PN. ACM-208

REVIEW REPORT ON THE CONDITIONS AND REPAIR OF THE ARPA-SEVAN DIVERSION TUNNEL

CONTRACT NO. LAG-I-00-98-00005-00
TASK ORDER NO. 9

Final Report

Prepared for:

United States Agency for International Development
AID/ENI/EUR/DR/EI
Ronald Reagan Building
1300 Pennsylvania Ave., N.W. Suite 5-10.075
Washington, DC 20523

Prepared by:

Hagler Bailly
1530 Wilson Blvd., Suite 300
Arlington, VA 22209
(703)351-0300

Contact:
Philip Hoover
Masoud Keyan

April, 1999

A

TABLE OF CONTENTS

1. BACKGROUND 1
2. PROJECT DESCRIPTION 2
3. TUNNEL CONDITIONS 4
4. EXISTING PLANS AND DESIGNS 6
Scope *7*
Cost *7*
Schedule *7*
5. LAKE SEVAN WATER LEVEL 8
6. ENVIRONMENTAL CONSIDERATIONS 9
7. INSTITUTIONAL CONSIDERATIONS 9
8. CONCERNS AND ASSISTANCE OPPORTUNITIES 10
Review Opinions *10*
Technical Expertise *11*
Funding *11*
9. SUMMARY OF FINDINGS 12

ATTACHMENTS

A. Location of Vorotan-Arpa-Sevan

B. Water Level Variations of the Lake Sevan

C. Tunnel Profile and Sections

D. Tunnel Problem Photographs

REVIEW REPORT ON THE CONDITIONS AND REPAIR OF THE ARPA-SEVAN DIVERSION TUNNEL

The Arpa-Sevan Tunnel ("AST") is an operating portion of a system designed to divert water from Armenia's southern rivers to Lake Sevan. A review of the tunnel and its current condition was undertaken at the request of the U.S. Agency for International Development and U.S. Embassy.[1] The Hagler Bailly experts performing the tunnel review had previously inspected the construction of the upper portion of the same system, the Vorotan-Arpa Tunnel ("VAT").

The information within this review report has been assembled from a partial inspection of the tunnel, discussions with tunnel and Ministry of Agriculture personnel and additional information from other sources. The prior review provided additional insights to this effort. This report is intended to provide an understanding of the tunnel project, its condition, the implications of its current condition, and some possibilities for assisting in its renovation.

1. BACKGROUND

The Arpa-Sevan Tunnel is part of a large-scale scheme to divert water from rivers in the south of Armenia to Lake Sevan. The location of the tunnel is shown on Attachment A. Lake Sevan is a critical environmental, cultural, social, energy and irrigation resource for Armenia and is one of the world's largest alpine lakes. The lake has been severely damaged since substantial use of its waters for power generation and irrigation began in the 1930's. The original lake level has decreased by about 21 meters in the following 60 years. Much of the drawdown occurred prior to the early 1960's, when some management of the resource began. However, during the energy crisis of the early 1990's, the lake level again dropped several meters, when hydroelectric power was the only available electric generating option.

Attachment B shows the historic drawdown of the lake, with projections of the future increase in the water level, due to inflows from the tunnel system and decreases in release for irrigation and power generation.

In the 1960's, the plan to divert water into Sevan was undertaken that included the construction of a dam on the Arpa River. This dam formed the Kechut Reservoir. A tunnel was constructed to divert waters from the Kechut Reservoir, 48 kilometers to Lake Sevan. The tunnel was designed to divert 240 Million cubic meters of water from the Arpa River to Lake Sevan. The Arpa-Sevan tunnel began operations in April of 1981.

[1] This report was prepared as part of Task Order 9 of contract LAG-I-00-98-00005-00.

The second part of the plan is the VAT. This tunnel, now under construction, will divert waters from the existing Spandaryan Lake, the uppermost impoundment on the Vorotan River. The waters will be released in to Kechut Reservoir, then diverted through the AST to the lake. The VAT will lead to an additional 165 million cubic meters of water being diverted from the Vorotan River. The water will be diverted through free surface flow (non-pressure) in the tunnel, regulated by the gate opening at the intake. With VAT operating, the total diverted in to Lake Sevan from the southern rivers would be about 405 million cubic meters. The volume will vary somewhat from year to year due to hydrologic conditions.

Outflow demands from Lake Sevan, which are driven primarily by irrigation and secondarily by generation, are estimated by different groups to be on the order of 200 to 400 million cubic meters per year. The Arpa-Sevan Tunnel Operations Enterprise (the "Enterprise") reports that 300 million cubic meters were diverted to Sevan in 1999.

The AST represents a major civil work within the Republic of Armenia and a resource very difficult to replace. To construct the tunnel in today's economy would likely cost $200-300 million. Other options to maintain or re-establish the level of Lake Sevan are very limited.

2. PROJECT DESCRIPTION

The AST consists of several elements for the collection and diversion of waters to Lake Sevan. Attachment 2 provides a profile of the AST.

The tunnel project begins upstream where a dam on the Arpa River forms the Kechut Reservoir. The dam impounds waters of the Arpa, allowing a continual minimum flow to be passed downstream while collecting water for diversion to Lake Sevan. After completion of the upstream Vorotan-Arpa section of the project, waters from Spandaryan Reservoir on the Vorotan River will also collect in the Kechut Reservoir.

The intake for the AST is located on the Kechut reservoir. A control gate at the reservoir regulates the amount of flow in to the tunnel. Flows then travel through the AST works to the outlet at Lake Sevan, about 49 kilometers away. The actual tunnel part of the works is about 48.2 kilometers long, with the remainder of the distance an open channel leading to the Lake. The tunnel system carries water in open (not pressure) flow. The water goes from the typical Kechut Reservoir surface elevation of 1,942 meters to the Lake Sevan level just above elevation 1,896 meters, a drop of 46 meters.

The AST is composed of two tunnels that are connected by an aqueduct. The upper section is referred to as Tunnel No. 1. It runs from the Kechut Reservoir for a length of about 18.6 kilometers to the aqueduct at the Yekhegis River. This section of the tunnel was constructed from four active faces; one from each end and two from a vertical shaft (Shaft No. 1) located near the mid-point of Tunnel No. 1.

