

Emergency Underwater Rehabilitation of the Poti Main Diversion Weir, Georgia

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SYNOPSIS. The Dam Safety Project (DSP) in Georgia, which is a part of the Irrigation and Drainage Community Development Project (ICDDP) financed by the World Bank, was implemented by Jacobs during the period August 2003–July 2004. The DSP project included four irrigation dams as well as the main diversion weir on the river Rioni at the town of Poti, the third largest town in Georgia and currently the busiest Georgian port on the Black Sea.

The diversion structure, which discharges flows of $4,000\text{m}^3/\text{s}$ through 10 identical openings, was constructed in the 1950's to protect the town of Poti from frequent flooding by the river Rioni. Scour problems related to the downstream pool of the diversion structure have been known for almost 50 years. Currently the structure operates at a verge of breakdown endangering the safety of the population in the town of Poti and nearby villages, as well as the important transportation links (Poti port, motorways and railways) and sustainability of the Black Sea coastal zone. Failure of the diversion structure would cause flooding of the Rioni-Khobi Drainage Scheme which has already been rehabilitated under the IDCDP.

As a part of the safety assessment, emergency rehabilitation works have been developed. The implementation of the emergency works by the IDCDP started in October 2004 and were completed in February 2006.

INTRODUCTION

Location and use

Poti is the third largest town in Georgia and is currently the busiest Georgian port on the Black Sea. The diversion structures across the Rioni river were constructed to protect the town of Poti from frequent flooding. They comprise a left bank regulator weir and the main weir, both located about 2km from the Black Sea. The diversion structures were designed by 'GidproVodKhoz' Design Institute from Moscow between 1948 and 1951.

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Construction of the structures started in 1952 and continued until 1959 when the structures were commissioned.

Since then, the main weir has also been used as the only road bridge across the Rioni river that leads to Poti. During the last decade the traffic across the bridge has intensified and the bridge, also known as the “Euro – Asian bridge”, has been used for transport of heavy goods to and from the Port of Poti.

Description

The diversion comprises two independent weir structures (see Figure 1), namely:

- the left bank regulator which discharges $400\text{m}^3/\text{s}$ into a canal that goes through the town of Poti and
- the main weir which contains ten openings that discharge up to $400\text{m}^3/\text{s}$ each, and divert the river flood flow towards the Black Sea, away from the town of Poti.

The left bank regulator weir is placed at an angle of 120° to the axis of the main diversion structure. This weir is 80m long and has 20 sluice openings. Each opening was designed to discharge $20\text{m}^3/\text{s}$ and is regulated by a vertical lift gate.

The main diversion structure is approximately 180m long and is located across the Rioni river channel and was designed to discharge flows of up to $4,000\text{m}^3/\text{s}$. The structure consists of 10 identical sections; each section is 17m wide and 19 m long. The main piers (11 Nos) which support the superstructure are 3m wide and are located at 17m centres. Each opening (see Figure 2) is 14m wide and contains a radial gate 14m x 4m high. Maximum upstream water level is at +4.21m and minimum downstream water level is at -0.61m with respect to the Black Sea datum. The spillway slab is 2.2m thick and 14m by 19m in plan and spans between two piers. The spillway slabs have energy dissipators in the form of a row of “teeth”. There is a 20m wide and 1.4m thick stilling slab downstream, followed by a 40m long downstream apron consisting of 2m square slabs each 0.4m thick. Upstream from the weir there is a concrete apron 15m long and 0.6m thick.

The structure was constructed in the dry with the river being diverted. To ensure that the foundation remained dry, a timber piled wall was installed on the downstream face of the structure and a steel sheet pile wall was installed on the upstream face. The construction was carried out in 17m long and 19m wide sections and it appears that there is no structural connection between the section with main joints on the axis of the piers.

