Investigation and Rehabilitation of Chardara Dam Spillway

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SYNOPSIS. A reported vibration problem with 40 year old spillway outlet gates turned out to be a hydraulically poorly designed structure with cavitation and hydraulic impact problems requiring alterations to the structure as well as replacement of the gates. Vibration surveys, hydraulic model testing and diving surveys were all employed successfully to investigate the cause of the problem and to assist with the design of the remedial works. Dewatering of the structure was required to carry out the remedial works and as there were no provisions to do so in the existing structure a caisson gate was designed that could be floated into the site and then positioned by flooding watertight compartments.

INTRODUCTION

Chardara Dam, which was built in the 1960s, is located in the south-west of Kazakhstan and it forms a reservoir of about 4.6 billion m^3 on the Syrdarya River. The reservoir is used primarily for irrigation. It has a 80 MW hydropower station generating from irrigation and surplus releases, and it also provides flood relief to 1000 km of river valley between the reservoir and Aral Sea.

There are a number of problems with the dam and it is now being rehabilitated. This paper will deal with the investigation and design work on the four low level spillway outlets, one aspect of the rehabilitation. The station operators have considered it is not safe to operate the service gates beyond about 40-50% opening owing to vibration, whereas 80% opening is required to pass the design discharge of 1,300 m^3/s.

DESCRIPTION OF THE SPILLWAY OUTLETS

The layout of the outlets is shown in Figure 1. The four outlets are located in 2 pairs, one each side of the turbines in a combined structure. Each outlet has a 6 m high by 5.5 m wide hydraulically operated vertical lift service gate to regulate releases. There is provision for upstream stoplogs and there is a single 3 section gantry crane operated stoplog gate. There is no provision to close off the stilling basin at the downstream end.

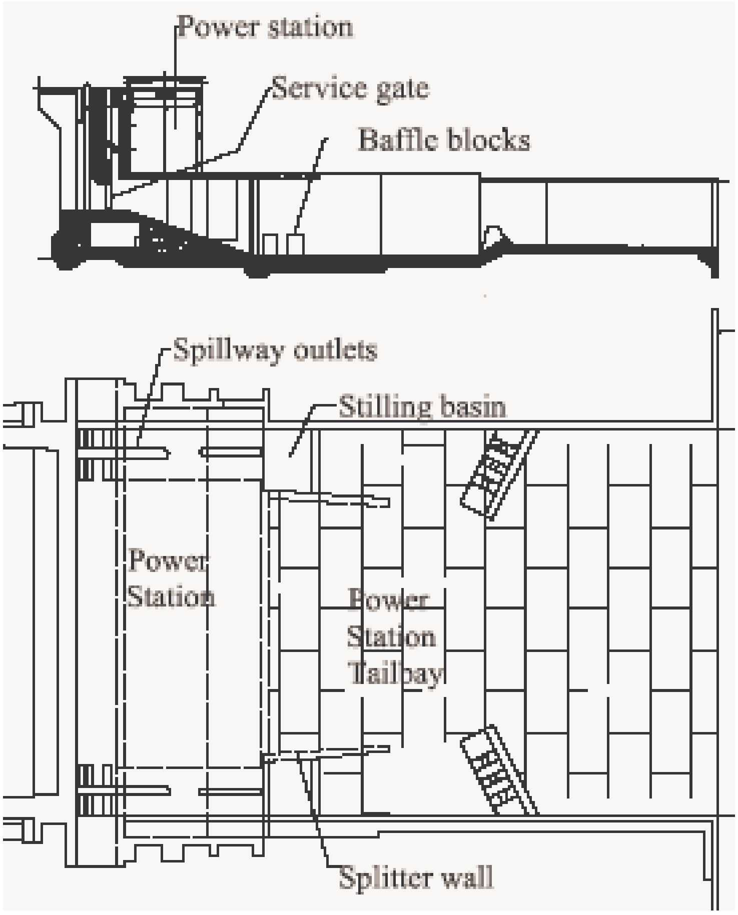


Figure 1: Longitudinal Section and Plan of Outlet Works

Significant aspects of the layout are:

