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ARMENIAN POWER SECTOR: DAM SAFETY CONDITIONS AND CONCERNS

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TABLE OF CONTENTS

1. BACKGROUND 1
2. CURRENT INSTITUTIONAL STRUCTURE 2
3. STRUCTURES AND CONDITIONS OF CONCERN 3
3.1 Spandaryan Dam *4*
3.2 Angeghakot Dam *5*
3.3 Tolors Dam *5*
3.4 Tatev Dam *6*
3.5 Argel Dam and Spillway *7*
4. KEY ACTIVITIES AND POTENTIAL FOR ASSISTANCE 9
4.1 Program of Dam Safety Review and Modification *10*
4.2 Estimated Costs of Implementation *11*
5. SUMMARY OF FINDINGS AND RECOMMENDATIONS 12
LIST OF REFERENCES 14

ATTACHMENTS

A. Plan and Profile of Vorotan Cascade
B. Angeghakot Dam Photographs
C. Tolors Dam Photographs
D. Tatev Dam Photographs
E. Argel Spillway Construction Photos - 1998

B

ARMENIAN POWER SECTOR: DAM SAFETY CONDITIONS AND CONCERNS

As part of the USAID program to assist in the maintenance, rehabilitation and development of electric power sources that would facilitate the closure of the Metzamor Nuclear Power Station, a rehabilitation program for priority hydroelectric stations was completed[1]. The rehabilitation priorities focused on the generating facilities and a workable financing plan for implementing the rehabilitation program. During the assessment of plants for rehabilitation priorities, concerns were expressed by several counterparts about the short and long term safety of several impoundment structures. These concerns were borne out by observations of engineers participating in the planning and by documents provided by various Armenian authorities. Further, it is widely accepted that the dams, designed before the Armenian earthquake event of 1988, would not meet stability criteria under revised earthquake loading conditions. The purpose of this report is to document and explain the situation and provide suggestions for addressing the problems.

1. BACKGROUND

During the Task Order No. 9 work undertaken in 1998-1999, an assessment of the hydroelectric generating resources in Armenia was made. The focus of the assessment was to provide a rehabilitation plan for the priority projects in need of work to maintain the system and allow for the ultimate retirement of the Metzamor Nuclear Power Plant. Site visits were made to all of the larger hydroelectric stations in the country, comprised of the Sevan-Hrazdan Cascade, the Vorotan Cascade and the Dzorages Project. During the survey and in subsequent phases of specific planning, management personnel expressed potential problems with the impounding and emergency spillway structures. Similarly, conditions were observed both on the ground and in documents that indicate that dam safety at the power dams is an important issue that is not being fully addressed.

During the design and construction of the existing works in Armenia, planning, construction and maintenance were done under the Soviet system. It is understood that most of the designs of the existing structures were completed by the Armenian Hydro Design Institute (Armhydroenergoprojekt), with assistance from other experts and approval of design at other levels. With the break up of this system, ongoing maintenance, dam surveillance and evaluation has become less rigid, with lines of responsibility less clear and funding and frequency of inspection decreasing. The current dam safety procedures in place are far less than those present in western countries, while there are substantial numbers of people and property downstream at risk, should there be a dam failure incident.

[1] This work was completed as part of Task Order 9 of Contract LAG-I-00-98-00005-00.

An overall review of the information presented indicates that there are four areas of concern regarding the current dam safety procedures in Armenia. These concerns are:

(1) The institutional changes place the final responsibility with the project owner, limiting independent judgements;

(2) Instrumentation typically present at such large impoundment structures is either insufficient, obsolete or inoperative;

(3) Monitoring of the dams is insufficient;

(4) Evaluation of the dams with regard to current safety criteria has not been done and there has been limited independent inspection and evaluation.

In 1995, the World Bank sponsored an Irrigation Rehabilitation Project that included a variety of activities, including work on dams to improve their safety. This program ultimately established a Dam Maintenance Program to address the problems at a number of dams and to implement physical improvements. This program is currently underway. However, the project is focused on the problems at irrigation dams, with only limited consideration of the power dams scheduled or funded.

2. CURRENT INSTITUTIONAL STRUCTURE

Since the restructuring of the electric sector, the major impounding facilities have come under the management of the Cascade joint stock companies. The companies are working under tariff and budget constraints and have had competing needs for scarce financial resources. The technical expertise for dam engineering within Armenia lies either in the Irrigation Group of the Ministry of Agriculture, or at the Hydro Design Institute (Institute). The Institute has in the past been primarily responsible for the inspection and evaluation of the safety and reliability of the power facility dams.

Under the current structure, the Hydro Design Institute only works for the Cascade company, when it is requested and paid by the company. Should inspection or analysis indicate that repairs or remedial works are necessary for impounding structures, the Institute has no authority to require that such measures are taken or that such measures will be funded.

This is not to imply that dam safety at the dams has been ignored. As the reference list to this document shows, a number of studies and reviews have been done in the past few years. However, there is no structure for acting upon the studies, nor is there complete confidence in the findings of the studies. Perhaps this is because some of the studies are done by the original designers of the dams, rather than by an independent party.
Typically, in many countries, dam safety for structures that could pose a public hazard upon failure is regulated by a separate governmental agency. For example, dams that are licensed for generation by the Federal Energy Regulatory Commission (FERC) are subject to a regular program of inspection. The program is set for every dam and typically includes regular monitoring of the dam, periodic internal inspections and recording/review of instrumentation

data. This program information is reported to the FERC dam safety group. The FERC also generally does an inspection of the dam structures. In addition, every five years, an inspection must be done by a qualified independent engineer. This engineering inspection includes a review of the dam stability analysis. Any modifications to the dam condition or structure, or other external conditions, result in a modification to the stability analysis. Should the dam no longer meet required safety and reliability criteria, a plan of correction is required. Under this system, the dam owner is required to conduct a safety program, but the program is under regulation and independent review.

During the World Bank Irrigation Rehabilitation Program problems with irrigation dam maintenance and reliability were recognized. In response, a program was developed to address dam safety, primarily at irrigation dams. A dam safety portion of the program was initiated in 1999, with a budget of about $30 million. The program established a Dam Maintenance Enterprise (DME). The DME is to be a sustained area of expertise to perform rehabilitation on critical dams and maintain the necessary technical and management capability to effectively operate and maintain the rehabilitated dams.

The program is focused on irrigation dams. A pre-program study identified 20 priority dams to receive some structural rehabilitation. At this point, all 20 dams have been studied and plans have been developed for repair work. All of these dams are embankment dams. The typical fix required is either for increasing spillway capacity to avoid overtopping in extreme runoff events, or in flattening embankment slopes, to meet stability criteria. The typical budget for repair of one of the 20 dams is between $400-700,000, with the maximum repair budget set at $3,000,000.