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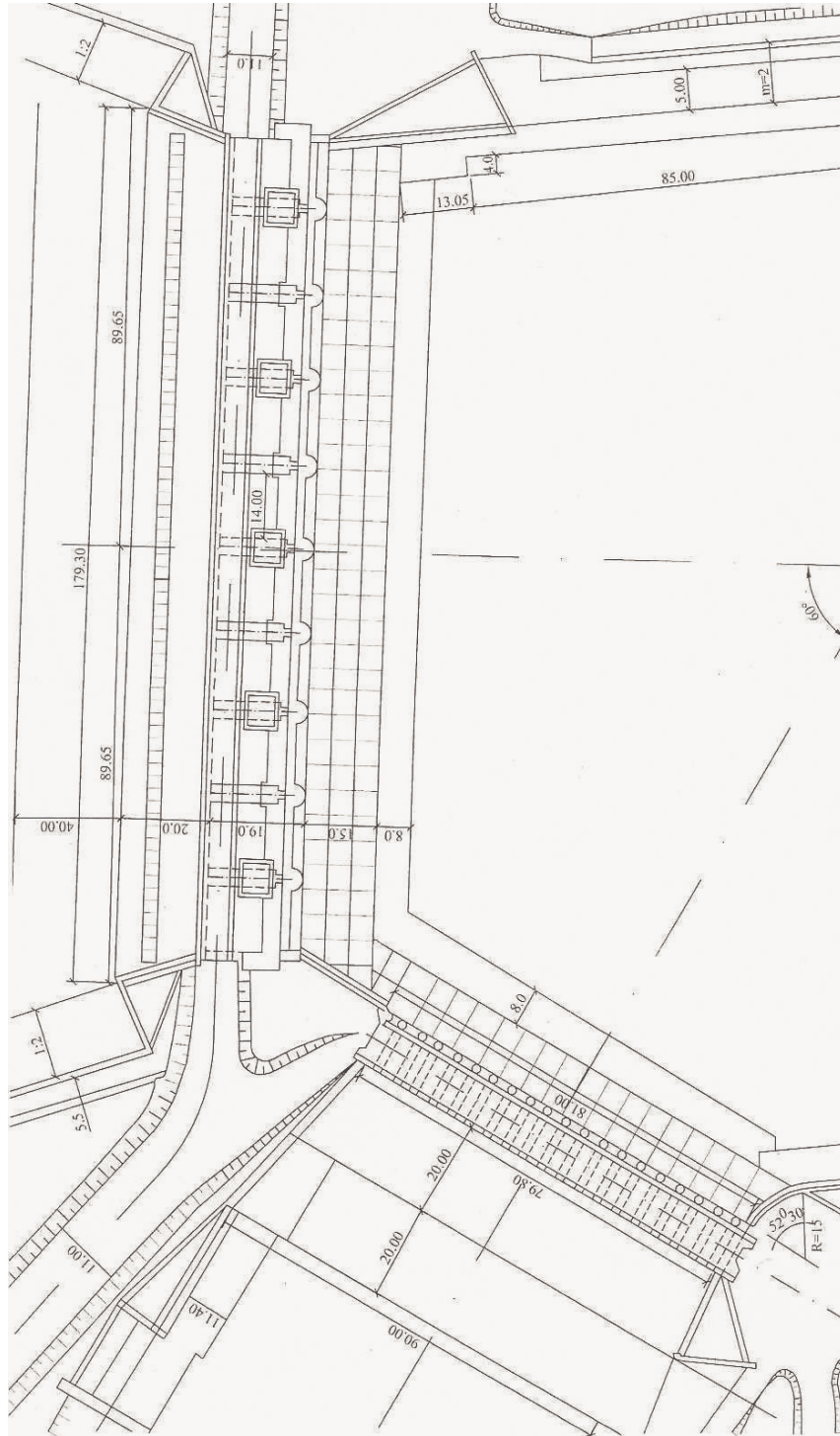


