Armenia Dam Safety Project

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SYNOPSIS. The Armenian dam safety project involves the technical investigation of 64 dams during the period June 2002 to July 2003. The scope of work includes:

- Fieldwork: Dam inspections, Site investigations (4000m of drilling), Topographic survey, microseismic survey
- Studies: Hydrology, Flood routing, Dam break, Stability analysis, Seismic hazard assessment, seismic analysis
- Risk assessment
- Rehabilitation preliminary design and costing
- Dam safety plans (Operation & Maintenance, instrumentation, early warning systems and Emergency Preparedness Plan)

The dams include irrigation, water transfer and hydropower schemes and range from 1.5m to 83m high with both embankment and concrete gravity structures.

The paper gives an overview of the project and its challenges. Particular project issues include working across national and engineering cultural boundaries, obtaining information on existing schemes, and using a risk based assessment procedure for prioritising rehabilitation works. Particular technical issues include the refurbishment of neglected mechanical equipment and the rehabilitation of a 65m high dam that collapsed during construction.

INTRODUCTION

The Project Implementation Unit (PIU) of the Committee on Water Economy Management of the Republic of Armenia is implementing a national Dam Safety Project to increase utilisation of the present water reservoirs and to protect the downstream population and infrastructure in the case of a dam break. The safety assessment of 24 large reservoirs was completed during 1999 – 2000, and a preliminary Rapid Investigation of a further 60 dams was carried out in 2000 by Hydroenegetica Ltd of Armenia.

Long-term benefits and performance of dams. Thomas Telford, London, 2004

LONG-TERM BENEFITS AND PERFORMANCE OF DAMS

This paper considers the follow up project to the 'Rapid Investigation', which studied a total of 64 reservoirs between June 2002 and July 2003. The project is funded by an IDA loan to the Armenian Government and has been carried out by Jacobs Ltd of the UK with the support of Hydroenergetica and Georisk of Armenia.

The importance of dams in Armenia is very high. Some 24% of National electricity demand is generated by hydropower stations. The remaining balance is generated from thermal stations powered by both nuclear reactors (31%) and fossil fuels (45%), all the fuel must be imported. Hydropower is important therefore not only because it is cheap and clean but also because it provides a secure source of power. The water stored in the reservoirs irrigates 2,870km^2 which reduces Armenia's dependency on food imports with consequential security, social and economical benefits. Dam safety is therefore of national significance, and not just to the population living immediately downstream of the dams.

The majority of the dams have been in operation since the 1960's and 1970's, with some in use since 1940. Based on several factors that include the dam height and the reservoir storage capacity, the reservoirs have been divided into the following groups:

- Large reservoirs (12 dams, 15m to 85m high)
- Small Reservoirs (33 dams, 1.5m to 20m high)
- Artificial lakes (17 dams, 0 to 5m high)
- Partially constructed (2 dams 14m to 21m high)

Six of the large reservoirs are hydropower dams and are under authority of the Ministry of Energy. Two large dams were originally built for mining organizations and are not in operation, the other dams are irrigation or multi purpose dams and are owned by Jrambar CJSC, which is a state organisation responsible for irrigation facilities.

SCOPE OF THE PROJECT

The scope of the Consultant services is as follows:

1. Dam Investigations: reveal the structural and non - structural defects based on dam inspections, topographical and geotechnical site investigation results as well as hydrological, geotechnical and seismic studies.
2. Determine the degree of risk for each dam.
3. Recommend rehabilitation measures.
4. Prepare dam safety plans, which include instrumentation, operation and maintenance (O&M) plans and emergency preparedness plans (EPP).
5. Recommend early warning systems where appropriate.

The project therefore covers not only all the technical issues relating to the reservoirs, but also the interface with the operators, owners, emergency services and general public. The investigations and studies into the ‘artificial lakes’ were more limited than those for the remainder of the reservoirs due to their low hazard, but covered the same general scope.

DAM INVESTIGATIONS

Field Investigations

Only limited information exists regarding the construction of each dam, and typically the information available is design data rather than construction records. For many of the smaller dams no records were found at all. Thus, although an archive search was carried out, it was necessary to carry out field investigations on most of the reservoirs including field inspections, topographic survey and mapping, and geotechnical site investigations.

The field inspections were generally carried out by expatriate dam specialists accompanied by local technical staff and where possible by the operators. An inspection report was produced for each reservoir, and this was then used to establish the requirements for further investigations, particularly the geotechnical site investigations. Topographic survey was carried out by local contractors.