The next phase of the project is to evaluate 60 other dams in Armenia, including the power facility dams. However, the total budget for evaluation of all of the dams is $200,000 with no allocation for repairs or modifications. It is also possible that this amount will not allow for full evaluation of the dams. Clearly, there is an opportunity for additional evaluation of the dams to be accomplished, as the DME is developing current expertise in the discipline.

3. STRUCTURES AND CONDITIONS OF CONCERN

The Vorotan River is a high gradient river developing high head for the generating projects. The Cascade has four major impoundments that would be considered high hazard dams. The designation "high hazard" does not imply evaluation of the reliability of the actual dam, but its height, impoundment volume and downstream conditions. High hazard dams are typically those that would result in substantial downstream property damage and possible loss of life. All four of the structures meet these criteria. By estimates of the Vorotan Cascade JSC, there are approximately 20,000 people downstream of some of the dams that could be affected. Based on observation during visits to the dams and river area, this estimate certainly seems reasonable. There are other impoundment structures that should be included for inspection under a continuing dam safety program, but these would appear to be of lower priority. The four major impoundment structures and their characteristics are: Spandaryan Dam, Angeghakot Dam,

Tolors Dam and Tatev Dam. Attachment A is a plan and profile of the Vorotan Cascade Development.

In addition to the Vorotan Cascade, the Sevan-Hrazdan Cascade have impoundment structures associated with its hydro plants. Due to the nature of Lake Sevan and the Hrazdan River, the impoundments are not as high as those on the Vorotan and these are of less concern. However, the impoundment at the Argel power plant (formerly Gyumush) previously experienced a severe spillway failure and has concerns remain about its safety.

3.1 Spandaryan Dam

The Spandaryan Dam is a zoned rockfill structure with a maximum section about 83 meters high. The dam has a surface area that when full covers 11,700,000 square meters and has a storage volume of 275,000,000 cubic meters.

When designed, the Spandaryan Dam included instrumentation that is expected of such a dam, including piezometers (water level measurement devices), seismic monitors, inclinometers (horizontal movement detectors) and a series of surface points for survey monitoring. During a site visit to the project, it was reported that the instrumentation was largely inoperative. The inclinometers were not usable, the piezometers were not usable and the seismic monitors had been removed as they were too sensitive to provide useful information. The surface survey points are apparently monitored every five years. No report from any of the instrumentation was available. Also, there is no collection or monitoring of leakage through the dam. Leakage through any impoundment structure is normal; however, for high hazard structures, leakage, along with the water profile with the dam, is regularly measured and monitored for advance notification of any changes.

During the visit to the dam, it was also clear that the spillway structure was in need of repair. The spillway concrete is in poor condition due to poor quality concrete during construction. Additionally, the spillway exit ends on what appears to be a soil surface that would readily erode during actual flow. Due to the low runoff conditions the past several years, the Spandaryan level has been far below the spillway. However, it is likely that the emergency spillway will be used sometime during the life of the structure.

Due to concerns heightened by the 1988 earthquake, a review report was prepared for the Spandaryan and other reservoirs. The Zhuk Research Institute prepared the report which included assessment of seismic conditions, methods of field exploration for data gathering and a seismic assessment of the Vorotan dams. This report was not available, but an expert review opinion (Reference 4) was made available. The Spandaryan dam was originally designed to a Seismic Force 8 criteria. However, the result of the 1998 earthquake required a Force 9 design. Therefore the dam does not meet a Force 9 criteria and only meets the Force 8 criteria at lower water surface elevations. In summary, the expert opinion criticized some technical assessment of the report, but found it to be at of sufficient scientific and engineering quality and concurred that the dam did not meet earthquake criteria.

In addition to the instrumentation and earthquake stability criteria, the dam needs an evaluation or review of the spillway capacity and condition including the original design inflow and sizing of the spillway.

To address the concerns of the Spandaryan project requires a complete engineering review and inspection of the project. Clearly, at a minimum, Spandaryan Dam needs proper instrumentation to be maintained and monitored. Based on the findings of the referenced papers, it is also likely that structural modification will be necessary in order to meet earthquake criteria. This can most likely be accomplished by flattening embankment slopes, as much as possible.

3.2 Angeghakot Dam

The Angeghakot Dam receives the discharge of the Spandaryan powerhouse, as well as impounding water from the Vorotan River downstream of the Spandaryan Dam. The dam is a concrete gravity structure, about 33 meters high. The dam has an overflow, ungated spillways, as well as a non-overflow section. Attachment B contains two photographs of the dam.

No information, with the exception of a plan and a profile, was available about the Angeghakot Dam. This dam is the only substantial concrete dam in Armenia; therefore, Armenia does not have a considerable amount of expertise in gravity dams.

It is also unclear whether the Angeghakot Dam was reviewed for seismic stability under the more severe criteria. The Vorotan Cascade management voiced concerns that the dam may not meet the stability criteria, but no studies were offered to provide a determination.

The instrumentation in a concrete dam the size of Angeghakot is typically less than that found in an embankment dam. However, seepage areas are typically monitored and there is usually a routine formal program of internal and external inspection. It is understood that in 1997 survey marks were checked by the Hydro Design Institute and no substantial movements were detected. However, no report was available for our review.

The Angeghakot Dam should also be subjected to a full inspection and re-analysis, including spillway capacity and focusing on whether the dam meets stability criteria under current earthquake criteria.

3.3 Tolors Dam

The Tolors dam is also an earth/rockfill embankment dam, about 70 meters high. The reservoir surface is 4,700,000 square meters and the dam reservoir capacity is 96,000,000 cubic meters. The impoundment is not on the Vorotan river, but receives water flow via a tunnel from the Angeghakot Dam and impounds the waters of the Sisian River and another tributary, to add to the generating reservoir pool for Shamb powerhouse. The city of Sisian is downstream of the project and would be subject to flooding if failure occurred.

No drawings of the Tolors Dam were available, although the Cascade and the Hydro Design Institute provided parts of several reports for review.

Similar to Spandaryan, Tolors was part of a study conducted to determine whether the dam met revised stability criteria. An excerpt of a report by the Hydro Design Institute (Reference 2) completed in 1998 was provided. The report concluded that the slopes of the dam did not meet earthquake stability criteria at any reservoir level. It was also noted that the dam could be made to meet criteria by flattening the slopes, both upstream and downstream, by adding about 450,000 cubic yards of additional embankment. The report also indicated that additional data on the design parameters of the existing project are needed, before final calculations can be carried out.