Figure 1: Plan of Diversion Structure

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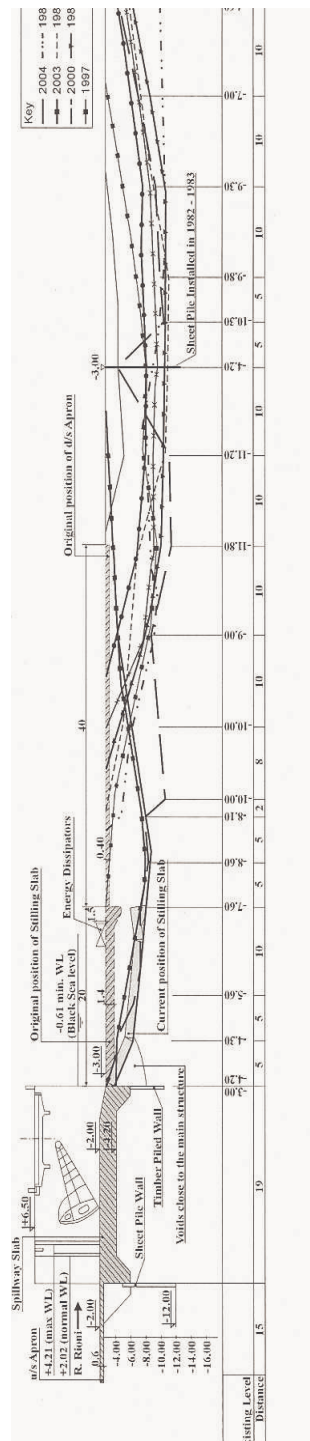


Figure 2: Section Through the Central Opening and Development of Scour

History of scour problems

Problems related to the main diversion structure have been reported for almost 50 years. The Institute of Water Industry and Engineering Ecology of the Georgian Academy of Science (hereinafter IWIEE) was commissioned in 1957 to carry out underwater observation of the diversion structure. It was reported by IWIEE that scouring of the downstream pool started immediately after the facility was put into operation. Figure 2 shows the progress of erosion of the downstream pool, and the river channel deformation at the central opening of the main weir.

At the end of November 1959, immediately after completion of construction, the first flow was passed through the left bank regulator (400 m³/s) and into the Poti city canal. This flow damaged the downstream apron of the regulator. Scour of the river bed, just downstream of the apron of the main weir was also recorded. During the July 1963 and July 1966 floods the flow in the Rioni reached 3,000-3,400 m³/s. The flood caused up to 6m deep scour downstream of the apron of the main weir, and by the end of 1967 the scour depth reached elevation -10m and was getting closer to the downstream apron.

In the late 1970's, under flood flow of 2,500m³/s, the scour in the river channel immediately beyond the stilling slabs of the main diversion structure came very close to the stilling slabs (see Figure 3). The condition was considered to be an emergency, and in 1981, following the IWIEE recommendations, "GruzGiproVodKhov" (now Georgian Water Project (GWP)) from Tbilisi developed a design for the rehabilitation of the downstream apron. The design comprised the installation of a steel sheet pile wall across the river channel, at a distance of 80m from the weir, and backfilling of the eroded space with large size riprap to the original elevation of -3m. The rehabilitation works were implemented in 1982-83. However, it became apparent in the following years, that these measures did not improve the condition of the downstream apron. On the contrary, they enhanced the scour and further deterioration of the downstream pool (see Figure 3). Data from surveys carried out over the period 1986-1992 showed that the scour continued to increase. The scour was also fostered by incorrect gate regulation during floods of the river Rioni, whereby the river discharges were continuously passed only through the central sections.

Observations made in 1998-1999 revealed that the scour was progressing further. The scour depth was 6-10m, and extended to the edge of the stilling slabs.

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In 2001 GWP was commissioned to carry out the design of the emergency rehabilitation measures. The design was put on hold several times due to a lack of funds. The survey carried out in July 2003 showed that the condition of the downstream pool had worsened: the apron was completely demolished over the whole width of the weir and the stilling slabs were demolished in the four central sections (see Figure 3).

Under the DSP in Georgia, which is a part of the Irrigation and Drainage Community Development Project (IDCDP) financed by the World Bank, Jacobs carried out safety evaluation of the main structure during the period August 2003–July 2004. An underwater survey was undertaken as a part of the safety evaluation and the results showed that the foundation condition had deteriorated rapidly since the last July 2003 survey, in that the erosion had now progressed close to the main structural foundation of the central piers. Emergency rehabilitation works were recommended under the DSP and the implementation of the emergency works was carried out from August 2004 till March 2006.

