Pressure Cells

In 1975, 9 pore-pressure cells were installed in the dam core to monitor the development of the pore pressure at various locations. 4 of these cells are still working and readings are taken from the Dam Personnel.
It is recommended to continue with the readings. Further, the readings shall be converted in pressures and examined whether or not the instruments provide reasonable data. The Expert Report of December 1976 concludes that no remedial treatment of the dam core is necessary. Thus, replacement of the broken pore-pressure cells is not considered necessary so far no new requirement demands for further observation.

Seismic Instruments

Strong motion instrumentation shall be installed at the dam allowing for the comparison of the dam behaviour during an earthquake with the one predicted for the design, and for the prediction of its behaviour during future earthquakes. It can also guide the search for possible damages and support the establishment of rehabilitation measures. Accelerographs placed at the dam and in its immediate vicinity address the observational needs, which are:

- Earthquake response of foundation-structure interaction considering canyon effects, kinematic interaction, incoherent excitation, and internal interaction.
- Dynamics responses and characteristic of dams.

The needs lead to an array configuration of tree-component accelerometers to be installed at the dam site. The arrangement of the instrumentation array depends on the type of the dam and the instrumentation objectives. For Derbendikhan Dam, the instrumentation objectives include:

- The observation of the free-field motion at the dam site;
- The observation of the effective input motion at the dam;
- The observation of the response of the dam;
- The installation of an earthquake warning system.

The resulting instrumentation scheme consists of total 5 accelerometers: 3 instruments installed at the dam crest (one approximately at highest dam section, one at each dam abutment), another instrument installed in the dam gallery, and one free-field instrument installed far enough away from the dam and the appurtenant structures as the readings are not affected by their presence and vibrations. The accelerometers are interconnected to a local strong motion network, which permits to co-ordinate and to monitor the function of the independent base units. Data recording, data evaluation and electronic data supply shall be supported by a personal computer system including a printer. It is foreseen that the system operates autonomous. Data collection shall take place once a year, considering normal circumstances.

The system shall comply with present international standards. This includes that the system permits to be upgraded with modern communication devices, if required in the future. Technical specifications were prepared by Mr. Wermelinger for a Supply & Installation Contract during the 2000 Mission.

Upgrading

The structural safety evaluation of an embankment dam founded on bedrock is mainly determined by the periodic comparison of the analytical data with the measurement records of displacements, pore pressures and seepage flows. At Derbendikhan Dam, the dam monitoring installations, after its rehabilitation and reinstatement, is based on the instrumentation layout established in 1979 or earlier. This layout does not fully comply with present international standards for the type and size of the dam. The following deficiencies on dam monitoring can be identified:

- Uplift gradient;
- Seepage force;
- Water temperature.

The possible extension of the instrumentation may comprise the following:

(a) Monitoring of uplift below spillway structure: Piezometers (pore-pressure cells) in drillings for measuring the water pressure.
(b) Monitoring the seepage forces: Piezometers (pore-pressure cells) in drillings for measuring the water pressure in the dam core and in the foundation of the dam. These would allow flow nets through the dam and through the foundation to be established.

A detailed study is required which shall provide the required extension of instrumentation for Derbendikhan Dam. It is recommended to engage a competent Engineering Company for this study, preferably as part of the comprehensive Dam Safety Review.

**Training and Transfer of Knowledge**

Training and transfer of knowledge regarding dam safety was provided to the Dam Office Personnel during Mr. Wermelinger’s site visits in 2000. Particular efforts were made for reviewing the process of reading, checking and recording the dam monitoring data available. At the Dam Project Office, spreadsheet formats (MS-Excel) were set up for recording and plotting the following data:

- The hydrological data;
- The all piezometer readings;

The Dam Office Personnel shall enter all collected data into the spreadsheets and prepare printed-outs. These allow for immediate plausibility checks and will also permit to export the data to other computer programs, which may be used for dam safety evaluation in the future. A training needs assessment is required to maximise the benefit of any future training programs. A particular focus that would warrant consideration is training to provide the Dam Office Personnel with a greater understanding in the interpretation of the monitoring results and under what conditions is it necessary to take corrective action?
Dam Monitoring Instrumentation at Dokan Dam

Scope and State of Instrumentation

General

The dam instrumentation was rehabilitated in 1986/87, but was properly in operation a few years only. During the recent time of political disorders, monitoring equipment was removed from the site or has been damaged. Since 1989, water levels and seepage flows could be measured only.