An expert panel also reviewed this work (Reference 3) and was critical of the methodology of the seismic analysis of the prior study, but concurred that the analysis, although preliminary, is correct in its conclusions. The expert panel states that before any final analysis can be made, considerable additional research must be conducted including seismic surveying, seismic analysis of the dam with two and three dimensional analysis and in-situ measurement of the dam's dynamic and material properties.

These conclusions certainly appear reasonable. Also similar to Spandaryan Dam, there is very little instrumentation that is operational in the project. Seismic sensors, piezometers, and seepage monitoring points are lacking.

The dam's survey monuments are checked every three to five years for settlement and movement. The last check was made in1997 and the report was provided for this review (Reference 6). The survey report concludes that the settlement detected was not substantial and within design and accuracy limits. However, the report suggests that the dam monuments be monitored annually. It is clearly prudent to monitor the survey monuments annually, particularly in the absence of other instrumentation.

Attachment C provides pictures of the dam and some of its features. The dam needs some concrete repair work that is not related to the above overall stability issues. The dam did not appear to have any alarming problems, but there was a zone mid-way on the downstream slope that has a vegetation slip zone (see Photo 3). This zone appears to be at a slope bench and may not be related to any movement. However, the presence of such a zone should heighten both formal visual monitoring of the embankment and the need for internal instrumentation. Such instrumentation would indicate any problem associated with the zone or other external causes.

The lack of drawings and documentation for the Tolors Dam is disturbing.

3.4 Tatev Dam

The Tatev Dam is the most downstream dam of the cascade and is on the main Vorotan river. The dam is a rockfill embankment structure with a height of 41 meters. The dam has a surface area of 1,120,000 square meters and a storage volume of 13,600,000 cubic meters. Attachment D provides photographs of the dam.

The Tatev Dam is of lesser concern than the other dams, mainly due to the lower number of downstream inhabitants that might be affected by a failure. There is an available plan and section drawing for the dam, but no studies or summaries of other studies done regarding stability under seismic or other criteria.

The 1997 report on the survey of monument points for settlement or movement was available. This work is done only every three to five years. The dam monuments have not moved more than the allowable criteria during the period of observation since 1972. The report also recommended that the monuments be checked annually. As with the Tolors Dam, this is a good recommendation, particularly given the lack of any other instrumentation.

Like the other dams, Tatev had instrumentation installed, but it is not operational. The dam should have leakage monitoring at collection points, seismic monitors and piezometers. Like the other dams, the Tatev Dam should have a complete inspection and stability review, including spillway adequacy to determine what complete repairs in addition to the obvious concrete work will be necessary.

3.5 Argel Dam and Spillway

The Argel Hydroelectric Project is on the Sevan-Hrazdan Cascade. The project includes an 83 meter high rock/earthfill dam enclosing the regulating pond for the powerhouse. Most flows from the reservoir are used for generating power, but an emergency spillway is available for periods when the powerhouse cannot use all of the inflows. The project suffered a severe accident in May 1995, when the reservoir spillway failed causing a major landslide and flooding the powerhouse.

The damage to the project was repaired and the unit returned back to service. The reconstructed spillway has raised concerns by the engineers working on the hydroelectric rehabilitation planning. Concerns are not based on a detailed engineering review; the general consensus is that the spillway is not designed for the type of flows experienced in 1995 and the possibility of damage is high if the spillway is used.

In 1999, Hagler Bailly provided a letter stating these concerns to the Ministry of Energy. The following excerpt from that letter articulates the concern:

> *Our review indicates two areas of concern for the spillway; the chute or channel design and the spillway exit. Typically, spillway design is accomplished with the use of a scaled hydraulic model. The model becomes interactive with the final design to avoid compromising hydraulic situations.*

The most common failure of spillway features is problems in the chute. Chute flow is typically at very high velocities, resulting in very large dynamic forces. The high velocities also result in cavitation. Resultant specific concerns about the chute include:

1. *Aeration devices are typically used to avoid cavitation. No such devices are apparent in the drawings provided.*

2. *In the spillway layout, changes in flow direction should be limited to sections where flow velocity is low. In the new layout, there is a bend in the chute at elevation 1530 meters and a change in the floor slope at elevation 1480. These positions are probably high velocity sections of the chute.*

3. *The chute floor design must be based on forces resulting from flow velocity considerations. Typically, sections must be joined by keyed or other special joints. If the foundation is competent rock, special joints may not be necessary. However, it is not clear that such competent rock is present.*

The exit of the chute spillway is also of a concern. Typically, the concrete chute opening would include concrete baffle blocks or other structures to create a hydraulic jump. The jump is a result of the change of water velocity from very high (super-critical flow) to moderate (sub-critical flow). Much of the energy should be dissipated at the exit structure. It does not appear from the drawing that there are energy dissipating structures designed. The exit water jet from the chute exit could impact the opposite bank or existing bridge structure downstream of the powerhouse structure.

The spillway is now complete. Attachment E has two photographs of the spillway while under construction in 1998. It is recommended that an independent review of the spillway be completed, possibly with a model built to ensure proper functioning under maximum design flow conditions. Although it is unlikely that such modeling expertise exists in Armenia, there are several in United States, Europe and most likely several in Russia that have this capability. The physical spillway model would be tested at several ranges of flow, including the amount of flow that caused the failure in 1995, and higher flow, if within design possibilities. There is some limitation volume on the flow that the spillway could be called upon to handle, as it is part of the cascade and the inflows to the project are limited by channels and tunnels rather than natural inflow conditions.

Aside from testing the model for sufficiency of the spillway design, the model could be used to test possible modifications. For example, if the profile (vertical curves of the spillway) were found to cause structural stress and failure, alternative designs could be tested that would minimize the changes to the existing structure. If the flow/energy dissipation at the flow outlet of the system were found to be a problem, alternative strategies of widening the outlet and placing blocks, weirs or other dissipating structures can be tested. Other possible structural modifications can also be tested in the spillway channel, if problems are found to exist. The

model output would be used by structural and hydraulic engineers to make final design modifications.

It is possible that the concerns regarding the spillway are unfounded. No qualitative evaluation of the design was performed for this review and the design flow levels were not provided. However, based on the amount of flow the system carried in the prior failure event, the probability that the spillway is under-designed is significant.