INSPECTIONS AND SURVEYS

The following inspections and survey were undertaken under the DSP:

- Inspection of the hydromechanical and electrical equipment of the main diversion structure and the left bank regulator
- Inspection of records of geodetic survey
- Underwater survey by divers and the bathymetric survey
- Supplementary geotechnical investigation

Due to aged hydromechanical and electrical equipment and a lack of maintenance funds, many parts of the equipment were out of operation; i.e. the main regulator could only discharge river flows through the central gates.

An underwater survey by divers and the bathymetric survey were carried out from January–March 2004. The survey was first carried out when all the gates were closed and it was subsequently repeated after the gates had been open and the sediments had been flushed. Conclusions from the survey were:

- It was found that the downstream erosion line was highly dependent on the operational regime of the gates and the flow of the sediments, related to the volume of the discharged water.
- Scour was taking place at the edge of the main structural foundation in the area of the central sections and pier No 5 where 3-4m deep voids were encountered (see Figures 2 and 4).
- The stilling slabs had been completely demolished in the central sections and partly in the remaining sections.

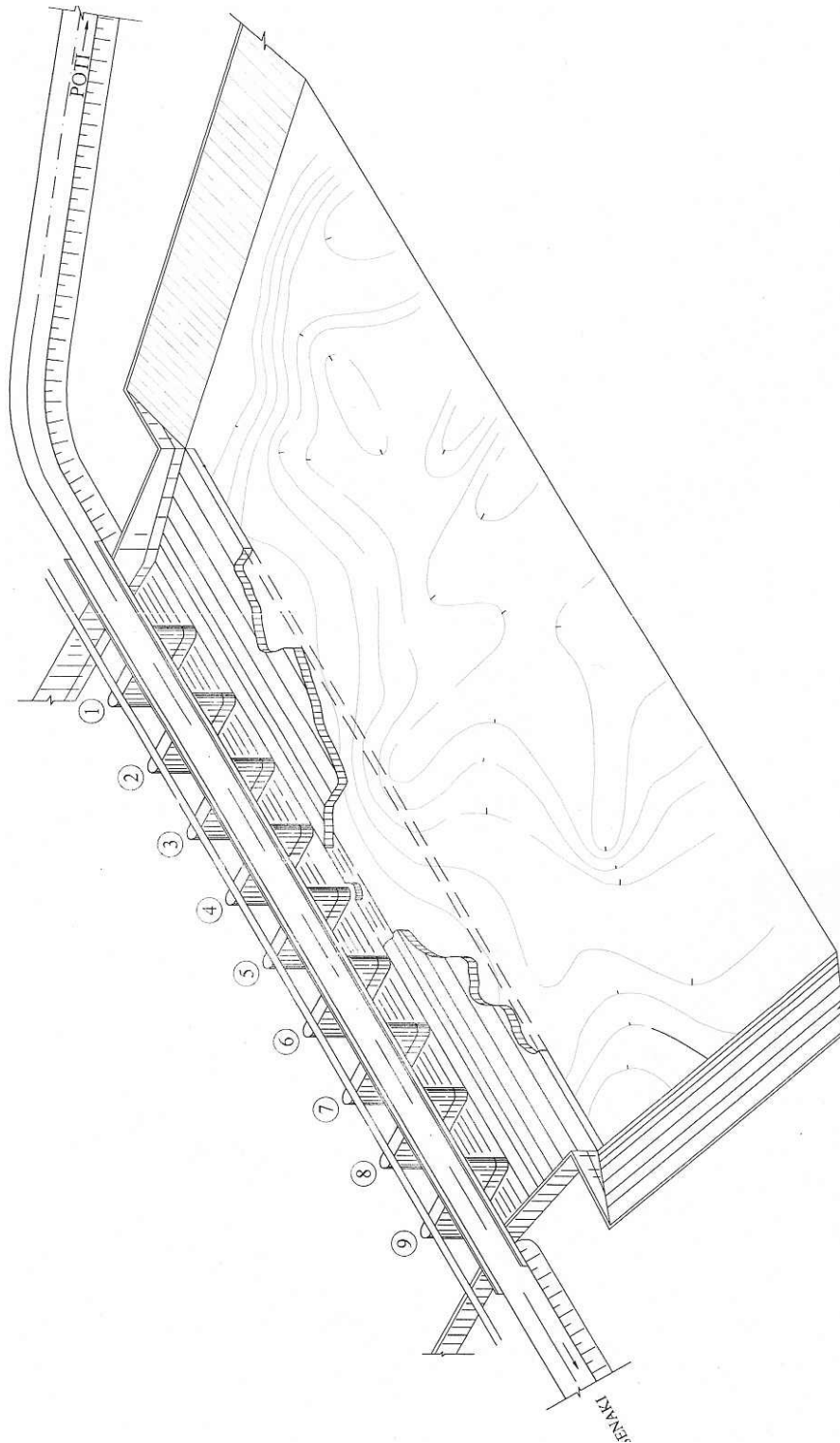


Figure 3: Extent of Damage of the Downstream Pool

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- The downstream apron had been completely damaged and largely disappeared
- The upstream apron had been damaged in the central part; the last 5m of the apron slab had been damaged over a length of 100m

A small scale supplementary ground investigation was also carried out under the DSP. The investigation included drilling of one 60m deep borehole on the left bank of the river Rioni, with in-situ permeability and penetration testing and laboratory testing.

SITE CONDITIONS

Hydrological Conditions

The river Rioni has a catchment of 13,400 km² which covers about 50% of the whole western Georgia. About 68% of this catchment is on the southern slopes of the Great Caucasus Mountain. The river is fed by both rainfall and snowmelt.

The maximum flow usually occurs in May-early July and is typically 2,300-2,400 m³/s. However, a maximum flow of 4,850 m³/s was recorded during the flood in January 1987 which was associated with rainfall causing early snowmelt.

The lowest flows in the river Rioni are during the months of August, September and October when the typical flows are 280-320 m³/s.

The main diversion weir was designed to discharge 4,000 m³/s and the left bank regulator discharges 400m³/s. However, the canal leading to the town of Poti was silted up and could only discharge 250-300m³/s.

