Somali Democratic Republic
Ministry of Agriculture

Mogambo Irrigation Project

Flood Relief Channel Head Regulator
Report on 1985 Scour Damage

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MOGAMBO IRRIGATION PROJECT

FLOOD RELIEF CHANNEL HEAD REGULATOR

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1. INTRODUCTION

The flood relief channel at Bulo Yaag, with its gated head regulator, was built in the 1950s to alleviate flooding in the banana plantations near the river downstream. The regulator is a concrete structure some 50m long with thirteen steel lifting gates each 2.15m wide and with a maximum clear opening height of 2.0m. It has a roadway 4.1m wide immediately downstream of the gates, which are operated by manual headgear on a walkway alongside the roadway (Figure 1). The invert at this structure is at a level of 10.1m above datum, but the channel invert was, at least by the late 1970s, significantly above that level, up to about 12.0 within the first kilometre. As a result, the discharge in the channel was, except for small gate openings, limited not by the regulator but by the channel. It is probable that the maximum flow was of the order of $20m^3/s$, although the regulator would be able to pass more than $100m^3/s$ if not drowned out. The level floor of the regulator extended 5m from the gates as a thick reinforced concrete slab, then a further 5.5m as an unreinforced concrete slab. The two slabs met in a stepped butt joint (Figure 1).

The regulator is normally operated by the Ministry of Agriculture on the basis of flood warnings from up-river and of requests from banana plantation owners and farmers.

The original MIP Feasibility Study by TAMS/FINTECS (1977, ref.1) proposed that the flood relief channel should be retained and should discharge into the irrigation project's main drain. The Supplementary Feasibility Study of 1979 (MMP, Ref. 2) also proposed the retention of the channel, after considering and rejecting the alternative of closing it and accepting the consequent increase of flooding of the banana plantations, or the need for higher bunds to protect them. But the channel's discharge was to be led round the north and west perimeter of the project (ref. 2, Annex 5, Chapter 1). This proposal was accepted and the flood relief channel was remodelled and, in part, realigned (ref. 4, Plates 5, 18, 19). The channel bed was lowered so that it began at the regulator invert level (10.51m above datum) and sloped at 0.00029. This enabled the channel to pass, probably for the first time, the full design discharge of $100m^3/s$. At the same time the regulator's erosion protection was extended: a gabion mattress was laid extending 8m downstream from the older concrete apron slab, its downstream end being 1m below the channel bed level (Figure 2). The banks were protected by gabion mattresses with a small turn-down.

2. THE 1985 FLOOD

2.1 Observations

In May 1985 a river flood occurred and the flood relief channel was used. The highest river level was 12.9m above datum, and when the river level was 12.4 the water level 200m downstream of the regulator was 12.1. The gates were opened by local residents but detailed records of the sequence of events were not kept. The central seven gates were opened but the outer six of the thirteen gates were kept closed and therefore the flow was concentrated in the middle of the channel.

When the flood receded it was found that a large hole had been scoured in the channel bed immediately downstream of the regulator. Opposite the central five bays of the thirteen-bay structure the gabion mattress and concrete apron had been undermined and had dropped into the hole, and the soil had been scoured out from underneath the regulator base slab. Over a width of about 4m this scour had reached the downstream face of a deep vertical cutoff wall under the gates, but the strip of this face that was exposed was only 200 to 300mm deep. The base slab did not fail or move and remained spanning the void. Apart from the structurally independent downstream apron, there was thus no damage to the regulator, and no water flowed under the structure.

Figures 3 and 4 and Photographs 1 to 5 show the extent and nature of the damage. Over almost the whole width of the channel the new gabion mattress remained intact and lined the sides of the scour hole, even at slopes steeper than 45°. Centrally it fell by up to 5m but moved less than 1m in a downstream direction (remnants of gabions visible at the downstream end of the scour hole, Photographs 4 and 5, came from an old gabion sill, presumably placed many years ago, and have nothing to do with the gabion mattress). The central downstream part of the old concrete apron, about 300mm thick and unreinforced, broke into several pieces which fell partly on top of the gabion mattress (Photograph 2). The rest of the central third of the concrete apron, 500mm thick and unreinforced except for a very lightly reinforced small downstand beam, broke into a few large pieces (Photograph 3).