The aqueduct connecting Tunnel No. 1 and No. 2 spans above the Yekhegis River. The aqueduct section consists of a concrete open channel, with gate structures allowing flows from Tunnel No. 1 to be diverted to the Yekhegis River when the lower tunnel is dewatered. Additional diversion facilities are also present at the aqueduct. The diversion facilities include gates, an intake and channel connecting at the portal to Tunnel No. 2, to collect the Yekhegis River flows. In addition, there is a diversion facility from the smaller Karakaya River in an adjacent basin. These facilities include a 700-meter tunnel and drop channel that provide water upstream from the aqueduct intake. The total additional tunnel water that can be diverted at this point is about 10 cubic meters per second.

In general, it was reported that about one cubic meter of water is added between the two tunnels for every five cubic meters that come from the Arpa/Kechut Reservoir.

In the last year, the Enterprise has constructed an additional portal at the aqueduct. This portal allows for direct entry to the tunnel by rubber tired vehicles, without assistance of any lifting/lowering devices. This portal will enhance inspection, maintenance and repair works. There is also a construction staging area and camp at the portal. Access roads to the area are in reasonable condition.

Tunnel No. 2 begins at the aqueduct and carries water 29.6 kilometers to Lake Sevan. The tunnel was excavated from seven faces, including one face from the upstream and downstream portals one face from the construction Shaft No. 2 and two faces each from access Shaft No. 3 and No. 4.

The entire length of tunnel was constructed by conventional drill and blast methods. The rock encountered over the length included a wide variety, as might be expected, including sands, clays, basalt and a wide variety of volcanic formations. Rock hardness varied widely. The construction process consists of excavating the tunnel section, constructing a concrete lining, placing a concrete floor, then drilling through the concrete lining to pressure grout voids behind the lining. Pressure grouting is a process in which a cement material is injected behind the lining to ensure full rock to concrete contact and facilitate the transfer of loads.

The excavation for the tunnel was completed in a horseshoe shape approximately 4.9 meters wide and 4.9 meters at the top. Lining of various designs, depending upon the rock situation, reduces the open tunnel area to a channel 3.7 meters wide and 3.6 meters high in most areas.

Significant parts of Tunnel No. 2 were rehabilitated in a major effort in the 1987-1989 time period. In a substantial portion of the lower tunnel, the entire cast-in-place concrete lining from the original construction was replaced with pre-cast, steel reinforced blocks of concrete that were apparently doweled together by steel. The joints were further fixed with cement.

3. TUNNEL CONDITIONS

The tunnel has a number of places where deteriorating conditions have become a major concern in the past few years. The tunnel was partially inspected on 30 March 2000 by Hagler Bailly consultants. Representatives of the Ministry of Agriculture, and the Enterprise accompanied the project team during the inspection. The inspection of about 14 kilometers of Tunnel No. 2, from the upstream end at the aqueduct entry was completed. The Enterprise personnel asserted that this section of the tunnel contained the sections of most concern in the tunnel. Inspection and other documents confirm this representation.

In general, Tunnel No. 1 has remained in good condition since construction. There are several areas where some treatment is necessary, but they are not emergency or severe conditions. During the 19 years of life, about 468 meters, or two percent of Tunnel 1 has received substantial maintenance or rehabilitation works.

The primary concerns are in Tunnel No. 2. In one nine kilometer section between Shaft No. 3 and Shaft No. 4 (see Attachment 1) about 2.6 kilometers or over 25% of the nine kilometer section had substantial rehabilitation.

The problems in Tunnel No. 2 are in a number of different sections of the tunnel. These include conditions occurring within several kilometers of the portal but are most severe in a section that lies between construction Shaft No. 3 and No. 4.

The tunnel problems can generally be categorized in to five different types of problems. Pictures of these problems are shown in Attachment C. The types are summarized individually.

Collapsing Rehabilitation Areas

As shown on Photograph 1 and 2, in certain areas the concrete blocks that were part of the 1980's rehabilitation are failing. The failure takes the form of cracking/crumbling lining and/or displacement of the concrete blocks. Photograph 1 shows a section of tunnel where steel frames have been installed to provide support for the block linings. Photograph 2 is a closer photograph of the deterioration of the individual blocks. Photograph 3 shows adjacent blocks, displaced, an indication of pending failure. This problem is the most severe and in need of immediate attention.

This very severe condition occurs in about 1,000 meters of the tunnel near Shaft No. 3 and extending to Shaft No. 4. In most of these areas, the Enterprise has installed steel sets and support, similar to Photograph 1, in the past two years. However, even with the installation of the steel supports, the area of deterioration is quickly spreading to sections immediately up and down the tunnel. The use of steel supports should be viewed as only a temporary measure to avoid collapse.

The cause of the problem is not readily evident. The problem is likely a combination of:

- a severe rock squeezing situation in this section;
- inadequate design of the rehabilitation lining blocks installed;
- poor construction quality of the rehabilitation.

Cracking Lining

For a section of the tunnel estimated to be 350 meters long, the original concrete lining section is actively cracking. This problem occurs in areas just up-tunnel from Shaft No. 2 or between working faces 5 and 6. Photograph 4 shows one such example. The glass material gauge is placed across the crack to monitor movement. One such monitor that had been in place only 10 days had broken, indicating a very active crack. These cracks, while not immediately as problematic as the failing lining blocks, indicate a severe and rapidly deteriorating condition.

The causes of the cracking could include weak zones of material placed during construction or failure of the lining structure due to incomplete grouting of the cast-in-place concrete lining. The growth and movement of the cracks heightens the level of concern.

Invert Problems

The floor or invert of the tunnel is deteriorated in a number of areas. The inspection did not include the reportedly worst area, which is down-tunnel of Shaft No. 4. It is reported that in this area, most of the invert needs replacement or rehabilitation. Photograph 5 shows a floor section that has bulged and heaved at the middle joint. This problem could also have a number of causes, including failure to grout the entire outside of the lining, causing excess loading in certain areas.

The invert apparently needs substantial rehabilitation along the entire nine kilometers from Shaft No. 4 towards Lake Sevan, as well as some additional areas. The repair made needs to be designed after the root cause of the problem is determined.