Geological and Geotechnical Conditions

The geology of the Poti area, situated in the Kolkheti depression is dominated by sedimentary deposits from the Holocene period which are of lacustrine origin. These sediments form the entire central part of the lowland and reach several hundreds meters in thickness. Lithologically, these formations consist of clays, silts and peat, whereas the underlying strata include sands, silty sands and silts.

The main founding strata of the diversion structure are the silts with occasional lenses of sand and peat.

Seismic conditions

The Kolkheti depression which, from the tectonic point of view, is the western end of the Georgian depression is bounded by major folds and active faults.

A Probabilistic Seismic Hazard Assessment (PSHA) to determine site specific seismic design parameters, namely the macroseismic magnitude (I) and the peak ground accelerations (PGA). The results of the PSHA showed that the maximal credible macroseismic intensity in the Poti area is I=8, with an average recurrence period of 1,624 years. The maximum credible bedrock PGA = 0.22g, with an average recurrence period of 8,673 years.

Due to the very weak and unfavourable foundation soils at the site a special concern was the amount of the seismic acceleration amplification that can take place through the soft foundation deposits. A site specific modification of the bedrock PGAs was carried out using the computer software which models one dimensional propagation of the seismic waves. The results of the in-situ SPT tests were used to establish the model for the seismic wave propagation. The analyses showed that the bedrock PGA of 0.22g would be amplified to 0.60g.

ANALYSES CARRIED OUT

Based on the results of the visual inspection, underwater survey, supplementary site investigation and the site specific seismic assessment, three main areas of concern were identified related to the safety of the main structure. They are as follows:

- Can the structure withstand the hydraulic forces?
- Can the structure withstand the seepage forces?
- Can the structure cope with a potential loss of bearing capacity due to the 3-4 m deep voids under the foundation and increased hydraulic gradients?

All these areas of concern were analysed and are discussed in the sections below.

Hydraulic Studies

In order to understand the mechanisms which caused the failure of the downstream apron and the stilling slabs, the original design was studied and compared with good hydraulic engineering practice. The impact of the operational regime of the weir was also studied as well as the rehabilitation measures that were implemented in the early 1980's.