2.2 Causes of the Damage

The hydraulic characteristics of the regulator and the flood relief channel are such that, if some of the gates are opened while others are shut, or if gates are opened rapidly, the tailwater level immediately downstream of the structure can be too low to make the hydraulic jump occur on the apron. This would cause high-energy supercritical flow to extend onto the unprotected channel bed and to scour it. It was to protect the structure from the effects of such scour that the gabion mattress was laid in a gentle slope (1:6) down to 1m below channel bed level (Figure 2).

During the 1985 flood, with the outer six gates shut but overtopped, it is estimated that some 60 to 70m^3/s passed through the central seven gates. This means an intensity of flow (discharge per unit width) roughly 30% higher than the design condition (100m^3/s through thirteen gates). It seems most probable that this high intensity, coupled with a relatively low tailwater level corresponding to 70 or 80m^3/s flowing down the recently remodelled relief channel, caused the supercritical flow to extend beyond the new gabion mattress in the middle of the channel, even after scour had lowered the bed by 1m. The scour hole would then have undermined the gabion mattress, which, being flexible, was able to subside and line the scour hole. It appears however that the slight movement of the gabion mattress allowed turbulent water flow to penetrate between the downstream edge of the concrete apron and the gabion mattress, and then to undermine the apron. This would lead to progressive collapse of the unreinforced apron. Because the apron was not positively attached to the regulator base slab, but only resting on a step in the interface (Figures 1 and 2), this would immediately expose the soil under the apron and immediately downstream of the base slab to the scour action of turbulent water with energy corresponding to a velocity of about 5m/s. It was evidently this scour which eventually reached the underside of the 1.2m deep beam along the edge of the base slab, undermining it and part of the slab itself.

Since the damage to the apron was confined to the central seven bays, and the undermining of the base slab to the central five, it is considered that such damage as there was is attributable primarily to the unfortunate concentration of flow through the central seven gates. The additional erosion protection, i.e. the gabion mattress, was evidently not sufficient to withstand the unexpectedly high flow intensity, although it performed well in the outer bays and demonstrated the advantages of its flexibility by the way it lined the scour hole.

3. REPAIR WORK AFTER THE 1985 FLOOD

3.1 General

At the request of MIP, Sir M. MacDonald and Partners Ltd. sent a specialist to site from 14th to 18th September, 1985 to inspect the damage caused by the 1985 flood and to design repair works. The approach taken was to seek a low-cost solution that would be less susceptible to scour due to concentrated flow or low tailwater than the previous arrangement. Calculations showed that it was desirable to drop the bed downstream of the regulator by at least 1.5m while still providing a lining capable of resisting high velocities. This would ensure that the hydraulic jump would start on this hard bed. Then the bed should be protected for another 8 or 10m in a downstream direction, so that the jump would have dissipated most of the concentrated energy of the water before the fine-grained soil was reached. It was also decided that gate stops would be recommended in order to set limits to the intensity of flow through any one gate bay while still allowing $100m^3/s$ to be discharged. Advice on operation has been given which should, if followed and in conjunction with the proposed works, make significant damage in future floods very unlikely.

3.2 Repair and Reconstruction Measures

The possibility was considered of destroying the remainder of the concrete apron, opposite the outer 6 or 7 bays where it remains intact, and constructing a new, low-level stilling-basin over the full width of 46m. This would have been very expensive and time consuming in itself, and would also have required either the reconstruction of the entire bank protection works or the construction of vertical side walls. Hydraulic calculations showed that with a low-level stilling-basin downstream of it a gate would be able to pass $12m^3/s$ without severe scour (an intensity of $5.6m^2/s$ through the gate, and 3.6 on average in the stilling-basin). For a gate without a low-level stilling-basin, i.e. with the cross-section of Figure 2, discharge would be limited to about $5m^3/s$ (i.e. intensities of 2.3 and $1.5m^2/s$ respectively), which requires a tailwater depth to initiate a hydraulic jump of only about 0.6m. Since the scour hole opposite the central 5 gates makes it relatively cheap and quick to construct a deep stilling-basin there, it was decided to allocate the flood relief channel's design discharge of $100m^3/s$ as follows:-

$60m^3/s$ through the central 5 gates at $12m^3/s$ per gate,

$40m^3/s$ through the outer 8 gates at $5m^3/s$ per gate.