Chemical Reactions

Often concrete that is exposed continually to water develops a chemical precipitate, composed mostly of calcium. The precipitate is caused by water seeping through the concrete and reacting with the aggregate (stone) used in the concrete mix. The result is a white, hard substance on the concrete surface below any cracks in the concrete surface. The white material is residue left behind after the water evaporates. Generally, this calcification happens over a long period of many years and has minimal impact on the design strength of the concrete or its ability to perform as designed. In a number of sections of the AST, this type of water/concrete reaction is very severe. Photograph 6 shows a section of the tunnel where such phenomena are taking place. These sections are at points where heated waters intersect the tunnel. For a tunnel only 19 years old, this is a major concern. It is possible that this reaction is not as severe as the visible section indicates. However, since geothermal waters typically contain highly corrosive elements, the situation needs careful study and testing of the lining strength and quality. Cleaning and re-

surfacing of the concrete will do little to address the problem. Further, it will likely be impossible to stop the water/concrete interface. Thus, if this is problematic, the repair will require a structural measure. The length of these chemical reaction problems is estimated to be about 300 meters.

Lining Fall Out

In some areas, there are complete failures of lining, evidenced by "fall out" of the concrete. In some cases, the rock behind the lining is also falling. This problem was observed in about 10 areas during the inspection (see Photograph 7 as an example). In many cases, this is caused by construction deficiency, either in construction placement or materials. In some cases, inadequate grouting behind the placed lining could be the root cause of failure.

In addition to these five problem areas, in many areas of the tunnel it can be seen that the tunnel lining was not properly grouted after concrete placement. With full contact grouting, any stresses are transferred to the arch shape, so that the entire structure handles the external pressure. In many cases, the area above the roof or arch of the lining has major voids. These voids can be the cause or at least contribute heavily to the problems noted above. It is not known how much of either tunnel suffers from poor grouting behind the lining. This is a construction installation problem.

4. EXISTING PLANS AND DESIGNS

The Ministry of Agriculture and the Enterprise have been very worried about the condition of the AST for several years. Concerns began in 1995, when the Government of Armenia approved a plan for rehabilitating the tunnel. Money has been allocated and expended during the following four years from 1996-1999 to perform some rehabilitation. Additionally, $800,000 was made available from the European Commission for additional rehabilitation works. These works include placing steel in the areas of most concern of immediate failure and replacement of lining/invert in several areas. Additionally, the construction area and new vehicle access portal at the aqueduct was completed early this year.

In February of 1999, a special committee completed an audit/report on the tunnel. The group included engineers from the Ministry of Agriculture, the Enterprise, the HydroProject Institute (engineering center for hydro in Yerevan) and other agencies. The group completed a report that was provided to Hagler Bailly. Many of the findings are consistent with our opinions. The group concluded that there was about 1,000 meters of tunnel in extreme need of rehabilitation and another 1,000 meters with substantial need. They also noted some of the other problems also identified during Hagler Bailly's inspection.

Following the report, the Ministry embarked upon assembling a plan for rehabilitation of the tunnel, along with documents and specifications for bidding. The plan was put together primarily by the HydroProject Institute with input from other tunnel expertise found within Armenia.

Scope

The program, in summary, consists of three parts or intended contracts. The contracts would each be for a section of the tunnel most susceptible to problems. The program did not address 100% of the identified problems, but did reflect treatment of most. A full translation was not available at the time this report was issued.

Most of the proposed repairs to the tunnel are similar to those that have been used before. The plan also obviously reflects the experience of the local industry in terms of treatment, time and costs.

Aside from the actual tunnel repairs, the work would include:

- Re-establishment of construction Shaft No. 3 and No. 4 for rehabilitation work. This would include fixing the areas and re-installing or rehabilitating the sizable lifting and access equipment at both Shaft No.3 and No. 4. Shaft No. 3 is 660 meters deep and Shaft No. 4 is 365 meters deep. Everything entering or exiting the shaft must be lifted/lowered this distance. Clearly, the installation and/or rehabilitation of very heavy lifting machinery is necessary;

- Rehabilitation of access roads to the areas;

- Re-establishment of power supplies and other electrical/mechanical mobilization.

Cost

The rough estimate for the work made by the commission was about $13 million, including about $11 million for the tunnel work and $2 million for other items. The costs for re-activating the shafts is about $1.4 million, with the major part of this amount going to Shaft No. 3.

After more detailed planning was completed, the total estimate was reduced to an amount of $10 million. The actual amount would be determined by bids. The current plan is to bid out the work to other enterprises but the bid will not take place until the funding has been identified and committed. At present, funding is not committed. It should be noted that this work does not include all of the needed repairs to the tunnel.

Schedule

The estimated schedule for the work is four years. This is not a full four years, as the tunnel cannot be shut down for that entire period. It is only accounting for a five-month construction season.

The tunnel had previously been operated on a full time basis from April through June, with a series of collection/diversion during the remainder of the year. Currently, so that repair works could be completed, the tunnel was shut down for five months, then will operate continuously for

the remaining seven. This schedule results in capturing a large percentage of the water possible for diversion, but all waters during the lower flow months are lost.

The original design provided for diversion of 240 million cubic meters of water each year. It is reported that 300-310 million cubic meters were diverted in 1999. It is hoped that for 2000, up to 330 million cubic meters will be diverted, even with the compressed schedule. Diversion is also dependent on snowfall and melting patterns, so availability of the tunnel is only part of the consideration.

5. LAKE SEVAN WATER LEVEL

The following section has been repeated from the prior Vorotan-Arpa Tunnel review to demonstrate the need for this project.

The 21-meter drawdown of Lake Sevan during the past 60 years is well documented. The lake clearly has strategic importance to Armenia that cuts across social, cultural, environmental, agricultural and energy sectors. It is clearly a high priority to protect the lake as a unique resource.

It is generally accepted that the return of the original lake level is not realistic, due to development and demands on the lake waters by downstream users. It is just as clear that the continued dropping of the lake level and unsustainable utilization of the waters is not possible. The lake is currently dangerously close to the current minimum intake level where waters can be withdrawn. This intake has already been rebuilt at a lower level one time in the past.

It is generally accepted that the water level can be increased 3-6 meters over the near term with water management and diversion of waters from the other rivers. There are no other practical inflow options. It is estimated that about 265 million cubic meters of water enter Lake Sevan naturally. An additional 240 million cubic meters of design water are diverted from the Arpa River. The experience of the past several years indicates that this amount might be exceeded under ideal AST operating conditions.