The work scope for performing a review and model study would consist of the following steps:

1. Review the design of the spillway. This should include all design criteria of flow and underlying data on foundation and topographic conditions. These would be provided to the engineer and probably in the document requesting their bid. Currently, we only possess two drawings of the features of the spillway.
2. The engineer in charge of the model should visit the Argel project and be fully informed as to how the cascade and project flows work, so they completely understand the dynamics of the situation and can independently judge whether the flow design criteria are appropriate. The engineer should also be aware of the dynamics causing the prior failure. Useful information would include reports done at the time of the failure and the videotape of the previous spillway failure.
3. Construct and model the new spillway under several selected flows, from minimum to maximum. Perhaps three or four flows would be tested, although it should be considered that the cost of testing many different flows would add significantly to the costs of the project.
4. Evaluate and report on any shortcomings observed in the spillway design.
5. Using the model, propose and test different possible solutions to the. During this phase, some interface between the model engineer and the in-country engineers and cascade engineers would be necessary.
6. Complete a final report with recommendations and findings. If modifications are necessary, the structural and hydraulic engineers would use this report as a basis for the design changes.

4. KEY ACTIVITIES AND POTENTIAL FOR ASSISTANCE

In summary, the power project impounding structures need to have additional focused attention with regard to current safety and reliability standards. A public hazard of some magnitude does exist, and steps should be taken to minimize these hazards.

Currently, under the Dam Maintenance Enterprise, some resources are spent reviewing the situation and prioritizing the remaining dams within Armenia for evaluation and repair. These power related dams will likely be near the top of the list. However, it is not likely that sufficient resources will be available for complete evaluation, let alone for actual remedial repair. It is also possible that additional expertise, aside from what is currently available within the DME, may be necessary.

The Hydro Design Institute also has some capability and information regarding these projects, as it originally had responsibility for design. Key remaining specialists from the Institute should be included on a team that undertakes new studies on these projects. Since the requests made during this review produced little in the way of design drawings, instrumentation drawings or geotechnical information, an effort should be made to clarify what is available. Secondly, a complete set of available documents on the structures, including their design and construction history, should be placed at the Cascade or at an appropriate location, such as DME or archived at the Ministry of Energy. Without a concerted and cooperative effort to locate, document and freely share information between participating analytical groups, most of the future efforts risk being wasted. This information collection effort should be a pre-condition to any further participation by donor funded efforts.

4.1 Program of Dam Safety Review and Modification

The following is a recommended program, regardless of how it is implemented:

1. Await the initial results of the DME study of further priorities for dam safety actions within Armenia. The DME should also review other power impoundment structures to determine whether others should be added to this list.
2. Resolve the institutional problem in order to determine who is responsible for dam safety, recognizing that dam safety is a public concern and should be outside the budgetary pressures of the cascade operating companies.
3. Develop and implement a detailed plan for study of the four dams noted above and the Argel impoundment/spillway. The study should include **a comprehensive inspection and review** program including:
    a) Inspection of the dams and evaluation of the initial design conditions and standards, as well as the condition of the dam relative to its initial design. The inspection team should include engineers that are not part of the original design team or the employees of the owner.
    b) Appropriate standards for the projects should be selected based on local conditions and Armenian code and international standards for dam safety. These standards include the level of design for hydraulic structures, loading conditions and seismic factors, as well as acceptable factors of safety. It is critical that these conditions be clearly documented prior to the initiation of additional work.
    c) Review the original hydrologic and hydraulic studies completed for the Vorotan Cascade dams and assess the spillway capacity for compliance with current standards, using current data.
    d) A complete stability evaluation of the project should be completed, including structural stability under appropriate loading conditions, including earthquake loading. Seismic studies should be completed, building on the work already done and the previous review by a team of local experts.

e) In the case of the Argel spillway, determine the need for and complete, if necessary, modeling studies of the recently re-constructed spillway.

f) Inspect and evaluate the level of instrumentation at each of the structures and the collection and use of any historical data by appropriate authorities. Establish an instrumentation installation program and future monitoring program including actions to be taken by the operators.

g) Provide a report and conclusions on the sufficiency of each of the structures and recommended modifications on a conceptual basis, if design criteria are not met.

4. Develop a formal Emergency Action Plan for the entire Vorotan Cascade and the Sevan-Hrazdan Cascade. This plan would include identification of potential inundation areas in the instance of a failure and specific actions for notifying local authorities in the case of a possible problem at one of the structures. The plan would be reviewed and updated and tested periodically. The test would be an example execution of the emergency plan, as if there were a dangerous situation developing at the dam.

5. Complete detailed designs and cost estimates for the recommendations from the detailed dam inspection/reviews. Although pre-judging the results, it is certain that the designs will include:

a) Implementation of instrumentation and monitoring at the four Vorotan Cascade Dams;

b) Remedial work at the Tolors and Spandaryan Dams including flattening of embankment slopes and patching of concrete in the spillways.

6. Implement the designed works.

4.2 Estimated Costs of Implementation

Estimating the costs for this program is difficult, particularly when the costs of future activities depend on the outcome of earlier activities. Budget level estimates are provided so that an order of magnitude of the cost of the work is available. Below are the activities listed in 4.1 with cost estimates for appropriate items.

1. The costs of the DME review and prioritization are included in the existing program.

2. Resolution of the institutional problem of responsibility and regulation is dependent upon the decision-makers of the Republic of Armenia. Information necessary to make such a decision is already available and possible agencies for responsibility, such as the DME and/or the Energy Regulatory Commission, are already in place

3. The cost of implementing the individual dam inspection/reviews will depend upon:

a) The success of the collection of information work to be done before the study;

b) The level of participation by local expertise and/or international expertise;

c) The sufficiency of existing information or need for laboratory work or other activities.

Assuming that international experts are working with a small team of local expertise, considerable information is available, limited laboratory and field work is necessary and no additional drilling work is required, the cost/site for the work is estimated at $75,000 for each dam. If the work for the four dams was planned in one project, the total budget cost would be approximately $200,000. In order to meet this budget, it must be emphasized that full cooperation and sharing of information between groups is necessary.

The cost to review the Argel spillway by an international spillways expert would be an initial $20,000, with the total cost rising to about $100,000 if a physical model is necessary.

4. The cost of implementing Emergency Action Plans for the Vorotan and Sevan-Hrazdan Cascades is estimated at $50,000 for each cascade with the participation of local expertise and the full availability of topographical and hydrological data.