For this purpose gate stops would be installed to prevent the outer 8 gates from being opened more that 0.5m and the central 5 gates from being opened more than 1.5m. This would allow the structure to pass $100m^3/s$ with a river level of about 13.0m above datum.

The repair and modification works were then designed on site by 18th September, 1985, and are shown on Figure 5 (Drawing M2/13.S). In the interests of rapid construction and low cost, the low-level stilling-basin follows as closely as practicable the shape of the scour hole. Over the central 18m, the first 7m downstream of the edge of the intact base slab is heavily armoured with a jointed concrete slab designed to resist high velocity but still be slightly flexible and thus relatively invulnerable to undermining or differential settlement (section CC of Figure 5). The next 7m is protected by a new gabion mattress, the old one being left in place below it as a second line of defence against the unlikely event of deep scour. This new gabion mattress is to be at a level of approximately 8.0, i.e. 2.5m below the regulator floor, because this gives more than adequate tailwater depths and because deeper location would make dewatering during construction unnecessarily difficult. Backfill of the scour hole below this new mattress can be done with any readily available material. The broken pieces of the old concrete apron can be placed beyond the downstream end of the new mattress, to provide an additional armouring effect. In principle no remedial measures are necessary at the downstream edge of the scour hole, although some general tidying-up would be desirable. This can cheaply be combined with the construction of the necessary access ramps for the proposed work.

To protect the soil and backfill below the new jointed slab and mattress from erosion and piping, while still allowing drainage of pore water to prevent uplift, filter cloth is specified under the whole area. To prevent separation of one element of the system from another, the slab is to be anchored into the mass concrete under the base slab and the mattress is to be firmly attached to the downstream edge of the jointed slab. (As a minor improvement to the details shown on the drawing of September 1985, it is suggested that a lip be formed at this edge if practicable, to encourage the early lifting of the jet in the hydraulic jump). The jointed slab is also to be reinforced in the upstream-downstream direction by 22mm bars near its underside. These, together with keys and compressible joint filler, will provide a hinged effect allowing accommodation to subsoil movements but preventing shear displacements and separation of blocks.

The protection downstream of the outer six bays is to be restored to the state of early 1985 (Figure 2), except that the gabion mattress is to be attached to the downstream edge of the old concrete apron and the attachment of gabion baskets to each other is to be improved slightly from the former spacing between ties of roughly 0.7m to a spacing of less than 0.5m.

The transition between the central deep stilling-basin and the high-level apron and mattress of the outer 6 bays is to be achieved by a transverse ramp at a slope of 1:2, approximately opposite the fourth bay from each end (gates 4 and 10). As shown in sections AA, BB and DD of Figure 5, the part nearer the regulator is to consist of a jointed concrete slab like that of the deep stilling-basin, and the rest is to be of gabion mattress. This form of transition is cheaper and easier to construct, and less vulnerable to subsoil problems than one involving vertical or near-vertical walls.

The bank protection mattress, which survived the 1985 flood intact despite some erosion at its downstream edge on the right bank, should be left in position. To protect its downstream edges from undermining, however, it is recommended that the mattress be extended at an angle of 45° to the channel axis in the form of wings extending into the banks (this requires the removal of the existing small turn-down on each side). Then the earth banks downstream of the mattress should be allowed to erode in the natural "onion" form as far as 30m from the centreline (at the base of the bank; the design bed width of the channel is 55m). This unfortunately requires that the large kapok tree on the left bank just downstream of the regulator should be removed: it might otherwise be undermined in a flood and might then float down and damage or partially block the nearby road bridge.