The causes of failure of the downstream apron and the stilling slabs could be grouped under three main headings:

- inadequate original design

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- inappropriate operation of the gates
- inappropriate design of the rehabilitation works implemented in 1982-1983

Inadequate original design

The following are the main points identified:

- The spillway slabs and downstream apron are located at high level (-3m) causing high velocities and erosion
- The stilling slabs and downstream apron were of inadequate thicknesses. The slab thickness was determined on the basis of seepage uplift pressures, as measured in a model for the following design conditions, which gave a factor of safety against uplift of 1.47:
 - Normal water level in the upstream reach is at +2.02m,
 - Minimum water level in the downstream reach is at -0.61m (Black Sea level)
- The design condition did not take into account the following:
 - during discharges of less than 300 m³/s the lowest surface level of the jet flow is -1.03m (i.e. below the sea level of -0.61m). In this condition the head at the upstream end of the slab increases by some 20% and reduces the factor of safety to uplift pressure from the design value of 1.47 to 1.17
 - influence of the dynamic loading on the slab was not taken into account
- A row of energy dissipator blocks such as teeth do not work very efficiently

Inappropriate gates operation

The stilling slabs were originally designed in such a way that their stability and safety strongly depended on the correct gate operation regime. However, the operation regime of the gates has frequently been violated, mainly due to a lack of automatic gate controls, failure of gate hoists and shortages in power supply.

It was shown that the uplift pressures increased when flows of less than 300 m³/s are passed through one or two gates, in the case when the gates are opened before the water levels downstream are steadied and the flow volumes are equalized. In such a case the shallow depth downstream appears to be insufficient for “drowning” the jump, so that the jet flow drives away the downstream waters, causing decreased pressures over the slab and increased uplift pressure. With the gates open, this condition can cause the slabs to lose their stability and start vibrating between the neighbouring slabs, indicating that the design slab thickness of 1.4m is not adequate.

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Inappropriate design of rehabilitation works implemented in 1982- 1983

The main inadequacy of the design of the rehabilitation works is that the design did not take into account the erosion processes in the river channel. The design provided for the riprap backfill to come up to the original level of -3m, and without the layer being extended to the line of the sheet pile wall. Due to the inadequate rehabilitation and absence of bedding layers underneath the riprap backfill, the river bed under the riprap was soon scoured and the stone blocks, that had themselves fostered the flow turbulence, sank into the weak foundation soils.

The sheet pile wall installed 80m downstream from the structure increased the scour depth by 25-28% and encouraged the scour line to move closer to the main structural foundations.

Seepage Analyses

It was noted that in the original design, seepage analysis was undertaken assuming isotropic soil conditions which is an unsafe assumption bearing in mind that, due to their nature of deposition, the sedimentary soils are known to have a significant anisotropy. Therefore in the seepage analysis careful consideration was given to estimating hydraulic gradients at the point of exit.

The seepage analysis was undertaken for the following design conditions:

1. Isotropic condition; horizontal permeability coefficient, k_x , is equal to vertical permeability coefficient, k_y , with upstream apron and stilling slabs present but with no downstream apron
2. Isotropic condition, $k_x = k_y$, with upstream apron only
3. Isotropic condition, $k_x = k_y$, with no stilling slabs, and no upstream apron
4. Same as Case 1 but anisotropic condition, $k_x = 10 k_y$,
5. Same as Case 2 but anisotropic condition, $k_x = 10 k_y$
6. Same as Case 3 but anisotropic condition, $k_x = 10 k_y$

The analyses showed that the actual hydraulic gradients are likely to be higher than the critical hydraulic gradient against piping failure for cases 5 and 6. This logic indicates that some internal erosion of the foundation is likely to have taken place in the areas where the downstream apron and the stilling slabs are damaged leading to their progressive destruction.

Structural Bearing Capacity

Structural bearing capacity was checked in order to estimate:

- The influence of the voids close to the structural foundation
- The influence of increased hydraulic gradients due to the damaged downstream pool

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Structural bearing capacity checks found that, due to the voids and increased hydraulic gradients, the actual bearing capacity of the soil close to the pier No 5 could be expected to be reduced by 20%.