The World Bank's Lake Sevan Action Plan estimates that releases from Lake Sevan should be limited to 370 million cubic meters per year to satisfy downstream demands. At this rate, re-filling times are estimated to be as follows:

Options	Lake Level Increase 3 Meters	Lake Level Increase 6 Meters
Limit releases to 370 million cubic meters per year	34 years	85 years
Complete the VAT and limit releases to 370 million cubic meters per year	15 years	37 years

Source: World Bank's Lake Sevan Action Plan

No analysis of the benefits of the diversion were done as part of this review. There is no real alternative to the maintenance of the AST; *even if releases are curtailed from Lake Sevan and the tunnel does not operate, the lake level will continue to drop*. Clearly, loss of the tunnel diversion at this point is unacceptable from water supply, irrigation, power generation, environmental and strategic considerations.

6. ENVIRONMENTAL CONSIDERATIONS

The negative environmental impact on Lake Sevan by the extended draw down is well documented and obvious. Aside from negative pressures by development and agriculture practices on the lake's water quality, the quantity loss that would begin to be mitigated by the VAT would presumably begin to mitigate:

- Loss of critical habitat;
- Significant decrease in fish and aquatic production;
- Loss of lake shoreline;
- Loss of associated wetlands and productive areas;
- Degraded water quality; and,
- Loss of recreation opportunities.

Clearly, to recognize some of these benefits the overall management of Lake Sevan must improve.

The rehabilitation of the AST will have minimal impacts upon the existing environmental situation. Water has been diverted from the Arpa and Yekhegis Rivers for 19 years and environmental losses in those basins have been realized. While restoration of flows to those rivers would have some positive effect, the further loss to Lake Sevan would be tremendous.

7. INSTITUTIONAL CONSIDERATIONS

The AST has diverted water for 19 years and for a substantial period during the time prior to the break up of the Soviet Union. Thus, there is substantial precedent for the water diversion. This is a different situation than the incomplete Vorotan-Arpa Tunnel that will divert water otherwise flowing east to the country border and in to Azerbaijan. Armenia has used the diverted water for years including the period when they were not a sovereign nation. There are no apparent legal water rights issues associated with maintaining and rehabilitating the tunnel.

The timing of the tunnel repairs is very important. Currently, Armenia is expending resources to complete the Vorotan-Arpa tunnel. Since the tunnel is near full capacity during much of the planned seven month operating period, the Vorotan-Arpa tunnel would have to divert waters from the Vorotan River during periods when it is not available on the Arpa. The completed Vorotan-Arpa tunnel will sit idle most of the time if construction is being done during the period of November to March for four years. Lake Sevan would gain little from the new upstream tunnel. Complete shutdown of the Arpa-Sevan tunnel due to catastrophic failure for several years will completely negate any possible benefit from the upper tunnel.

8. CONCERNS AND ASSISTANCE OPPORTUNITIES

Based on our review of the AST situation, it is clearly important that tunnel rehabilitation be undertaken as quickly as possible. Delay in enacting a fix to the tunnel problems could result in complete failure of the tunnel and a much more expensive project to rebuild a complete failure; also, no water would be diverted to Lake Sevan at all in the event of a complete failure. Tunnel failures are very hard to predict and it is possible that one may not happen in the near future, despite the warning signs. However, at a minimum, the costs for fixing the tunnel problems will increase more and more each year, as the areas for rehabilitation grow rapidly. The rapid growth of cracks and other damage results from stress relief in a failed area being transferred to another area of the tunnel.

Review and Opinion

Based on a quick review of the work scope, it appears that the plan for rehabilitating the tunnel would be aided substantially by technical assistance from outside of Armenia. While the design team has experience with this particular tunnel, and several other tunnels within Armenia, they do not have the advantage of working in tunnel rehabilitation internationally. Thus, they do not have available the technology updates of tunnel and lining technology used elsewhere by tunnel engineering professionals. For this reason, it is quite possible that other technologies widely used around the world, but not used at present in Armenia might provide more effective repair measures for the tunnel.

One possible example of technology improvement may be a different type of repair to the sections with failing concrete block sections. A better solution may be the installation of circular steel sets, with inter-spaced reinforcing. These sets would be filled in with a thickness of fiber-reinforced, nozzle-applied concrete. This technique may be quicker to install, less expensive than placed pre-cast blocks and provide a better end product.

While the Hagler Bailly project team members have knowledge in tunnel engineering and construction, the team does not include specialized tunnel engineers; such expertise would greatly assist this project. The technology example provided, as well as many other current methods, could be considered for repairing the tunnel.

Other areas where outside technical assistance is desirable include analysis of the root problems of lining and other failure and in staging the work to be done to complete the rehabilitation. With appropriately designed rubber-tired vehicles used for the tunnel access, it is likely that it would not be necessary to re-activate both Shaft No. 3 and No. 4. Shaft No. 3 is much more expensive to re-activate than Shaft No. 4 and may serve to provide utilities and some access that cannot be achieved through the portals.

It also seems from a quick review that the estimated cost and schedule for two kilometers of tunnel lining rehabilitation is excessive, at the level of $10 million and four construction seasons. With proper planning, equipment and techniques, no more than two seasons of work should be necessary and at a lowered cost. However, this is only a general observation and does not reflect detailed study.

Technical Expertise

Technical expertise is needed in the form of a small team, perhaps two, of experienced tunnel rehabilitation engineers. Their work scope would be to provide a detailed tunnel inspection and review of existing designs, rock mapping and tunnel rehabilitation plans. They would need to work with the HydroProject Institute, the Enterprise and the Ministry of Agriculture to make recommendations and improvements to the existing repairs to increase the quality of the repair plan to current international design and method levels. The result should be a revised plan and work scope for bidding out the tunnel repair effort. Further, the tunnel cost estimate and schedule should be re-worked, using the best possible logistics of tunnel entry and work, related to the recommended designs.

It is estimated that about five to seven man-months of effort is needed with the work being done during the period when the tunnel is diverting water but is able to shutdown for several days of entry and inspection. In addition to this time, considerable support time for assisting the project may be necessary.

Technical assistance of some level may also be needed during construction. Final repair designs are typically made during actual construction, when in-situ conditions are fully exposed. Prior to construction and bidding, the anticipated conditions and associated repair are identified. A qualified engineer makes the final design decision on site. The contractor is paid his bid price for the specific repair directed by the engineer. Typically, reasonably accurate quantities of repair volumes can be made prior to bidding.