It was and is recommended that a deliberate sequence of operation should be followed in future floods, as follows:-

- stage 1 : open the central 5 gates, approximately uniformly, to an opening of 1.0m;
- stage 2 : open the outer 8 gates, uniformly, to the stops (an opening of 0.5m);
- stage 3 : open the central 5 gates, if more discharge is needed, to the stops (1.5m).

The initial opening of the central gates would quickly fill the stilling-basin to the level of the downstream channel bed, i.e. about 10.5m above datum, and thus provide the necessary tailwater depth to ensure energy dissipation and avoid the sort of scour that happened in the 1985 flood. By the time the outer six gates were opened, the tailwater would be significantly above 10.5 and the jump would start on the gabion protection. It may be desirable to limit the openings of the extreme gates (nrs. 1 and 13) to help limit bank scour, but this can be determined by observation and experiment. To restrict the rate of gate opening and help keep control of the structure, it may prove desirable to remove and store elsewhere the gate handwheels, but this is a question for the operating authority.

It was recommended on site on 18th September, 1985 that the most urgent work, namely the placing of concrete under the base slab and the grouting-up of the inevitable void above it, should, if possible, be completed by about 15th October, 1985 to protect the regulator in the event of a flood in October or November. Temporary measures for the stabilisation of the scour hole in this event were also devised, but up to the time of writing (25th November, 1985) these have not been needed. It was intended that the measures shown on Figure 5 should be complete by April 1986 so as to be ready for a possible flood in May or June.

3.3 Cost

At the time of writing the cost of the proposed work has not yet been finalised but application of the MIP Contract M2 rates to the estimated quantities gives a rough preliminary estimate of Somali Shillings 1,500,000. This very approximate figure is given as an indication of the order of costs involved and should not be used for budgeting purposes.

REFERENCES

1. MIP, Feasibility Study; TAMS/FINTECS, 1977.

2. MIP, Supplementary Feasibility Study; Sir M. MacDonald and Partners Ltd., August 1979.

3. MIP, Additional Study for an Alternative Development; Sir M. MacDonald and Partners Ltd., March 1980.

4. MIP, Contract Nr. M2; Irrigation, Drainage and Flood Protection Works, Contract Document, Drawings; Sir M. MacDonald and Partners Ltd., 1982.