After completion of the rehabilitation in 1987, the dam instrumentation comprised the following measuring installations:

- One reservoir level indicator and one staff level;
- 3 Plumb-lines (plumbbobs) with micrometer microscopes;
- Survey reference points (benchmarks) forming a triangulation network;
- 12 survey target points fixed to the downstream face of the dam at crest elevation;
- Survey instruments including a Wild T2000 theodolite and a Wild D15 distomat;
- 10 standpipe piezometers at the downstream toe of the dam;
- 7 piezometers installed from the surface at the left dam abutment and 3 sets of 2 piezometers installed in the Left Bank Grouting Gallery;
- 4 Sets of 2 piezometers installed in the Right Bank Grouting Gallery;
- Series of V-notch measuring weirs in both abutment galleries and at the left tailrace river bank;
- Crack monitoring instruments (Demec gauge and pocket microscope);

The current state of the equipment is documented in the following subsections.

The original scope of the instrumentation, as outlined in the as-built drawings of the original project, is listed in the Swiss Consultant’s 1981 report. The dam instrumentation at this time also included 258 strain gauges, 825 thermometers and 13 pore-pressure gauges (all vibrating-wire type).

Reservoir Level Monitoring Equipment

A mechanical type of reservoir water level monitoring device is installed above a stilling shaft located in Block 4 of the dam. The device is driven by a float hanging on a steel chain. It is reported in the 1998 Binnie Report, that the equipment was repaired in 1986. The installation included at this time a water level chart recorder located at the control room of the dam’s control tower. The chart recorder indicated the reservoir water level to an accuracy of about 0.5m.

Presently, the reservoir water level is monitored by a pressure sensor installed in the existing stilling shaft with a read out unit located in the Dam Control Room.

A staff gauge is installed at the upstream face of the dam at the left abutment. The staff is in good condition. Readings from elevation 486m up to the crest elevation are possible.

Plumb-Lines (Plumbbobs)

Four plumb-lines (hanging pendulum) were installed during the construction of the dam at the following locations:

- In the lift shaft at the left abutment reaching into the bedrock (2 plumb-lines);
- In Block 7 close to the highest part of the dam;
- In Block 13 partly through the right abutment reaching into the bedrock.

In 1986, all plumb lines were replaced by new ones at the same locations. The line in the lift shaft is equipped with two measuring points at elevation approx. 465m and at
elevation approx. 426 m (in the lift pit). The line in Block 7 can be read from the dam
gallery at elevation approx. 407 m (invert of the gallery). The line in Block 13 is accessible
via the Right Bank Grouting Gallery. The measurement point is at elevation approx. 451 m
(invert of the gallery). The plumb-lines were supplied by Soil Instruments Limited,
Uckfield, East Sussex-UK.
The existing parts of the equipment are in operational conditions and could be further used.
The portable Microscope Measuring Units were removed from the site. Dripping water
running down the wire shafts is pushing out the oil from the oil tanks, which are installed
at the bottom of the lines. Further, dripping water produces deposits on the measuring
frames, in particular at the plumb-line in Block 13.
No instruments for measuring deformations of the dam foundation (rockmeters, inverted
plumb-line etc.) were installed.

Survey Reference Points and Triangulation Network
A complex survey network was established for dam construction including some 40
reference monuments. All monuments are located in the downstream area of the dam. The
network was re-surveyed in 1986 using a Wild T2000 theodolite and a Wild D15 distomat.
According to the 1987 Binnie Report, no appreciable movements within the network were
detected since it was first established. Also during 1986, two new monuments A and B
were established for measuring the movements of the dam crest. The layout of the network
is given in Appendix 11-3.2 of Mr. Wermelinger’s 2000 Mission Report.

Dam Survey Target Points
In 1986, 12 survey targets were installed to the downstream face of the dam for measuring
the movements of the dam crest. Two survey monuments (named "A" and 'B") were
additionaly established at the abutments as reference datum for the observations of the
target points. One Wild T2000 theodolite with a Wild D15 distomat was provided to the
Dam Project Office.
The target plates on the dam face are not visible by eye from downstream of the dam.
However, it was reported that these plates are still in place.