- 5 m downstream of the gates the floor drops 10 m at a constant slope of about 1 on 3 (H:V) into a stilling area;
- there are three 5 m high baffle blocks shared between a pair of outlets immediately downstream of the sloping section;
- there is a partial splitter wall and two columns between the pair of outlets;
- there is a further partial wall between the stilling basins and the turbine outlet channel;
- the sloping section and baffle block parts of the basin are covered by a slab that forms the generator hall service bay and takes the station access road.

The turbines are in use throughout the year and with no plant outage they pass between 550 and 800 m^3/s depending on the level of the reservoir. The reservoir goes through an annual cycle, storing water from the snow melt releases in the spring from the reservoirs further up the Syrdarya River and releasing the bulk of the water during the summer irrigation period, although it discharges throughout the year. This regime gives a low flow period of about 5 months each year when the outlets are not necessarily required and works may be undertaken.

THE PROBLEMS

It had been previously reported in a feasibility study that remedial works were required on the service gates as they were vibrating. However, it became apparent from discussion with the operator that the problem was different from that previously reported, although the gates did prove to require replacing owing to general deterioration, but not owing to vibration. The station operator had noted damage to the upper part of the slope when examining the gates during a low flow period when the tailwater levels were low. He had employed a diving company to examine the structure further. They had found cavities, particularly at the top of the sloping section and to a lesser extent around the gate slots and elsewhere. The diving company had carried out some underwater repairs.

Inspecting the basin in operation was difficult owing to the covering slab. In addition the operator was reluctant to operate the gate beyond about 40% opening owing to the vibration as they were concerned that they would damage the structure further. It was also impossible to inspect the condition of the structure without the use of divers as the basin could not be dewatered.

Original drawings of the structure were available and these showed the configuration of the basin with its sloping section and baffle blocks. There was no design information so hydraulic calculations were carried out based on the dimensions shown on the drawings and assumed gate discharge coefficients. It was concluded that the cause of the damage was most likely to be cavitation. On the top of the sloping section of the basin, where there was an abrupt change in the floor profile, negative pressures would occur, and there was no steel liner to provide protection around the gate slots.

The cause of the vibration was not so obvious. The basin did not follow any conventional design. For a hydraulic jump basin it was too shallow for the sequent depth of a jump to be suppressed by the tailwater at design discharges, but conversely the baffle blocks were too large, which suggested they were being used to force the jump. No evidence could be found as to the events that occurred during design and construction and we are left to postulate whether there were cost, construction or other reasons for the unconventional design. It was also considered that the partial splitter wall and columns would cause flow disturbance prior to the hydraulic jump.

A number of causes of the vibration were thought to be possible, namely:
- strong turbulence in the basin due to the large baffle blocks;
- impacting of flow on the baffle blocks and deflected flow from the blocks onto the adjacent side walls;
- flow impacting on the slab over the basin due to the jump being forced on the upper part of the slope by the large baffle blocks;
- cavitation;
- gate vibration due to general deterioration, poor design or construction.

A further issue was the degradation of the downstream river bed, although not a cause of the problems that had been experienced. Since commissioning the river the tailwater levels had dropped by 1 m, and with no immediate downstream control the degradation was clearly going to carry on. Any solution would need to take the future degradation into account.

DESIGN

The complexity of the problems with the spillway had not been envisaged, and the project programme did not allow for investigations before the remedial works contract was let and there was a need to progress other remedial works which were urgently required. It was decided to include those works on the outlets that were most obvious in the contract and to make provision for other works that may be considered necessary after further investigation and testing, which would also be included in the contract.