Figure 1

Regulator Cross-Section as it was in 1981

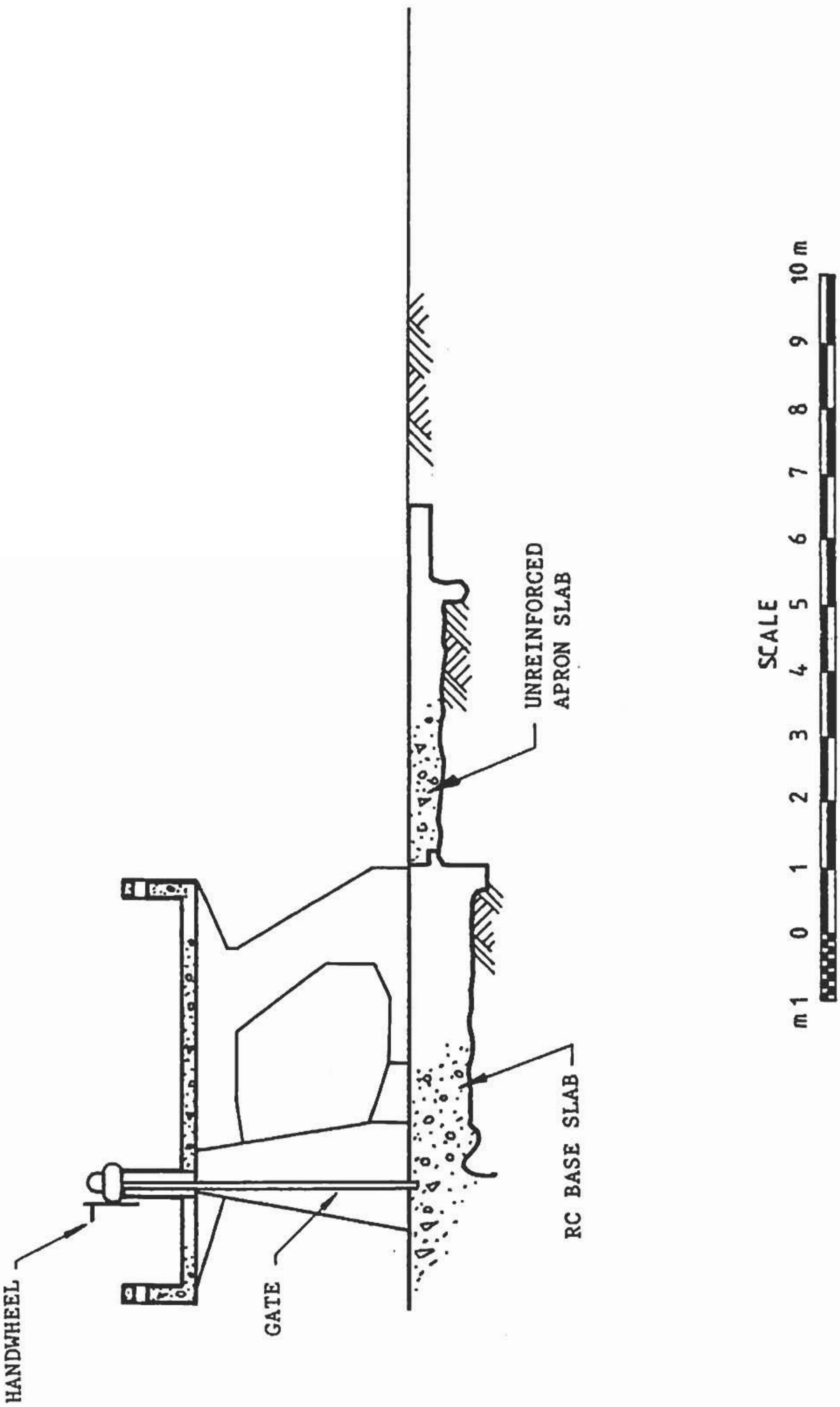


Figure 2

Regulator Cross-Section as it was in April 1985