Conclusions of the analyses

It appears that the initial and the main causes of the events that damaged the stilling slabs and the downstream apron of the main diversion structure are related to inadequate hydraulic design of the downstream structural elements (the stilling slabs and the apron slabs were too thin and placed at a high elevation). These problems were however enhanced by irregular operation of the gates and installation of the sheet pile wall, as a part of the 1980's remedial works. For many years the water was discharged through the central gates only, so the damage to the stilling slabs and the downstream apron is extensive in the central area.

As a consequence of the damage of the downstream apron and the stilling slabs in the central section, the water seepage path has been shortened and consequently the exit hydraulic gradients have increased.

It was also shown that the erosive processes were likely to affect the bearing capacity of the soil underneath the main foundation of the pier No 5.

RECOMMENDED EMERGENCY REMEDIAL WORKS

Following the conclusion of the analyses, emergency rehabilitation works were recommended under the DSP. As it was not possible to divert the river away from the weir, the emergency rehabilitation works had to be carried out under water, but during a complete closure of all ten gates. The flow of less than 400 m³/s had to be diverted via the left bank regulator into the Poti canal. The following were the recommended actions:

1. Prohibit the use of the diversion structure by heavy traffic until emergency rehabilitation works are implemented. This was recommended by the DSP and was endorsed and implemented by the Georgian Government in March 2004.
2. Rehabilitate hydromechanical and electrical equipment on the main regulating structure and the left bank regulator
3. Clear the Poti canal so that flows of up to 400 m³/s could be discharged through the left bank regulator
4. Backfill the voids (approximately 500m³) close to the structural foundation, in the areas of the central sections and the pier No 5, that are associated with erosive processes and are likely to have impact on the structural stability (see Figure 4). This was carried out by placing sand-cement-clay mix underwater through tremies installed through voids identified in the broken stilling slabs, close to the structure. Prior to the

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backfilling a site trial was carried out to check the exact mix and the pumping pressures. Quality of backfilling works was checked by drilling and sampling of the backfilling.

5. Reinstatement of the stilling slabs (approximately 1,600m²) and the downstream apron (approximately 7,200m²) in the areas where the slabs and the apron are damaged (see Figure 4). This was carried out using Maccaferri gabion baskets (2m x 2m x 1m) which were assembled on the river bank, dropped into position from barges and subsequently interconnected underwater by divers. A geofabric was placed along the outer sides of the gabion baskets to prevent upward migration of the fines from the foundation soils into the gabions. Prior to placement of the gabions, a bedding layer of sand and gravel was placed over the scoured foundation to level the area. In places where the gabions were to be placed over broken slabs close to the main structure, smaller and more flexible cylindrical gabions were used. The cylindrical gabions were 1m long and 0.65m in diameter. They were also used at the ends of the “gabion structure” to provide a transition between the gabions and the natural river bed. Divers were employed to ensure that the gabions were properly placed and interconnected. An independent team of divers was employed by the implementing agency, Project Coordination Centre of the World Bank, to control the quality of the underwater works.

Detailed design of the emergency rehabilitation works was carried out by GWP under guidance and review by Jacobs. The total cost of the works was estimated by the GWP to be GEL 4M (approximately US\$ 2M). It was anticipated that the rehabilitation works would be completed within 140 days, between September 2004 and February 2005, when the flow in the river Rioni is the lowest. A local Georgian contractor was commissioned to carry out the rehabilitation works. Personnel from Maccaferri's Moscow office provided specialist advice on placement and connection of gabions underwater.

The implementation of emergency rehabilitation works started in September 2004 with rehabilitation of the hydromechanical and electrical equipment on the main regulating structure and the left bank regulator, and clearing of the Poti canal. These works were delayed and had impact on the programme of placement of the gabions. Between February and March 2005 the works were undertaken with full closure of the gates, except for a short period of three days at the end of February when the flood flow was about 1,400m³/s and gates 1, 8, 9 and 10 were opened. After passing of the 1,400 m³/s flow at the end of February, a bathymetric survey was carried out.