Seepage Monitoring (Piezometers and V-Notch Weirs)
Uplift pressures under the dam are measured in 10 vertical piezometer pipes installed at the
toe platform (el. 418.50 m) of the arch dam. Further, pressure relief holes are installed in
the dam gallery (spacing approx. 3 m), which control the uplift pressure underneath the
dam. According to drawings, the holes are inclined 25° towards the downstream side and
extend to a depth of 5 m into the bedrock. The holes are regularly flushed by the Dam
Personnel every 2 years. During an inspection, the drain holes showed few discharge flow.
The total leakage from the pressure relief holes is not measured, but shall be recorded
every month. The Dam Personnel confirmed that this is possible by recording the discharge
of the dewatering pump installed in the access gallery.
The effectiveness of the grout curtains along the left and the right abutment is controlled
by series of piezometers installed from the surface at the left abutment as well as installed
in the left bank and the right bank grouting galleries. Only one of the piezometers is
permanently equipped with a Bourdon gauge. The pressure in the others is measured by
installing a gauge temporarily. The water table in some piezometers, in particular in the
right bank gallery, is measured by electrical dipmeter.
Further Bourdon gauges are available in the Dam Project Office: 5 gauges with pressure
range up to 10 bar and 3 gauges with pressure range up to 6 bar. All gauges are equipped
with one part of a quick-release connection piece. However, only one counterpart piece of
the connection system is available which is not satisfactory.
The seepage flows in both abutment galleries and the discharges of three springs on the left
tailrace river bank are measured by V-notch weirs. The three weirs at the river bank are
full of sediments and no access is available to the locations. The overflow plates of the
weirs installed in the galleries are corroded. Appendices 11-3.4 to 11-3.6 indicate the location of the piezometers and of the V-notch weirs. Appendix 11-3.7 provides detailed information of the piezometers.

A special feature is a fan of 9 drain holes installed in the Left Bank Access Drive close to the lift shaft. Drainage water form these holes is directly conveyed to the V-notch weir V2. No specific report could be found dealing with these drain holes. However, it can be assumed that the holes drain the boundary fault complex in close vicinity of the left dam abutment.

Regular readings are taken from all piezometers and from those measuring weirs which are in operational conditions.

Rehabilitation

General

The dam monitoring system, in place since its rehabilitation in 1986, was considered appropriate for Dokan Dam at that time. The instrumentation provides, after its rehabilitation, base data to assess the state of the structural integrity and safety of the dam in general. However, experience in dam engineering was grown in the meantime and better measurement techniques are now available. No evidence could be found which would require immediate upgrading of the installations.

The following Sub-chapters provide the requirements for the rehabilitation of the existing dam monitoring system. Additionally, design concept and specifications for supply and installation of seismic instruments to be installed at the dam site are included. These instruments are considered as a replacement for the seismograph, which was installed before in Sulaimaniyah. But, the seismic instruments also provide essential information of the effective input motion on the dam and its response to an earthquake.

Further comments on possible upgrading of the dam monitoring system are given in Section 0.

Reservoir Water Level Monitoring Equipment

The reservoir water level is the main load acting on a dam. Deflections of the dam can be directly correlated to the water load. Also seepage rates depend on the reservoir water level. Therefore, regular and accurate readings of the reservoir water level and its presentation provides essential information for the evaluation and interpretation of most of the monitoring data. Because of the importance of these readings, redundancy is absolutely necessary.

The mechanical float device installed at Dokan Dam is out of order since 1991 or longer. The 1987 Binnie Report noted that the recorder chart, repaired in 1986, indicated the reservoir water level to an accuracy of about 0.5m, which is insufficient accurate for any detailed hydrological analysis.

The current pressure sensor installed in the existing stilling shaft is performing satisfactorily, but needs to be supplemented with a water temperature device.

The temperature instrument should comply with the following requirements:

- Measuring range of water temperature: 0°C to 35°C
- Accuracy: +/- 0.1°C

Plumb-Lines (Plumbbobs)

The installed hanging plumb-lines allows for monitoring elastic and plastic deformations by measuring the deflection in two orthogonal directions. This type of measuring device is well proven over many years. It is a simple and accurate measurement which is practically irreplaceable for the periodic recording of deflections of an arch dam.

The fixed parts of the plumb-lines installed at Dokan Dam are in operational condition. The reading units, however, are missing. The supplier of the plumb-lines was contacted to
inquire whether the missing parts are still available. But, the hanging pendulum design from the supplier has changed since the supply in 1987 and the portable microscopes have been superseded by an optical-direct reading unit. Thus, the remaining parts of the existing plumb-lines cannot be used anymore. Complete new plumb-lines were required to be installed.