The site investigation involved almost 4000m depth of boreholes and trial pits. Both disturbed and undisturbed samples were taken for characterisation and strength testing in local soil mechanics laboratories. Two local contractors worked under the supervision of local and expatriate geologists.

The terrain of Armenia is very mountainous and the winter is severe, making access to remote areas impossible for several months. The most remote reservoirs are only accessible in the late summer. So far as possible all reservoirs were inspected and the site investigations completed in the Autumn of 2002. Some follow-up work was carried out in late spring of 2003. Security concerns limited access to some border reservoirs. The Turkish border of Armenia is manned by Russian troops and the border with Azerbaijan is unstable, so access to major dams on these borders was restricted. Inspections were carried out on these dams but site investigations were not possible.

Hydrology

Two methods were been used to analyse the flood inflows into the reservoirs. The first, the SNIP method, is based on standard Russian techniques and is in general use in the country. The second, a statistical method using all annual maxima flow data recorded in Armenia, has been used worldwide to check more particular methods (the Regional Method).

The Soviet Norme (SNIP)
This has two approaches, depending on the information available:
1) Applying analytical distribution functions for annual exceedance probabilities where sufficient hydrogeological data is available for the catchments.
2) In the absence of observed data, the peak flood of a given return period is calculated using a formula in terms of m^3 per km^2 which has terms for basin area, rainfall, geographic characteristics and vegetation.

The Regional Method
The basic hydrological records available for analysis in Armenia comprise the annual maximum flows for 102 gauging stations. The average record of over 40 years ensures that a reasonable sample of floods is available at these sites. By combining the records at different sites it is possible to estimate relations between basin characteristics and the mean annual flood, and also a relation between the mean annual flood and the flood of a rare frequency or long return period.

The relationship between mean annual flood (MAF) and the flood for a given return period (Q_T) was determined to be:

Return Period, yrs.	100	500	1,000	2,000	5,000	10,000
Q_T/MAF	3.23	4.7	5.47	6.33	7.65	8.79

A regression between mean annual flood, (MAF), and basin area (AREA) and annual rainfall (AAR) provides a significant relation between the variables:
$MAF = 2.53 \times 10^{-6} (AREA)^{0.782} (AAR)^{1.764}$

These two relationships were then used to assess the MAF and Q_T for each reservoir at the relevant return periods.

Comparison of the SNIP and the Regional method
The Armenian Standard (SNIP) was found to give higher estimates of peak flow for smaller catchments (up to 100km^2). For very large catchments (100,000km^2) the regional Method gave a slightly larger estimate, with reasonable agreement between the two methods in the middle range. See figure 1 below which compares the 1000 year flood estimates.

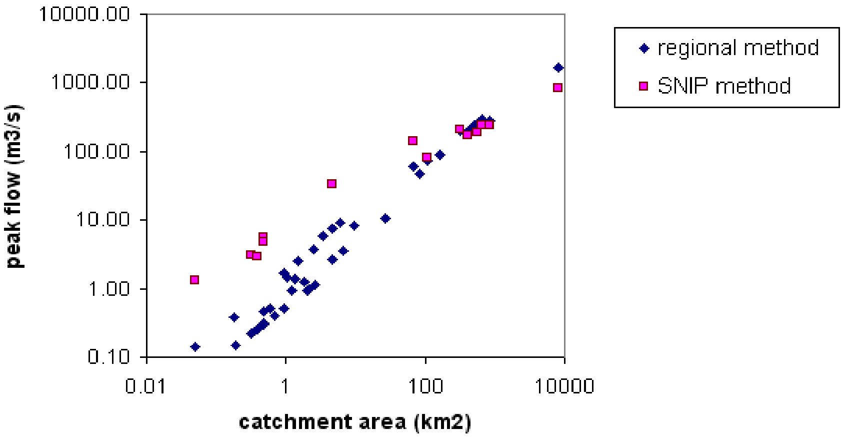


Figure 1: Comparison of 1:1000 year flood estimates

Flood Routing

Flood routing studies were carried out making use of either inflow hydrographs based on SNIP hydrology and SNIP rules for the return periods to be considered, or inflow hydrographs based on Regional Method hydrology and ICOLD recommendations for return periods where this gave larger floods [only the large reservoirs were affected].