The works that were obvious were:
- remodelling of the sloping section to provide positive pressures;
- infilling of the gaps between the partial splitter wall and columns to improve hydraulic conditions;
- provision of a steel liner around the service gate slots to protect the area from cavitation damage;
- replacement of the service gates and rehabilitation of the hydraulic operating system;
- provision of an additional upstream stoplog gate so works could be undertaken on both outlets in one pair at the same time;
- provision of a caisson gate to enable the basin to be dewatered (the gate was also to be given to the operator so that they had the means to carry out future maintenance).

The works for which provisions were made were modifications to the baffle blocks. An outline of the modifications to the outlet structure is shown on a longitudinal sectional elevation in Figure 2.

INVESTIGATIONS

The following investigations were considered as being necessary and included in the remedial works contract:

- vibration survey to try to identify the cause of the vibration;
- hydraulic model test to determine the optimum baffle block arrangement, and also to confirm the assessment that an abrupt change in the stilling basin floor slope was the cause of damage in that area;
- underwater survey to obtain information for the remedial works.

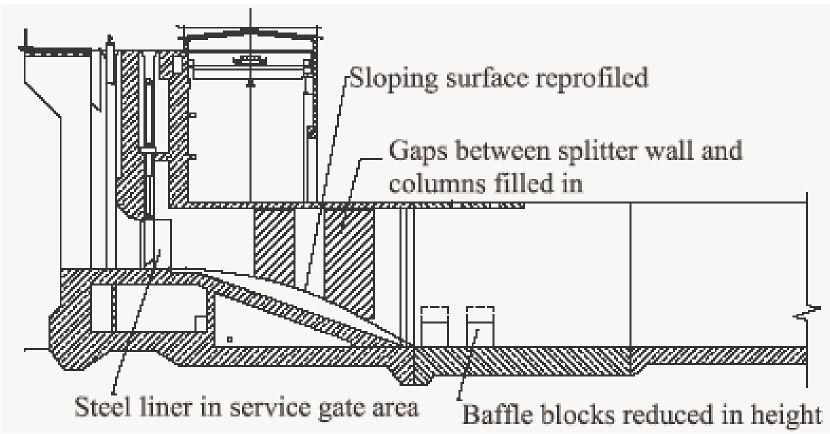


Figure 2: Modifications to Outlets

Vibration Survey

The vibration survey was carried out using a vibration level meter. This measured on three axes simultaneously. The readings were taken at 11 points around the gates and basin. Each reading was taken over a 60 second period with amplitudes being recorded every second. Initial readings were taken with the gates closed, to pick up background vibration from the power station, and then at 0.5 m incremental openings to 4.0 m, at which point significant long period vibration occurred on the gates and the operator refused to open the gates further. This opening was, however, greater than had been achieved during earlier inspections, and it enabled additional observations to be made.

The principal observations from the readings were:

- there was no significant variation in gate vibration with increasing gate opening except at 4.0 m, when there were distinct irregular peaks (Figure 3);

- there was a distinct increase in vertical vibration of the slab over the sloping part of the basin from a gate opening of 2.5 m (Figure 4);
- there was noticeable increase in lateral vibration adjacent to the baffle blocks (Figure 5).

The additional observations made during the survey were:

- that there was a distinct pressure fluctuation in the gate operating area at 4.0 m opening;
- that it was not possible to see a depression in the flow line after the gate on the upper part of the slope and the flow was hitting the underside of the slab from about 2.5 or 3.0 m opening.

It was apparent from the survey and observations that:

- the hydraulic jump was forming from the upper part of the sloping section (probably due to baffle blocks being too large);
- at 4.0 m opening the venting airflow was being closed off by the jump meeting the slab causing pressure variations behind the gate with resulting vibration;
- flow was impacting on the basin walls after being diverted off the baffle blocks and this was likely to be causing vibration.