Technical specifications have been prepared for supply and installation of a new Hanging Pendulum System during the 2000 UNDP Mission. The specifications can be summarised as follows:

- 3 hanging plumb-lines shall be installed at the existing location in the lift shaft, in Block 7 and in Block 13;
- Reading points shall be established at the existing locations;
- Reading of the deflections by Optical-digital Direct Units is foreseen;
- The installations shall be designed to minimise severe affections of dripping water running down the wire shafts;
- The new system shall allow for future upgrading with inverted pendulums and automatic reading units with minimal replacement of the installed parts of the plumb-lines.

The plumb-lines described above have now been installed and measurements are being taken on a monthly basis.

Survey Reference Points and Triangulation Network

Survey reference points (reference datum) forming a triangulation network is required to assess absolute displacements of the control points at the dam site. The survey reference points must be located outside of the dam and the region that may be affected by the impact of the dam or the reservoir. These fixed points are, moreover, essential to identify behavioural trends in the surroundings of the dam. Monitoring dam deformations requires a spatial, i.e. three-dimensional measuring installation.

The measuring method is based on the principal of triangulation to define the coordinates of the points. The very accurate measurements require to be carried out by specialised personnel using precision theodolite and distomat and very redundant observations. Further, the evaluation of the survey readings is, these days, done by using computer programmes. The network and its points shall be periodically checked e.g. every 5 years or in case of unusual events e.g. after a strong earthquake.

The check of the triangulation network by an International Survey Engineer / Engineering Company with extensive experience for such work is now required. The Dam Project Office shall rehabilitate all the survey monuments forming part of the network before the check survey.

Dam Survey Target Points

Spatial deformations of the dam at crest elevation are monitored by surveying 12 target plates installed at the dam face. Two reference monuments "A" and "B" were established at the abutments of the dam to take the observations. This measuring system permits, in combination with the triangulation network, to convert relative deformations, measured by the crest target plates as well as the plumb lines, to absolute deformations. Periodical checks of the reference datum by triangulation are required (see Section 0 above).

The precise survey of the target points requires suitable survey instruments. In 1986, one Wild T2000 theodolite with a Wild D15 distomat was provided to the Dam Office and readings were taken for a few years until the instruments were removed from the site. The survey requirements at Dokan Dam are:

- Accuracy of survey results in Hz and V: +/- 1 mm
- Accuracy of level survey: +/- 1 mm

The list of the necessary survey instruments are given in Appendix 11-4.1. The list was discussed and agreed with the Dam Personnel. Although theodolite model Leica TCA1800 would provide results complying with the above requirements, but the Dam Personnel
prefers to work with the successor model of Wild T2000, which is model Leica TCA2003. Provision of this instrument can be justified under consideration that this theodolite is used for checking the triangulation network of both dams, also of Derbendikhan Dam.

**Seepage Monitoring (Piezometers and V-Notch Weirs)**

Every reservoir entails seepage through the dam structure, its foundation, and the abutments, even if there is a grout curtain. But, any unusual rise of the seepage rate is a danger warning. Seepage flow through the dam foundation and the abutments causes pore-water, uplift, and erosion which should be carefully monitored, particular in concrete dams, in view of the crucial impact on stability.

The total seepage rate, in any type of dam, indicates whether seepage as a whole may be considered as normal. Partial seepage rates (i.e. those occurring in selected isolated zones) permit to identify the critical zone if an abnormality is detected. The effectiveness of the grout curtain underneath the dam and along the abutments should be checked and carefully monitored. Rise of pressure levels at the downstream side of the grout curtain indicates an abnormality which should be treated before it will became a safety issue.

The uplift-pressure relief holes installed in the dam gallery of Dokan Dam shall be regularly flushing to ensure their proper functioning. Regular readings of the vertical piezometers pipes at the downstream toe of the arch are essential for monitoring the uplift pressure underneath the dam. The drainage discharge from the relief holes shall be regularly measured (see also Section 0 above).

The piezometer pipes installed in both bank grouting galleries permit checking of the effectiveness of the grout curtain. Regular readings are required. Quick release connection for the pressure gauges shall be purchased and installed at those piezometer pipes, which are constantly under pressure. This ensures reliability and longevity of the installations. Capacity curve for the V-notch weirs was provided to the Dam Project Office by Mr. Wermelinger in 2000 allowing conversion of the readings to flows. All overflow steel plates are corroded and need replacement. The measuring weirs installed on the left tailrace river bank shall be overhauled and access to the weirs shall be reinstated. The Dam Directorate will prepare the corresponding Work Orders. The number and the locations of the existing measuring weirs appear to be adequate. Regular measurements of the seepage flows shall be taken and recorded.