Dam Break

Dam-break modeling was used in this project both for input to the Risk Assessment and the Emergency Preparedness Plan (EPP). The dam-break assessment was carried out in three steps:

i.) Initial screening carried out by identifying the potential flood paths on 1:100,000 scale mapping. In the case of some small reservoirs this indicated that the flood wave presents no hazard, passing through no populated areas and joining river channels which are large relative to the size of flood. In this case no further study is needed. In most cases this initial phase defines the extent of flood route which requires further study.

ii.) 'Quick Dambreak'. This is a spreadsheet based method of analysis which predicts the flood size and characteristics and from which inundation mapping is prepared. The approach was developed from the methodology given in CIRIA Guide C542, Risk Management for UK Reservoirs. For this analysis 1:25,000 and 1:50,000 mapping has been used as this is all that was available to the project.

iii.) BOSS DAMBRK. This is commercial software using more sophisticated analysis methods. For this project it was used for the analysis of the most critical reservoirs and to calibrate the results of the 'Quick Dambreak'.

The output from the Quick Dambreak analyses were inundation maps, coloured to show the flood damage parameter velocity x depth, with tables showing flood depth and width, and the time to peak flow at points along the flood path. The analysis has the great advantages of simplicity and ease of use. It has enabled the assessment of all the dams within the project to an adequate level.

The results of DAMBRK were compared with the Quick Dambreak results and demonstrated that within the tolerances of the mapping available the output was satisfactory for risk assessment and emergency planning.

Geophysical Investigations

Seismic refraction survey was carried out at Marmarik dam. The results were used for the assessment of seismic intensity magnification due to the site specific soil conditions.

Electrical resistivity was measured along two profiles at the Landslide N4 at Marmarik dam. The results were used, together with the drilling results, to determine the thickness of the landslide material.

Landslide hazard studies

Desk studies were carried out of potential landslides around Marmarik and Bartsrouni reservoirs. The work involved analyses of satellite images and aerial photos that were taken in 1948, 1976 and 1986.

Four potentially hazardous seismogenic landslides were identified within the Marmarik reservoir area that may influence the dam safety. The impact of the landslides onto the dam safety was assessed and special design provisions were made as a part of the rehabilitation works. They are described in detail in the paper on Marmarik dam.

Bartsrouni dam was constructed on a large, ancient landslide. Recent landslide activities have been demonstrated by numerous scarps. The dam has already been partially destroyed by landslide movements and it is anticipated that future movements will continue to damage the dam.

Seismic Studies

Seismic studies for the dams include the assessment of the seismic stability and assessment of liquefaction potential of fill and the foundation material.

Seismic stability analysis has been carried out using the methodology given in the Seismic Design Standards of Republic of Armenia (SDSRA) –, II.2.02-94 for all dams.

The susceptibility of loose, saturated sands and silty sands in the foundation and dam body to liquefy during an earthquake was carried out according to the methodology given in the Japanese standard.

Seismic design parameters have been selected based on the SDSRA for all dams, and on a Site Specific Seismic Hazard Assessment (SSSHA) for seven critical dams. The selection of dams was based on the level of acceleration assessed in the SDSRA, dam height and the results of the site investigations. The SSSHA was carried out using both a probabilistic and a deterministic approach. The results are given in Table 1 below, and indicate the significant seismic hazard in Armenia.

Table 1. Site Specific Seismic Hazard Assessment (SSSHA) – Design Accelerations

	Design Peak Horizontal Acceleration, g			
	OBE		MDE	
	Ground	Crest	Ground	Crest
Marmarik	0.32	0.6	0.44	0.82
Shenik	0.12	0.30	0.25	0.61
Tsilkar	0.34	0.49	0.49	0.65
Landjaghbiur –1	0.22	0.25	0.68	0.74
Hors	0.24	0.39	0.69	0.71
Gekhi			0.35	0.675
Akhuryan (concrete)	0.4		0.7	

<u>Stability Analyses</u>

Stability analyses for the embankment dams were carried out using the computer programme SLOPEW (GEO- SLOPE International) based on data from the topographical survey and on the site investigation. The load cases analysed are in accordance with SNIP standards. They include consideration of the upstream and downstream slope under static and seismic loading; and full supply level, maximum flood level and rapid drawdown cases.

For all except four of the dams, the factors of safety obtained in the stability analyses for the static condition were higher than the minimum required. Stabilistation works were designed for the four sub-standard dams. For some of the dams, factors of safety obtained for the seismic condition were less than unity. However, the displacements that could be generated were assessed to be negligible.