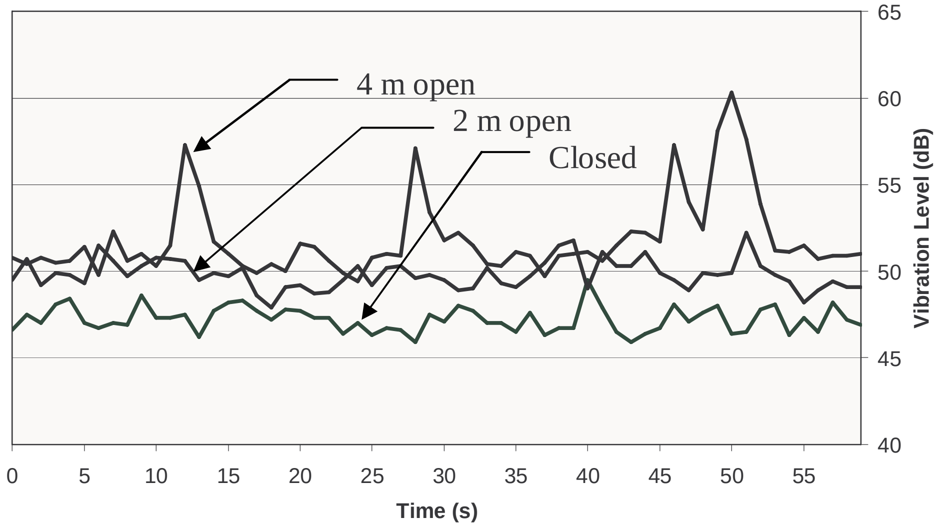


Figure 3: Vibration Survey Gate vibration Y-axis (flow direction)

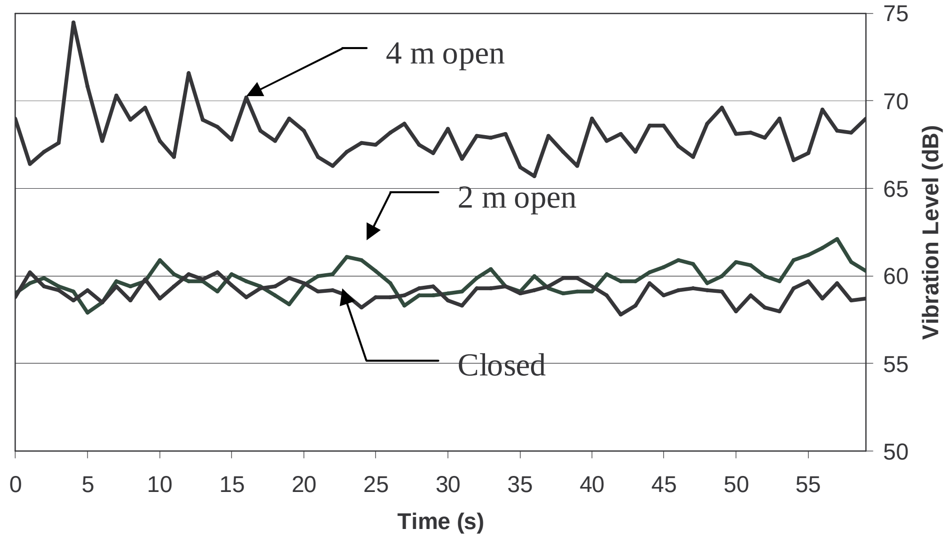


Figure 4: Vibration Survey Slab vibration Z-axis (vertical)