During the time of this review, all local individuals involved in the AST agreed that the rehabilitation effort could benefit considerably from outside technical expertise.

Funding

In addition to the technical assistance, funding would be of large benefit to the rehabilitation project. The tunnel is of vital importance to Armenia and the Government of Armenia has been

willing to provide some investment during the past several years. However, allocating the total amount required for this infrastructure investment from Government of Armenia sources will be very difficult. The tunnel does not directly produce any income, unless its cost is somehow recovered through a tariff collected on downstream water users, including agriculture and power generation. However, this means of raising funds runs somewhat counter to the need to preserve Lake Sevan and increase the lake's water level.

The European Community has shown a willingness to invest in the tunnel, providing a reported $800,000 for the past construction season. Potentially, several donor agencies could collectively fund the repair works.

However, as with new tunnel construction, it must be recognized that underground works such as the AST are relatively risky and expensive undertakings. Unanticipated conditions are common, requiring close management and auditing of the work when funds are being released. The project is much less risky than new tunnel construction, but the risk remains high that the funds could be expended and yet the job may not be complete.

It should be noted that for tunnel rehabilitation, final design is typically only completed during the actual construction. Thus, as the contractor in place encounters problems, the engineer makes a final decision on the exact repair to be applied. This situation, which is difficult to avoid, requires substantial cost control efforts.

In similar construction projects in the United States, there is a risk assignment mechanism by the contracting parties. Depending on the compensation method, the contractor and owner divide the risk. During the planning process, the type of contractor to be selected (domestic or international) should be decided and contract/risk documents should be designed accordingly.

As with new tunnel construction, the possibility that inadequate funding based on inadequate plans would be inappropriately managed and controlled is quite real. Any funding must be based on a clear plan to complete the project based on engineering plans, techniques implemented to maintain schedule and cost estimates assigned to a full work scope. Thus, providing funding without prior technical assistance is not recommended. Clearly there has been a great deal of various efforts including engineering that has been expended in the past two years, but outside funding should be contingent upon production of a clear and complete itemized work scope, with a realistic and scrutinized budget and schedule

9. SUMMARY OF FINDINGS

To summarize the findings of this review:

1. The Arpa-Sevan tunnel has about 2,000 meters in a severe state of deterioration. It is possible that a partial or full tunnel collapse could happen in the relatively near future, although precise prediction of such collapse is highly speculative.

2. If the rehabilitation of the worst areas, and possibly some other dilapidated areas is not done soon, the costs of the repair will increase considerably. Duplicating the existing tunnel might require capital investment of $200-300 million, thus the tunnel represents a valuable infrastructure project for the Republic.

3. There are no specific environmental or institutional issues associated with the repair, as it would only allow continued diversions as have occurred during the past 19 years.

4. The upstream Vorotan-Arpa Tunnel construction is continuing. The major rehabilitation works on the AST should be done before completion of the upper tunnel, or the lower tunnel will not be available for diversion of upper stream waters during the rehabilitation period.

5. The local authorities, including the HydroProject Institute and Ministry of Agriculture have produced a plan and documents for bidding out the rehabilitation work of the most severely damaged areas. The work estimate by the local group is scheduled to take four years and cost $10 to $13 million. The provision of technical assistance for the project design may possibly result in a faster and less expensive program, with better long-term results.

6. The project's continuing operation is critical in maintaining or increasing the level of Lake Sevan, even if water management/use controls are instituted.

7. The project has not been assessed from an economic perspective, due to the unique nature of the water supply, irrigation, power generation and environmental benefits from moving water to Lake Sevan. The continued operation of the tunnel can be considered essential for the maintenance of the lake.

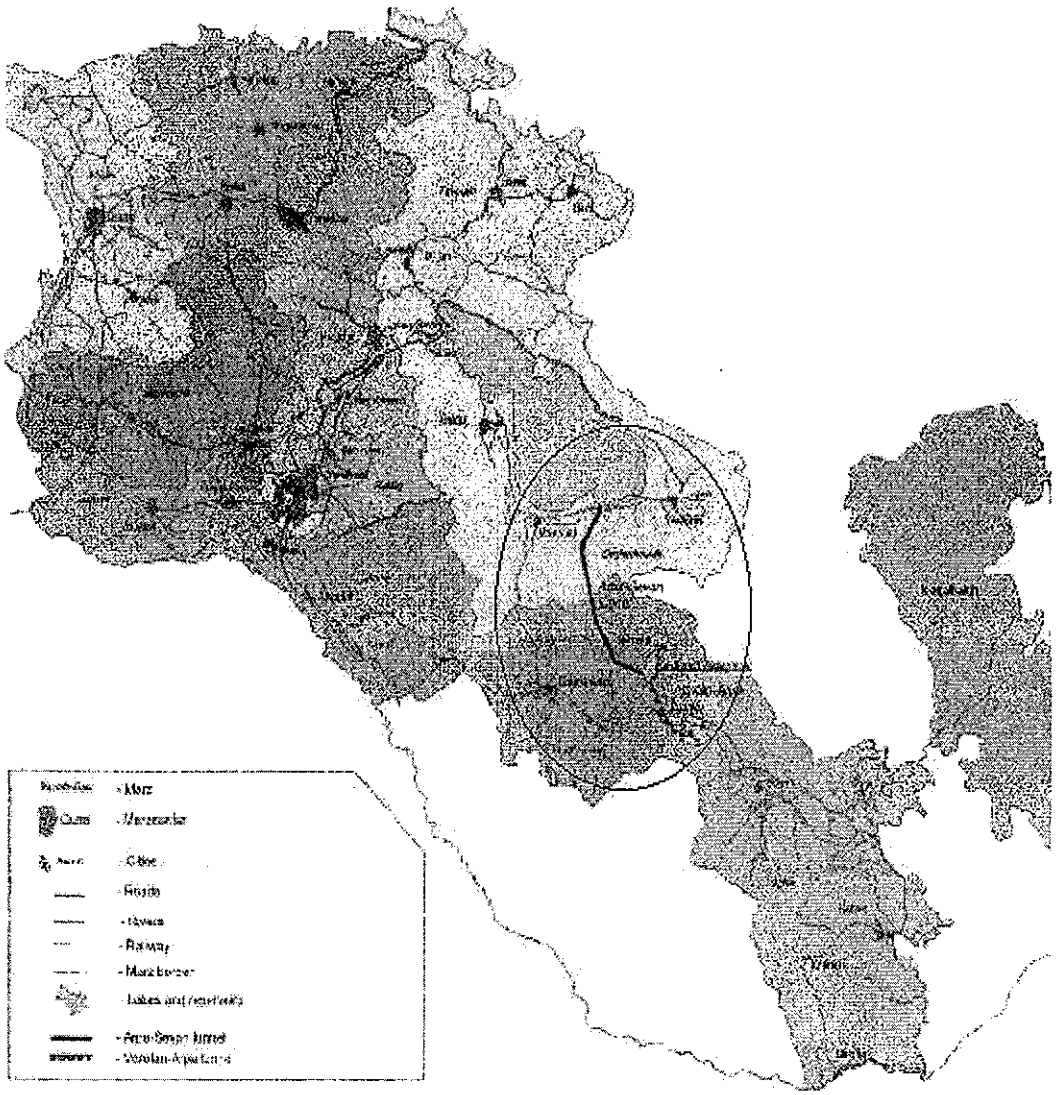
8. Due to prior participation in funding by the European Commission, there may be an opportunity for funding assistance by a group of donors.