The concrete gravity dams were assessed by using a spreadsheet based analysis. Static and dynamic stability cases were assessed under a range of water levels and uplift assumptions. The dams were generally shown to have satisfactory stability under static conditions, but were liable to some local overstress in seismic events. One dam, which had an unauthorised spillway raising, was shown to have inadequate safety margins unless the spillway was restored.

Summary of Defects

A wide range of defects relating to design, construction, operation and maintenance were identified. In many cases these could be attributed at least in part to the results of the break up of the Soviet Union. Typical defects included:

- Deliberate blockage of the spillway to increase freeboard.
- Inadequate spillway capacity / freeboard.
- Structural repairs required to spillway or outlets.
- Damaged or deficient riprap or wave protection.
- Outlet valve refurbishment required.
- Slope stability inadequate.
- Leakage through embankment.
- Leakage through reservoir floor.
- Unsafe access to equipment.
- Refurbishment required to hydromechanical equipment.

On the basis of the assessment of defects, remedial works were recommended and outline designs prepared. Detailed design is to be carried out by Armenian consultants. In a limited number of cases 'emergency works' were recommended immediately following the inspection. One reservoir was recommended to be drawn down and abandoned (Bartsrouni, built on a landslide), others were recommended to be maintained at a low water level pending remedial works.

RISK ASSESSMENT

Methodology

The approach that has been used in the assessment of risk of all the dams is a semi-quantitative method in which both the probability and the consequences of an event are ranked from low to high and the relative risk levels indicated by the position on a matrix. This method has been adapted from CIRIA Report C542. The following stages are required:

i) identification of failure modes (instability erosion etc.).

ii) comparative assessment of probability of failure (probability of event x probability of this leading to failure).
iii) comparative assessment of consequence or impact of failure (population at risk and economic loss).

All factors are quantified on scales of 1 to 5 or 0 to 4, leading to semi-quantitative assessments. The risk index is the product of the total impact score and the risk score. A comparison of this score for all dams will provide a ranking showing where the priorities for remedial works lies. In addition, if the risk assessment is repeated for the case where it is assumed that the recommended remedial works have been carried out, the reduction in the combined score will enable a quantitative assessment of the benefit of the remedial works to be made.

The risk profile of the dams, as measured by the risk index, is presented in Figure 2. This Figure also shows the reduction in risk that will be achieved by the implementation of the Emergency Preparedness Plans and the remedial works.

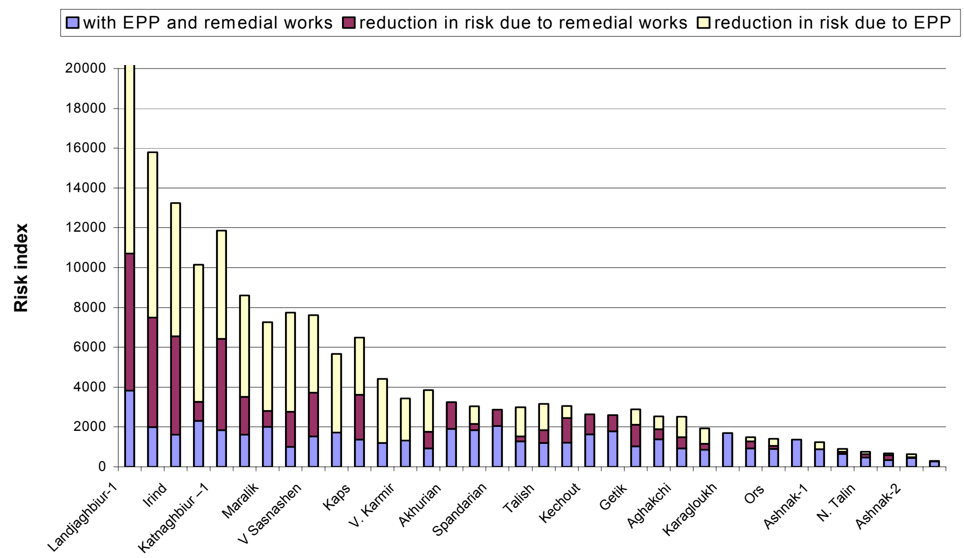


Figure 2: Risk Profile

<u>Cost effectiveness</u>
As a means of assessing cost effectiveness, the reduction in risk index has been divided by the corresponding cost for both structural measures (remedial works) and non structural works (safety materials and emergency preparedness plans) to give benefit/cost ratios for structural and non-structural works.
Figure 3 shows the ranking in terms of the benefit/cost ratio of remedial measures. The average benefit cost ratio is 29 and the range is from 128 (V

Sasnashen) to 0.8 (Kechout). One effect of this ranking is to highlight the significant benefit that can be gained from relatively minor works ($17000 at V Sasnashan compared with $1.3 million at Kechout).