5. The cost of implementing remedial works for the dams is very speculative, without the results of a comprehensive study of the projects. With the understanding that instrumentation installation will be necessary on the dams, a reasonable budget estimate for each of the projects would be about $70,000. Quite possibly, the embankment dams would cost more, than the concrete dam. For the four Vorotan Dams the total would be about $200,000. For comparison purposes, the installation of instrumentation at the Enguri Dam in Georgia is about $170,000. However, the Enguri Dam is a very large concrete arch dam, requiring a higher level of instrumentation than the Vorotan Dams.

   Cost estimates for the repairs to the dams are far more speculative than the above estimates. Without specific plans, there is no basis for an estimate. It is fairly certain that flattening the slopes of the Spandaryan and Tolors Dams will be necessary to meet earthquake criteria. Such work will not only be expensive but also disruptive to the generation activities of the Cascade. It is essential that implementation planning for the dam repairs be integrated with generation activities of the cascade as well as remedial work that might be planned for the cascade. At the volume estimate made for the Tolors Dam, a rough estimate for embankment slope flattening is $5,000,000. The Spandaryan Dam cost is expected to be as much as or more as Tolors, although there were no estimates included in the documents reviewed.

5. SUMMARY OF FINDINGS AND RECOMMENDATIONS

1. The power generation dams in Armenia have suffered along with other infrastructure in terms of monitoring and maintenance. *It is generally accepted that at least some of the* impounding structures on the Vorotan Cascade do not meet current earthquake stability. There is unsatisfactory instrumentation at the dam and no overall evaluation is regularly performed. This does not mean that there are developing failures at the dams but their performance in the instance of a substantial earthquake is questionable. Also a developing problem would be difficult to detect.

2. The dams of most concern included in this review are the Vorotan Cascade Dams (Spandaryan, Tolors, Angeghakot and Tatev) and Argel in the Sevan-Hrazdan Cascade.

3. Currently, the institutional responsibility for dam safety is not clear. There is no agency with overall assigned responsibility, except for the individual cascades, who are focused on trying to run generation systems on tight budgets. Under a World Bank funded program, the Dam Maintenance Enterprise is addressing problems at the irrigation dams, but has limited budget and questionable authority for the power dams.

4. A program to fully inspect and evaluate four dams in the Vorotan Cascade and the Argel Dam and spillway in the Sevan-Hrazdan Cascade should be undertaken in the near future. This effort should be preceded by a comprehensive data collection effort on the dams, including all geotechnical information, construction information, as-built drawings, instrumentation details and data.

5. The inspection review should include full spillway adequacy review and stability analysis, with a particular focus on earthquake risk assessment.

6. At a minimum, the dams need to have design and installation of proper instrumentation, including piezometers, seismic monitors, inclinometers and seepage monitoring points.

7. Previous studies indicate that both the Tolors and Spandaryan dams will require flattening of embankment slopes to meet earthquake related stability criteria.

8. Both cascades should develop and maintain Emergency Action Plans to provide a plan for mitigating any downstream damage or injury in the instance of a problem at any of the dams.

LIST OF REFERENCES

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3. Expert Opinion of the National Seismic Protection Service under the Government of Armenia on the Report, "Analysis of Seismic Stability of Tolors Dam." Undated.

4. Expert Opinion of the National Seismic Protection Service under the Government of Armenia on the Report, "Geophysical Exploration and Redetermination of the Seismotectonic and Seismic Conditions of Spandaryan Hydro Power Plant". Undated

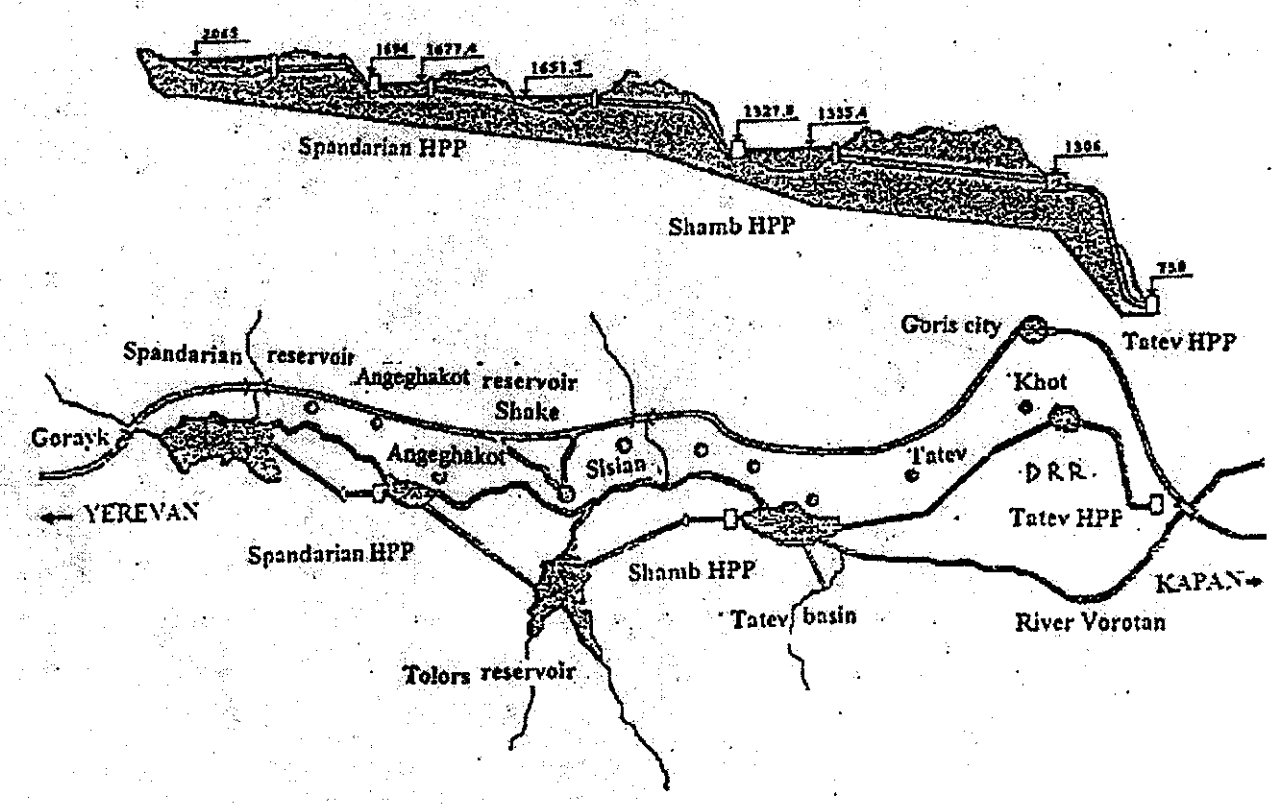
5. "Technical Report on Results of Geodetic Survey of Tatev Settlement and Shifts", Armgidroenergyprojekt (Armenian Hydro Design Institute), 1997.