9. If funding assistance is to be provided, it is recommended to be done only after technical assistance is completed. Funds should be disbursed contingent upon clear and independent verification of progress towards completion. Substantial engineering and planning work will be necessary to complete such a plan and its implementation.

ATTACHEMENT A

Location of Vorotan-Arpa-Sevan

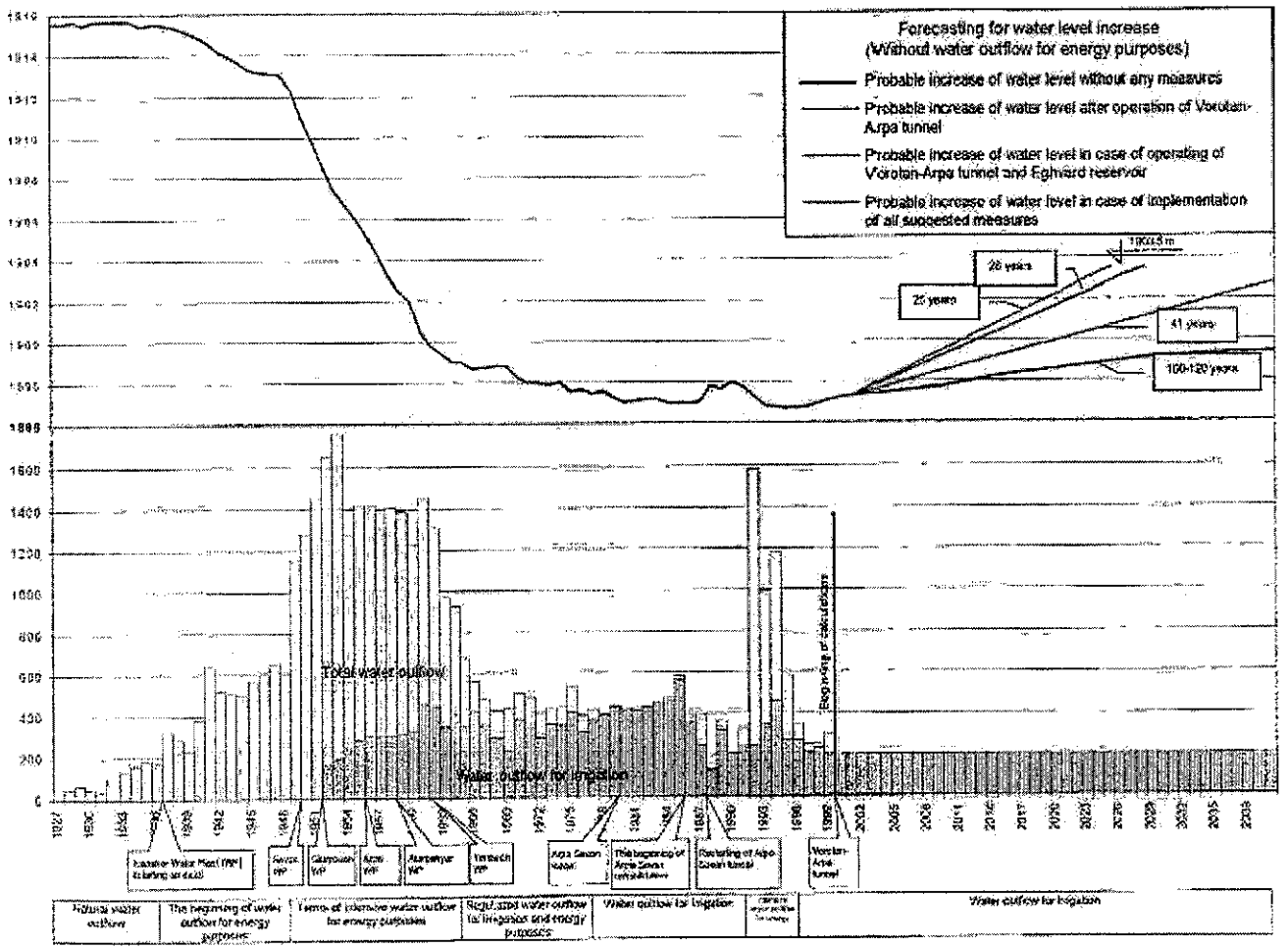
Diversion Project
(Restoration of Sevan Lake Water Level)



BEST AVAILABLE COPY

Water Level Variations of the Lake Sevan

ATTACHMENT B



Hagler Bailly

BEST AVAILABLE COPY

15.