Figure 4 shows the ranking of the dams in terms of the benefit/cost ratio of non- structural measures. Not only is the ranking of the dams quite different but the average benefit/cost ratio, 96, is much higher than the remedial measures cost benefit ratio and also the range, from 12 to 427, is more extreme. This indicates that non-structural measures can be regarded as providing better value for money but it is important to bear in mind that this depends on the efficacy of the EPP's which will require commitment and ongoing expenditure to maintain.

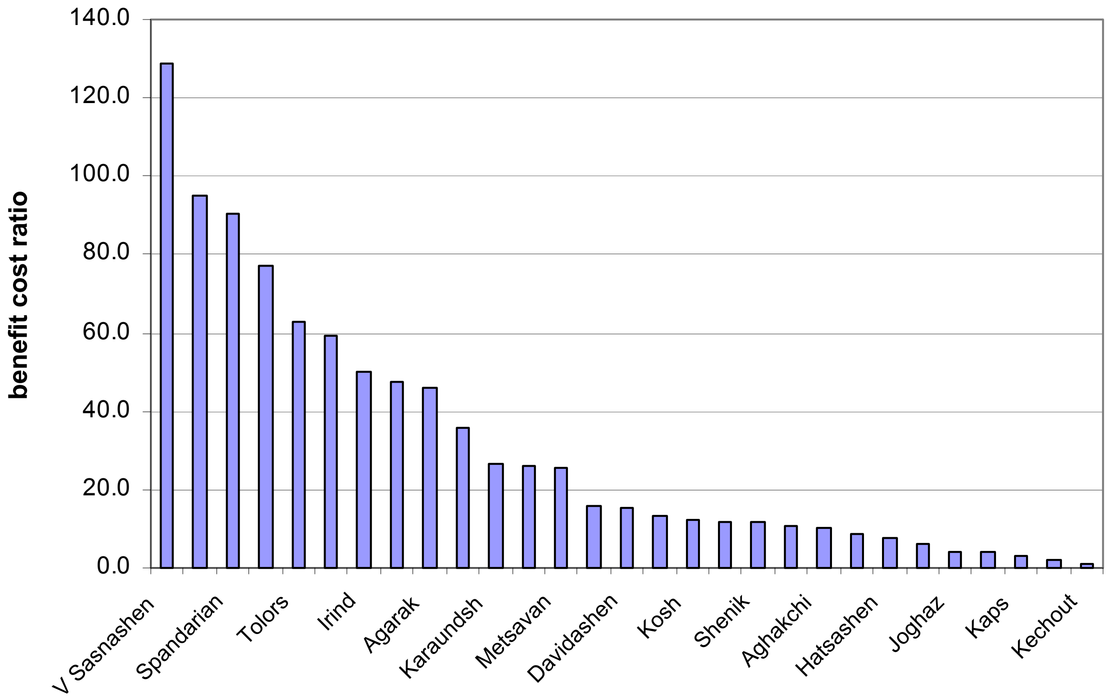
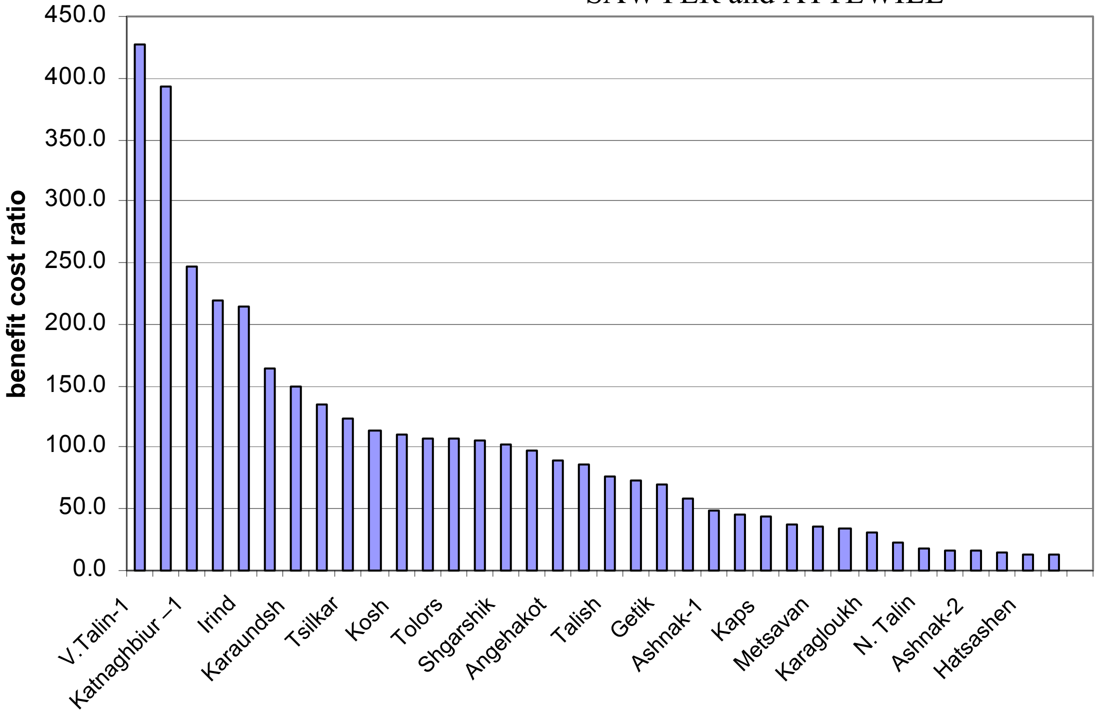