6. "Technical Report on Results of Geodetic Observation of Tolors Dam Settlement and Shifts", Armgidroenergyprojekt (Armenian Hydro Design Institute), 1997.

7. Summary Drawings of Tolors, Spandaryan, Tatev and Andregeghot Dams.

8. Information provided to the Vorotan Cascade by the Hydro Design Institute

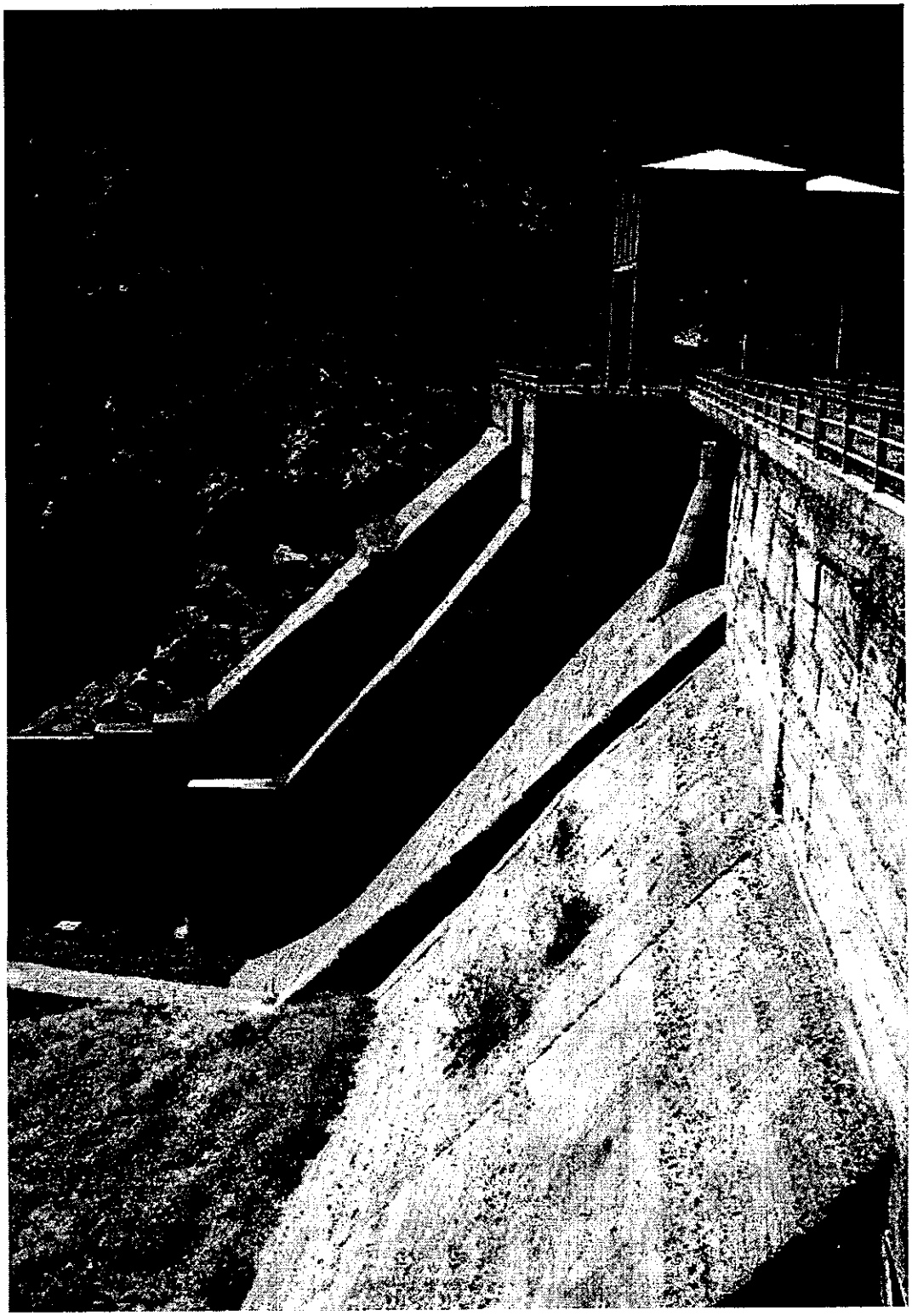
ATTACHMENT A



PLAN AND PROFILE OF VOROTAN HPPs CASCADE