BEST AVAILABLE COPY

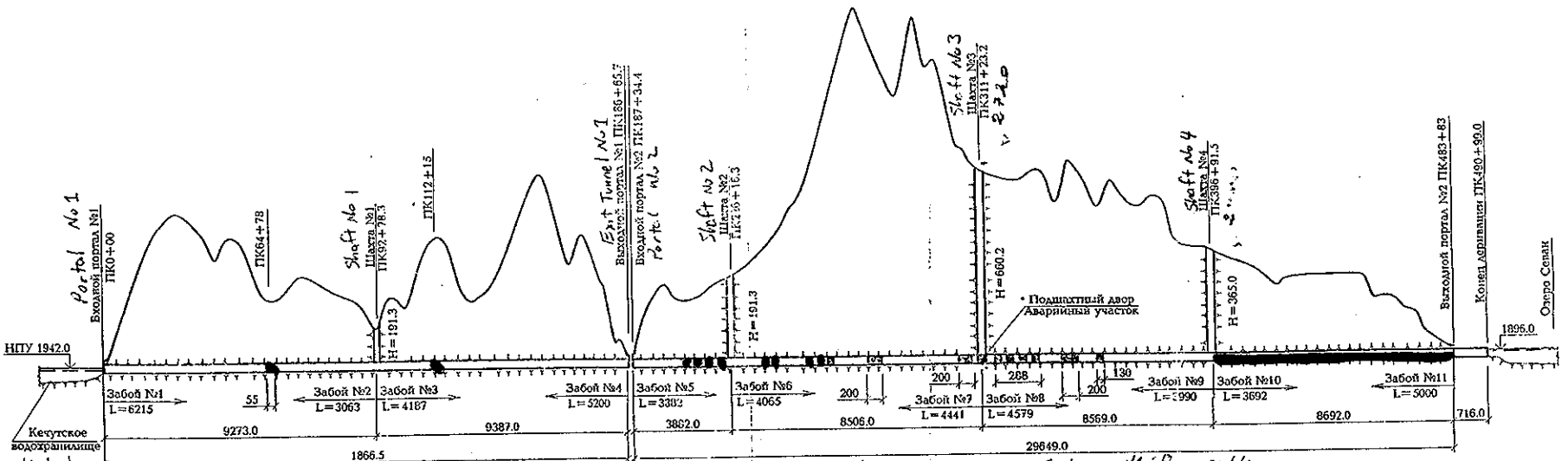
ARPA-SEVAN TUNNEL

ТУННЕЛЬ АРПА - СЕВАН

Оригинал
Экспонат 1
Exhibit 1

Продольный профиль

Vertical Profile



Cracks and Voids

Продольные трещины и пустоты за обделкой

cracks of 30 mm

Продольные трещины раск. до 30мм толщ. Деформация продолжается (2-3мм в год), процессы не стабилизируются. Обделка теряет прочность, разрушается. Общая длина деформационного участка L= 650м.

Total length 650 meters

Dangerous sections/Emergency

Аварийный участок

worstone L=341 m

Аварийное состояние на длине L=341м. Сборные ж/бетонные блоки б=0.5м(круглое сеч.) Обделка тунеля находится относительно устойчивом состоянии кроме длиной 130м от ПК359+10 до ПК360+40. Сборные ж/бетонные блоки б=0.2м(круглое сеч. приняло яйцевидное положение) опасность непрогнизируемого разрушения, L=288м. Типы X, V[a] на длине L=306м в аварийном состоянии.

Pending collapse

sections with floor problem

Разрушенные участки лотка

Дно лотка общей длиной 600-650м находится в аварийном состоянии.

Фундаменты припортальных подпорных стен нуждаются в восстоновлении

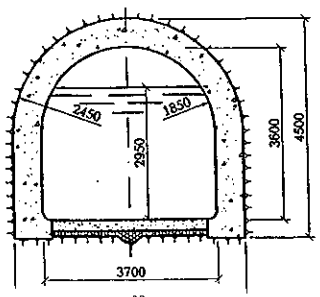
Fix invert and repair lining

В отводящем канале "Г"-обр.блоки стен находятся в деформированном состоянии.

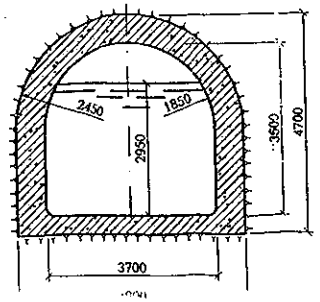
Основные типы поперечнего сечения

Basic type of section

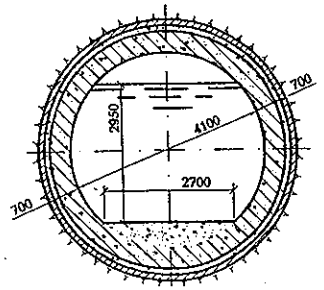
TYPE 5
ТИП V[a]