Figure 3: Benefit cost ratio of remedial measures
Figure 4: Benefit cost ratio of non-structural measures



DAM SAFETY PLANS

Dam Safety Plans were prepared for each dam. These include recommendations for instrumentation and monitoring, for operation and maintenance and where relevant an emergency preparedness plan (EPP). The plans were tailored to the particular reservoir, and reflected the size and hazard potential for each dam. The recommendations were generally for simple and robust instruments to monitor reservoir level, leakage and movement, typically just a staff gauge for the water level, V-notch weirs for toe drainage measurement, and survey monuments on the crest for the smaller embankments, with foundation piezometers to measure uplift in the concrete dams. Nine dams presenting a hazard to communities immediately downstream have been identified and an automatic water level alarm recommended to give warning in the event of the spillway discharge exceeding the design capacity. Equipment and materials for emergency works have been identified, to be maintained at each regional depot and each major dam. The proposals have been costed, including the requirements for routine supervision and inspection of the reservoirs, to allow the owners to budget for the long term implementation of the Safety Plans.

The EPP for each dam makes use of the technical studies, particularly the dambreak and inundation mapping, and then relates this to the emergency services and civil authorities. Local specialist consultants were used for these aspects as they require particular knowledge of local organizations.

PROJECT CHALLENGES

The project involved considerable challenges, most of which in some way related to communication. Particular issues included:

- Access to remote sites in difficult terrain and an extreme climate.
- Language: the Armenian engineers work in the Armenian and Russian languages, but technical vocabulary is primarily Russian.
- Engineering culture: the Armenians have historically worked within a tightly regulated system of Soviet Normes (SNIP), rather than to Western approaches. This affects not only design philosophy but also practical details of site investigation and testing and construction techniques.
- Construction records: it proved impossible to obtain reliable 'as-built' information for the majority of the reservoirs, largely due to the effects of the break up of the Soviet Union.
- Communication between the UK and Armenia: time zones, awkward flights, poor telecommunications and internet connections all add difficulties.

In this context it is essential to have Russian speaking technical staff and to adjust Western technical methodologies to suit the SNIP based designs and investigations. If all the geotechnical testing equipment in the country is to Soviet standards, there is little point in insisting on Western ones. It is also essential to have expatriate staff who will respect and adapt to the local culture, while bringing the benefit of their own experience.

CONCLUSIONS

The study has identified substantial remedial works required to the dams of Armenia. The use of a semi-quantitative risk assessment methodology has given a prioritisation of the remedial works. This has been used to substantiate a request for IDA funding. A programme of remedial works is now in progress based on priorities assessed in this study.

The project also delivered Dam Safety Plans for each reservoir which gave recommendations for instrumentation, monitoring regimes, maintenance and emergency planning. Implementation of these plans will require a significant long term organisational commitment, but will go a long way to limiting the need for future major remedial works programmes.

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