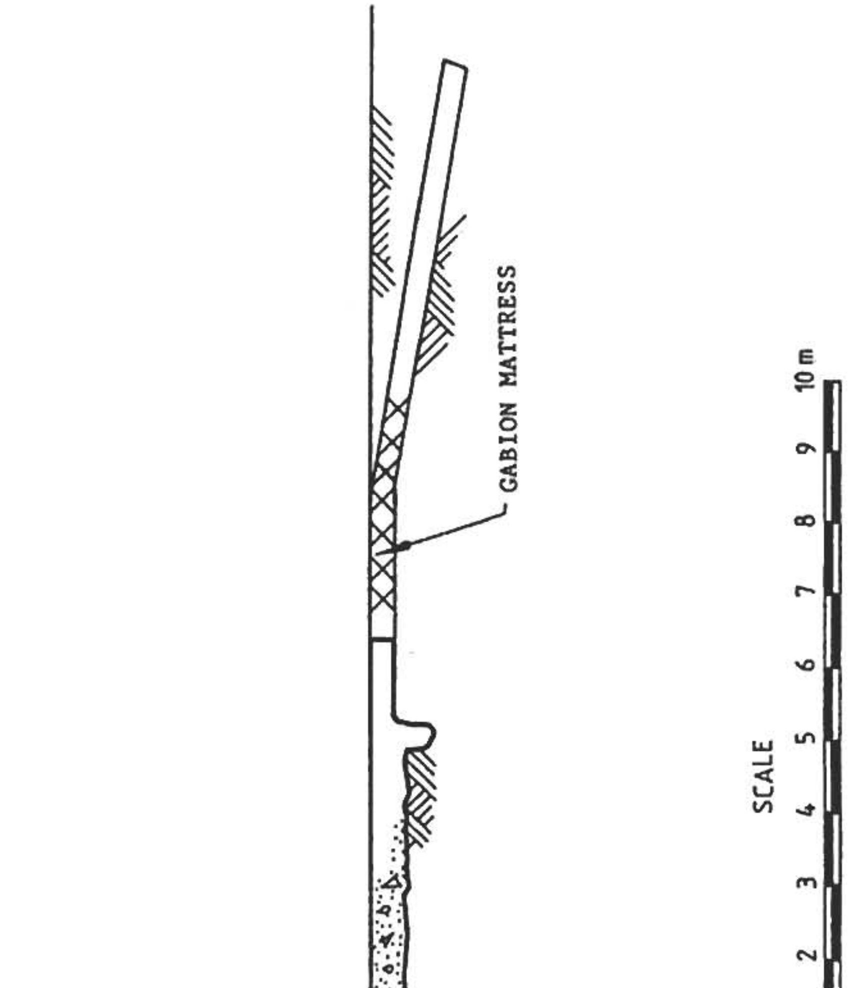


Figure 3

Cross-Section at Centre of Regulator as it was in September 1985

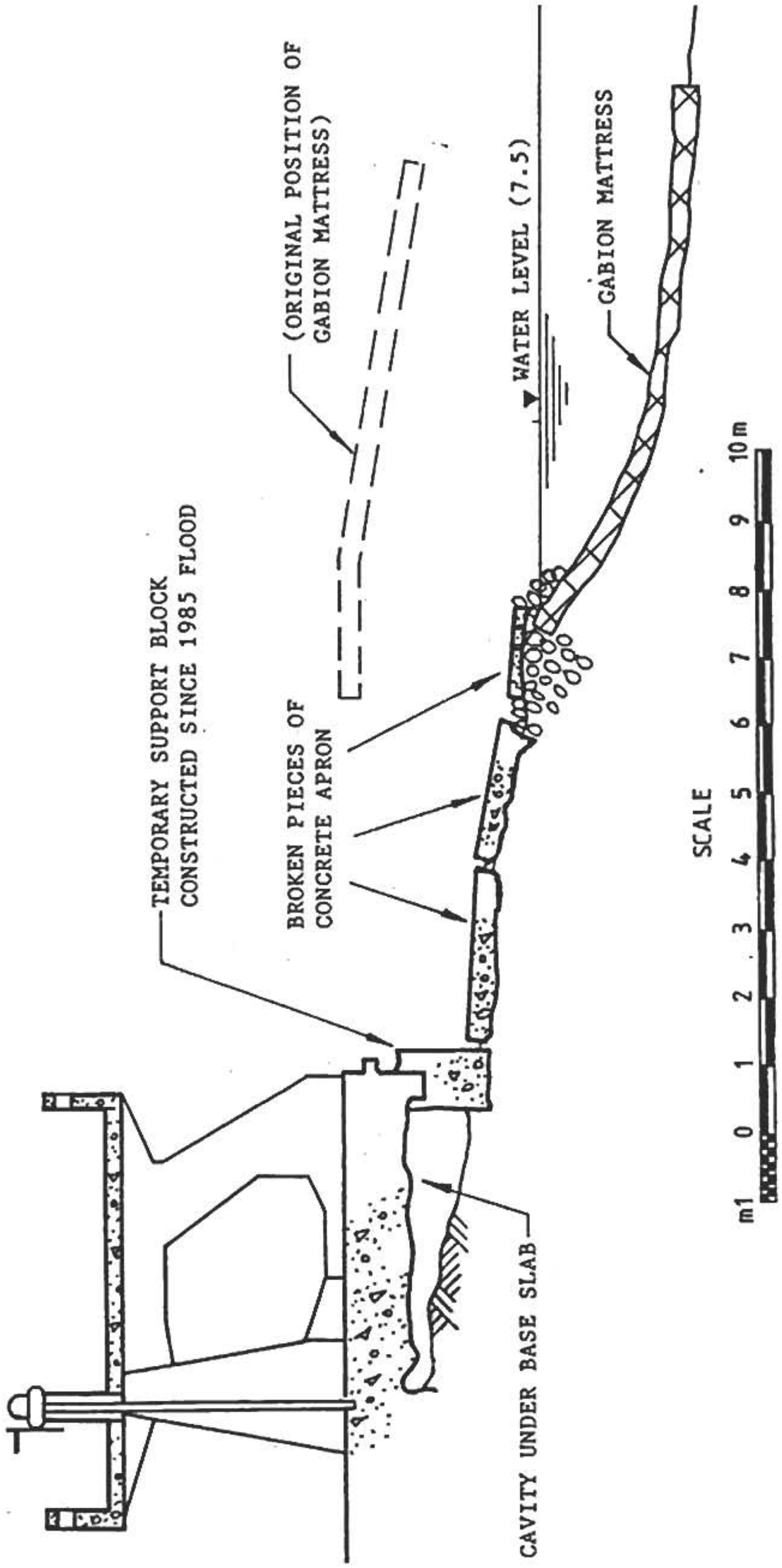