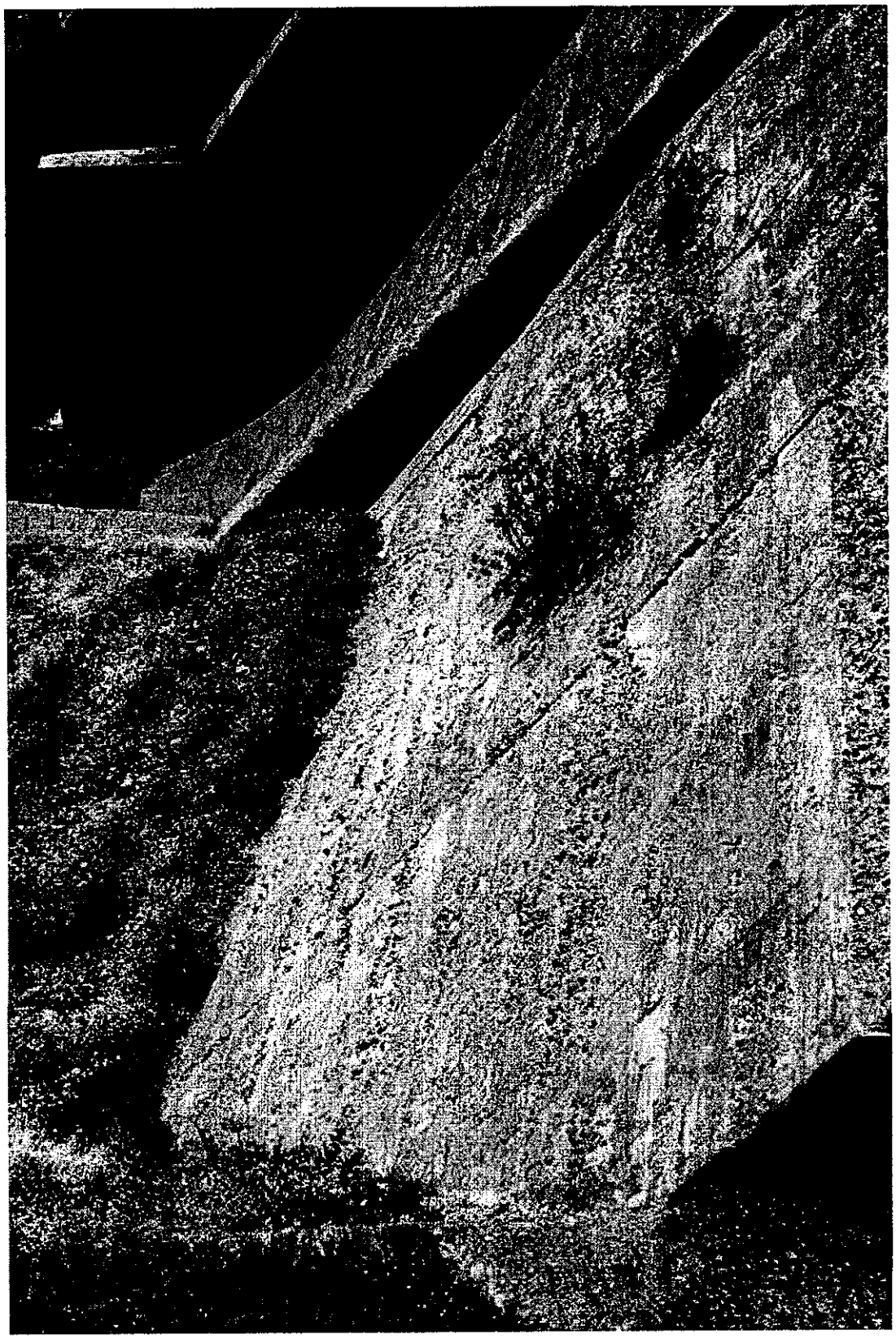
15

ATTACHMENT B
ANGEGHAKOT DAM PHOTOGRAPHS



Angeghakot Dam Downstream Face

BEST AVAILABLE COPY



Angeghakot Dam Concrete

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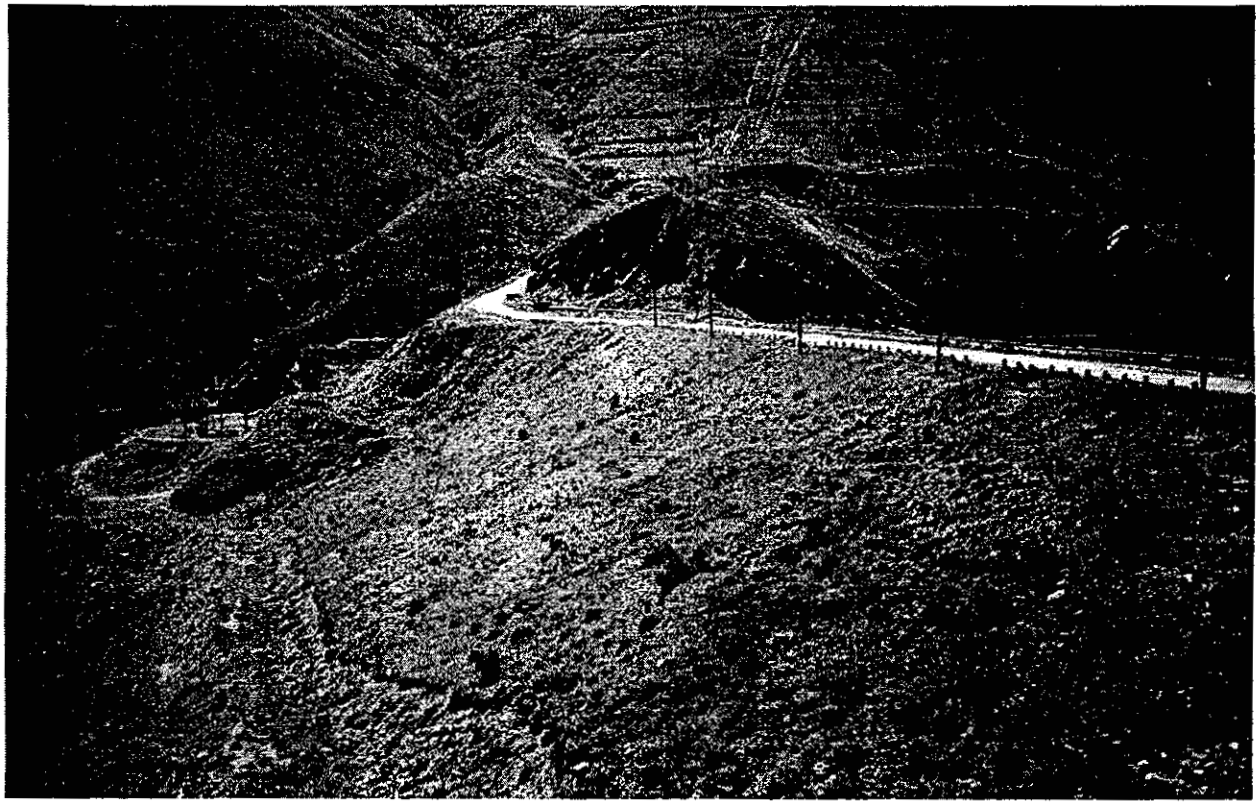
ATTACHMENT C
TOLORS DAM PHOTOGRAPHS

Tolors Dam (1)



Tolors Dam Crest (2)

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Tolors Embankment Slope (3)