**Seismic Instruments**

Strong motion instrumentation shall be installed at the dam allowing for the comparison of the dam behaviour during an earthquake with the one predicted for the design, and for the prediction of its behaviour during future earthquakes. It can also guide the search for possible damages and support the establishment of rehabilitation measures. Accelerographs placed in the dam and in its immediate vicinity address the observational needs, which are:

- Earthquake response of foundation-structure interaction considering canyon effects, kinematic interaction, incoherent excitation, and internal interaction.
- Dynamics responses and characteristic of dams.

The needs lead to an array configuration of tree-component accelerometers to be installed at the dam site. The arrangement of the instrumentation array depends on the type of the dam and the instrumentation objectives. For Dokan Dam, the instrumentation objectives include:

- The observation of the free-field motion at the dam site;
- The observation of the effective input motion at the dam;
- The observation of the response of the dam;
- The installation of an earthquake warning system.

The resulting instrumentation scheme consists of total 5 accelerometers: 3 instruments installed at the dam crest (at highest dam crest, at the quarter point of the dam, and at the abutment), one instrument installed at the base of the dam, and one free-field instrument.
installed far enough away from the dam and the appurtenant structures as the readings are not affected by their presence and vibrations. The accelerometers are interconnected to a local strong motion network, which permits to co-ordinate and to monitor the function of the independent base units. Data recording, data evaluation and electronic data supply shall be supported by a personal computer system including a printer installed at the dam site. It is foreseen that the system operates autonomous. Data collection shall take place once a year considering normal circumstances.

The system shall comply with present international standards. This includes that the system allows to be upgraded with modem communication devices, if required in the future. Technical specifications were prepared for a Supply & Installation Contract during the 2000 UNDP Mission.

Upgrading

The structural safety evaluation of an arch dam is mainly determined by its stress and deformation pattern -including foundation and abutments -and the periodic comparison of the analytical data with the measurement records. At Dokan Dam, the dam monitoring installations, after its rehabilitation and its reinstatement, are based on the instrumentation layout established in 1986. This layout does not fully comply with present international standards for the type and size of the dam. The following deficiencies on dam monitoring can be identified:

- Dam displacement;
- Displacement of the foundation and the abutments;
- Uplift gradient;
- Joint displacements;
- Concrete temperature;
- Water temperature.

The possible extension of the instrumentation may comprise the following:

(a) For monitoring dam displacements: Additional polygonal transverses at different elevations on the downstream dam face.
(b) For monitoring displacements of the foundation and the abutments: Inverted pendulums and/or rock meters.
(c) Monitoring of uplift gradient: Additional piezometers (pore-pressure cells) in drillings for measuring the water pressure upstream and downstream of the grout curtain.
(d) For monitoring joint displacements: dilatometers, joint meters etc.
(e) For monitoring concrete temperature: concrete thermometers (Note: the temperature is, next to the water load, another principal effect for deflection of an arch dam).
(f) For monitoring water temperature: water thermometer (see also Section 4.2 - above).

A detailed study is required which shall provide the required extension of instrumentation for Dokan Dam. It is recommended to engage a competent Engineering Company for this study. Alternatively, this detailed study should be incorporated into the proposed comprehensive Dam Safety Review.

Training and Transfer of Knowledge

Training and transfer of knowledge regarding dam safety was provided to the Dam Office Personnel during Mr. Wermelinger’s site visits in 2000. Particular efforts were made for reviewing the process of reading, checking and recording of the dam monitoring data available. At the Dam Project Office, spreadsheet formats (MS-Excel) were set up for recording and plotting the following data:

- The hydrological data;
• The all piezometer readings;
• The seepage flow measured at the V-notch weirs.

The Dam Office Personnel shall enter all collected data into the spreadsheets and prepare printed-outs. These allow for immediate plausibility checks and will also permit to export the data to other computer programs, which may be used for dam safety evaluation in the future. A training needs assessment is required to maximise the benefit of any future training programs. A particular focus that would warrant consideration is training to provide the Dam Office Personnel with a greater understanding in the interpretation of the monitoring results and under what conditions is it necessary to take corrective action?