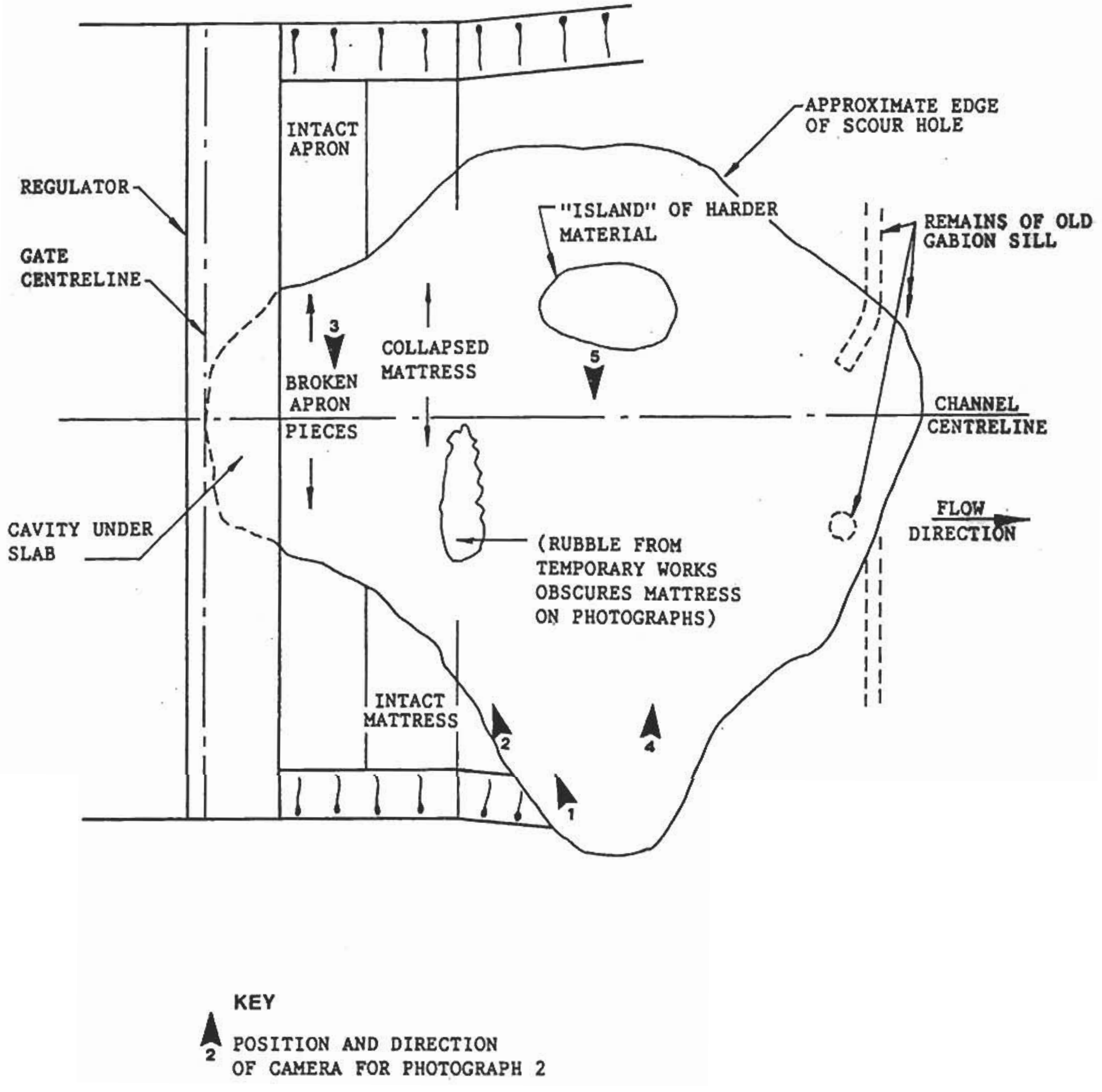
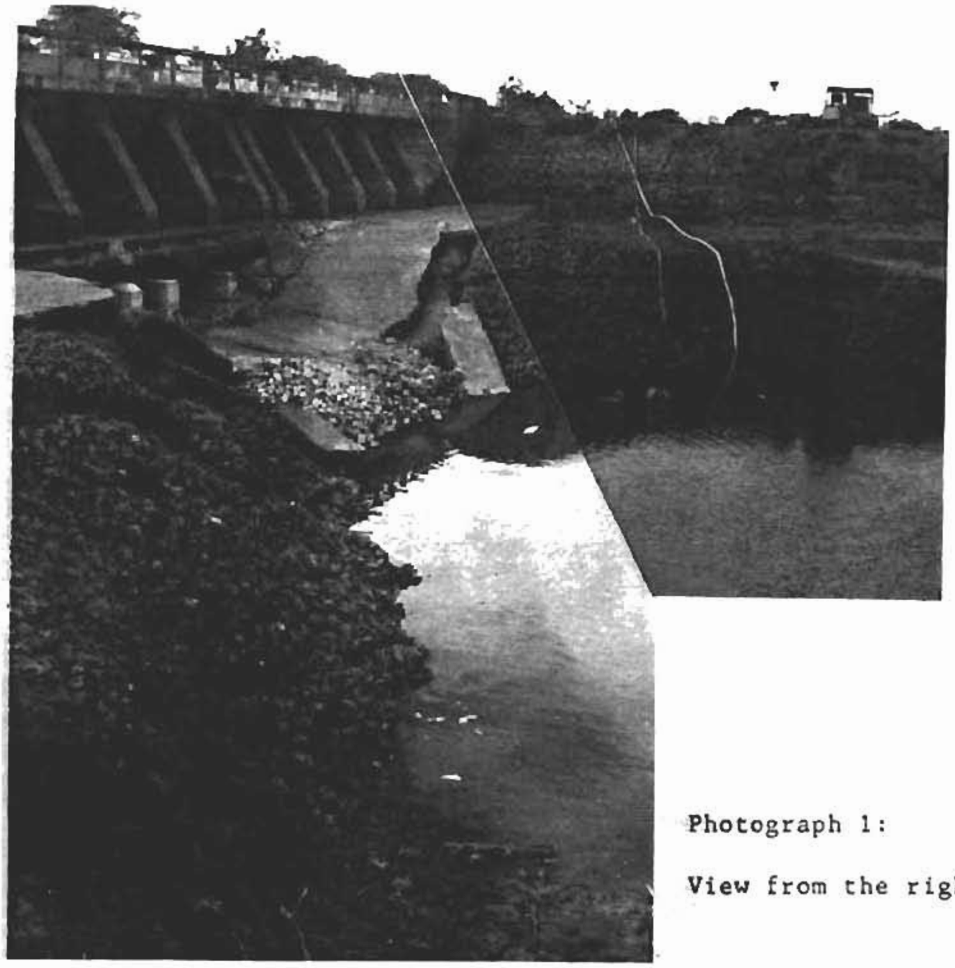


Figure 4

Extent of Scour Hole in September 1985





Photograph 1:

View from the right bank

Photograph 2:

Detail of deformed gabion mattress

Photograph 3:

The concrete apron

Photograph 4:

Looking towards the left bank

Photograph 5

Looking towards the right bank