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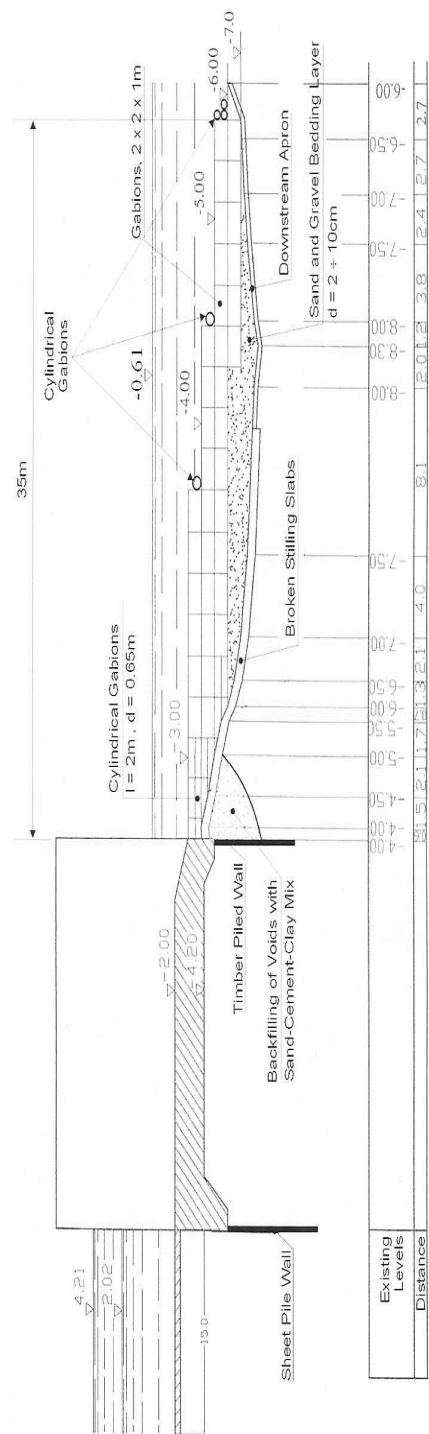


Figure 4: Emergency Rehabilitation Works- Longitudinal Section Through the Central Opening

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It was found that the bedding layer and the gabions installed had not been affected by flood discharge through gates 1, 8, 9 and 10.

The rehabilitation works had to be temporarily stopped on 15th April 2005 due to high flows in the river Rioni. By the 15th April backfilling of the voids, placement of the bedding layer and installation of gabions were completed in the central sections up to an elevation of –6m. The flood period lasted till mid August, with the maximum flood of 3,000m³/s being discharged through the weir at the end of April 2005. Underwater survey was carried out after the flood which showed that the gabions were unaffected by the flood releases, and that the river bed in the areas downstream of the placed gabions was not subjected to additional scouring. The works have since resumed and were completed in February 2006.

CONCLUSION

Inadequate design, inappropriate gates operation and a lack of maintenance fund over a prolonged period have brought the 50 year old main diversion weir on the river Rioni to the verge of collapse.

Rehabilitation measures implemented in the 1980's were not adequate and had encouraged further scour of the downstream pool. An other attempt to rehabilitate the structure at the beginning of 2001 led for the design to be put on hold several times due to a lack of funds.

Under the DSP financed by the World Bank, Jacobs carried out a safety evaluation of the main diversion weir during August 2003–July 2004 and proposed implementation of emergency rehabilitation measures. Detailed design of the emergency rehabilitation works was undertaken by GWP from Tbilisi under guidance and review by Jacobs with specialist input by Maccaferri from Moscow.

Implementation of the rehabilitation works started in September 2004 and was due to be completed by the end of February 2005. The implementation works were delayed due to a slow start of the contractor, lack of local experience with placement and connection of gabions underwater and requirements that an independent team of divers constantly checks the works. Works also had to be temporarily stopped for four months during the flood season when all the gates on the weir had to be open to discharge a flow of 3,000 m³/s. However, this flow did not pose any damage to the works installed. The emergency rehabilitation was completed in February 2006.