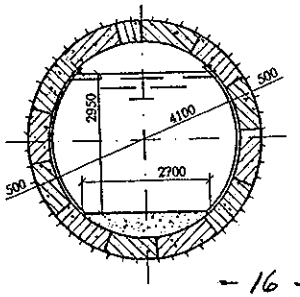
TYPE 10
ТИП X



TYPE 12
ТИП XII



TYPE 13
ТИП XIII



ATTACHMENT D

PHOTOS

PHOTO 1 - TEMPORARY STEEL IN POOR SECTION

PHOTO 2 – CRACKING AT TEMPORARY STEEL

BEST AVAILABLE COPY

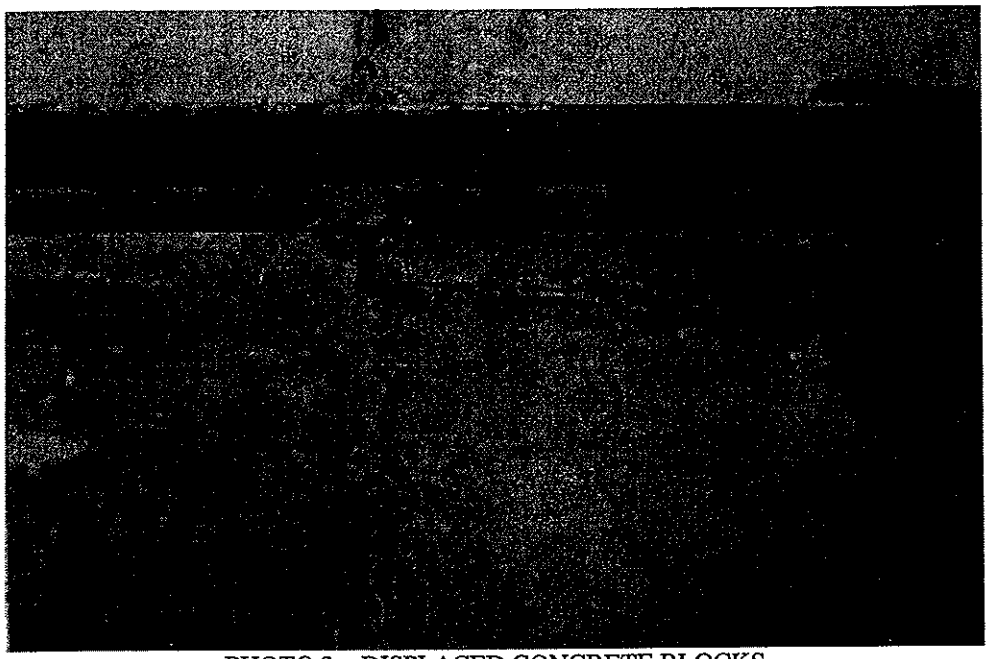


PHOTO 3 – DISPLACED CONCRETE BLOCKS

PHOTO 4 – ACTIVE CRACK IN SIDE WALL

BEST AVAILABLE COPY

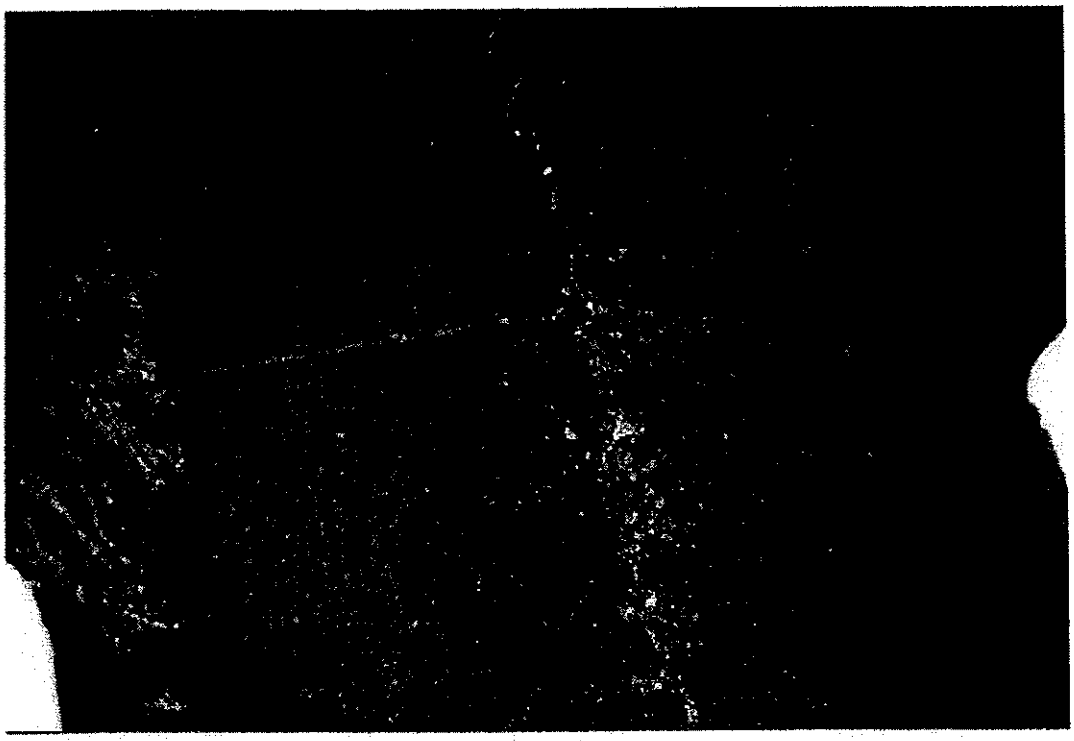


PHOTO 5 – FLOOR BUCKLING

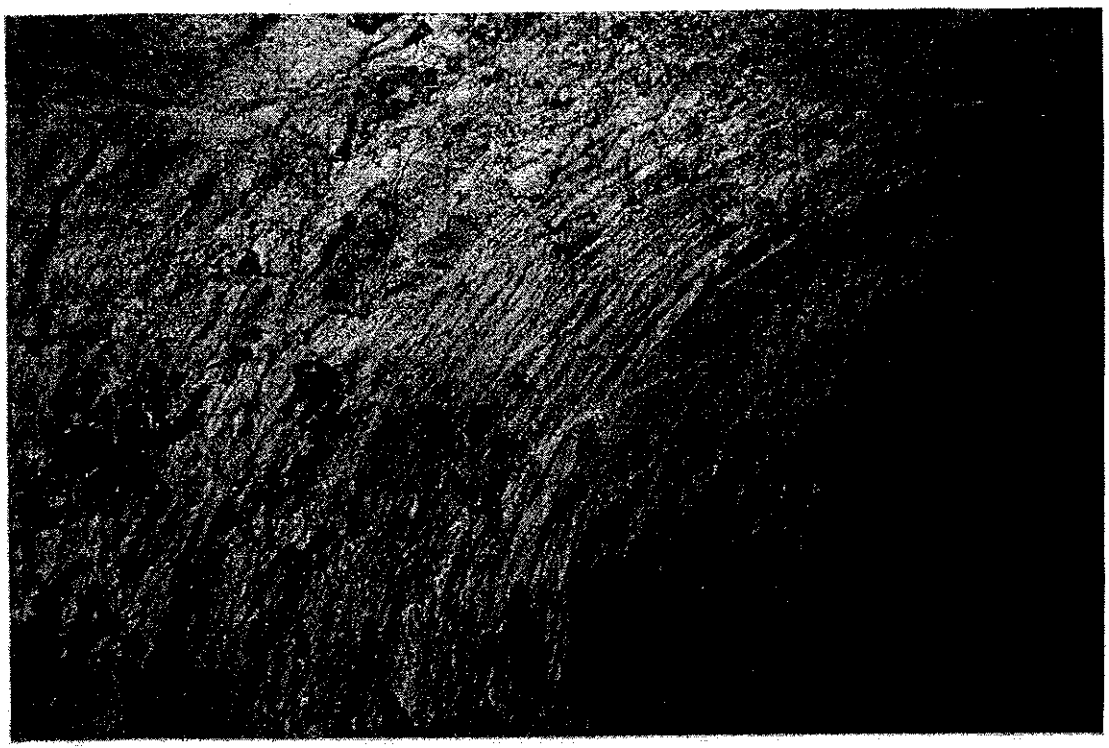


PHOTO 6 – CONCRETE CALCIFICATION FROM GEOTHERMAL WATER

BEST AVAILABLE COPY

PHOTO 7 – CONCRETE FALL OUT FROM CEILING

BEST AVAILABLE COPY