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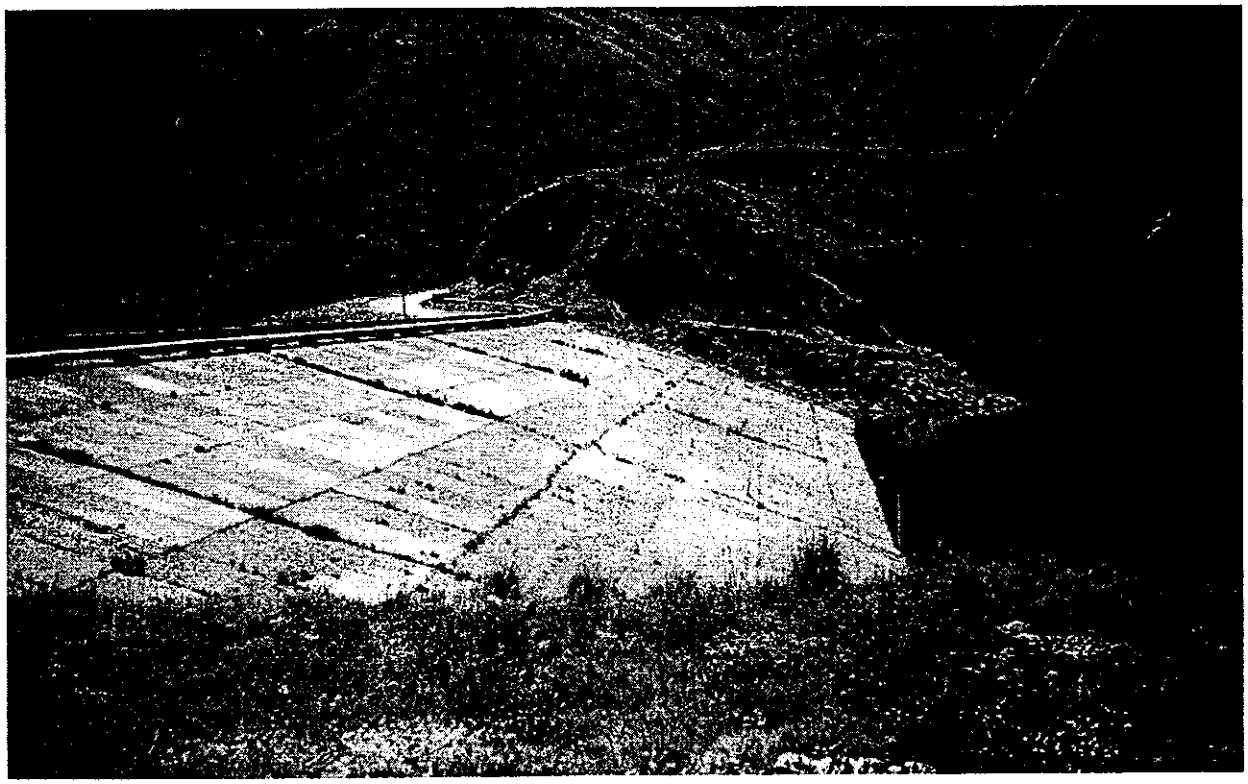
ATTACHMENT D
PHOTOGRAPHS – TATEV DAM



Tatev Dam Upper Slope

Tatev Dam Slope

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Tatev Dam Toe

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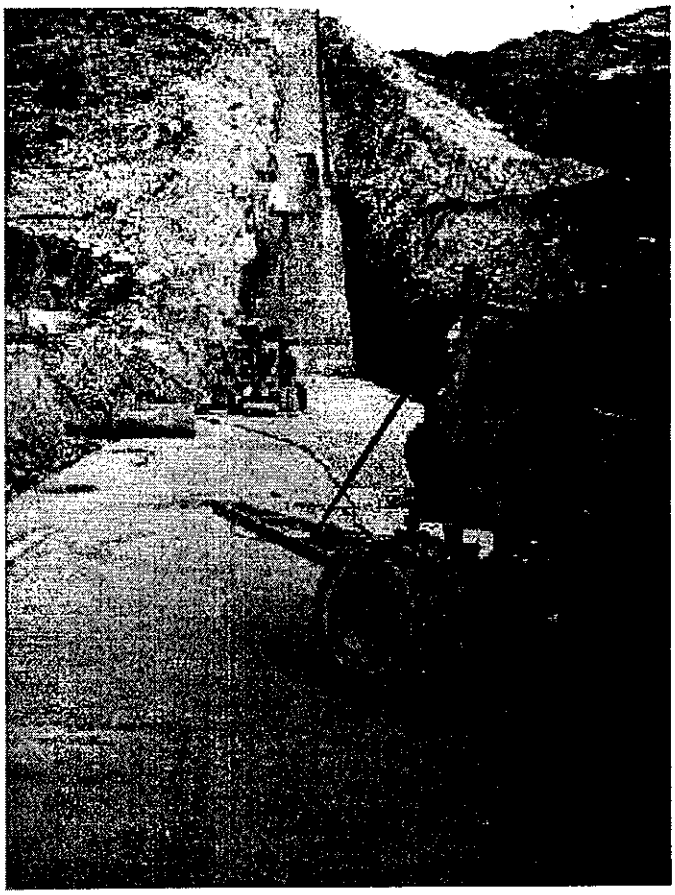
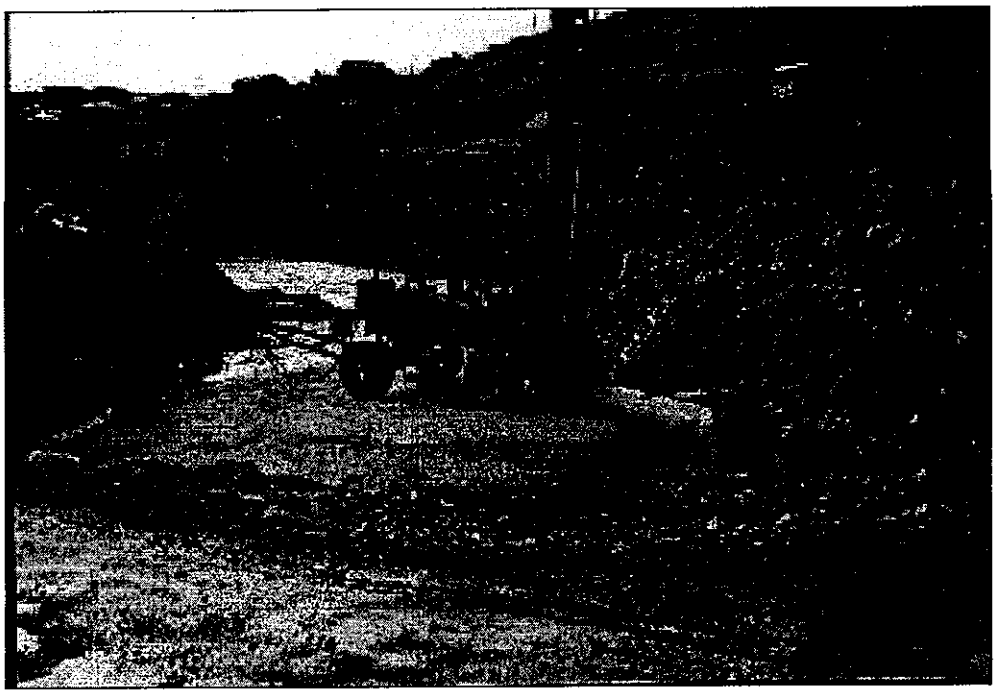
ATTACHMENT E
ARGEL SPILLWAY CONSTRUCTION PHOTOS - 1998



Argel Spillway Construction 1998



Argel Spillway Construction 1998

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