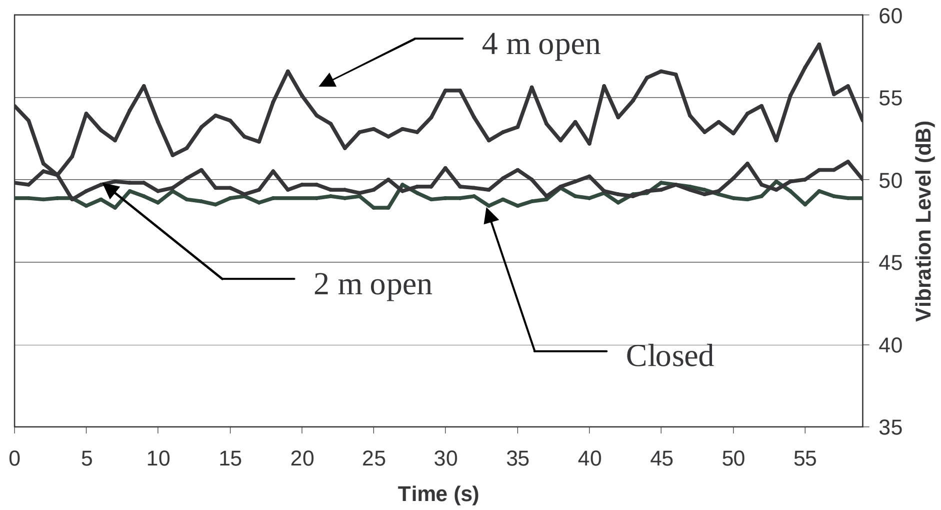


Figure 5: Vibration Survey Wall vibration next to baffle block X-axis (perpendicular to wall)

<u>Hydraulic Model Test</u>

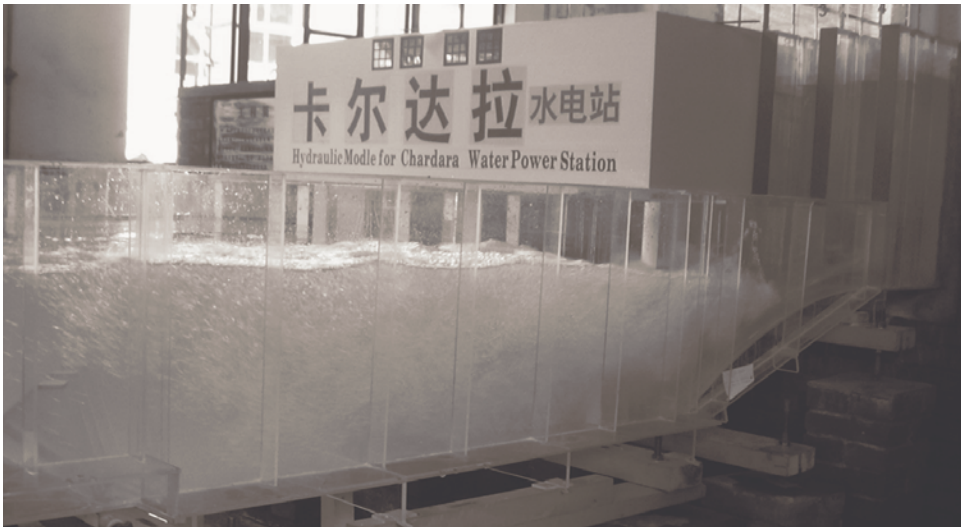
A 1 to 40 scale physical model (Photograph A) was built and the following configurations were tested:

- the existing arrangement;
- a positive pressure profile sloping section, with the gaps between the central partial splitter wall and columns infilled, and with the existing baffle blocks;

- the modified sloping section and walls with 10 variations of the baffle blocks, involving reducing their heights; changing the layout; and profiling the front of the blocks;
- testing the arrangement with current tailwater levels and also with potential future tailwater levels after further degradation.

The model has confirmed/shown that :

- negative pressures occur at the top of the sloping section;
- hydraulic conditions are improved with re-profiling the sloping section and infilling the walls;
- an adequate and less intense jump forms further down the basin with reduced height of the existing blocks;
- the water surface will overtop the side walls of the structure with reduced (future) tailwater levels, if the baffle blocks are not reduced in height.



Photograph A: Model Test

Longitudinal hydraulic profiles for 5 m (existing), 4 m and 3 m blocks for current and future tailwater conditions are shown in Figures 6 and 7 respectively.

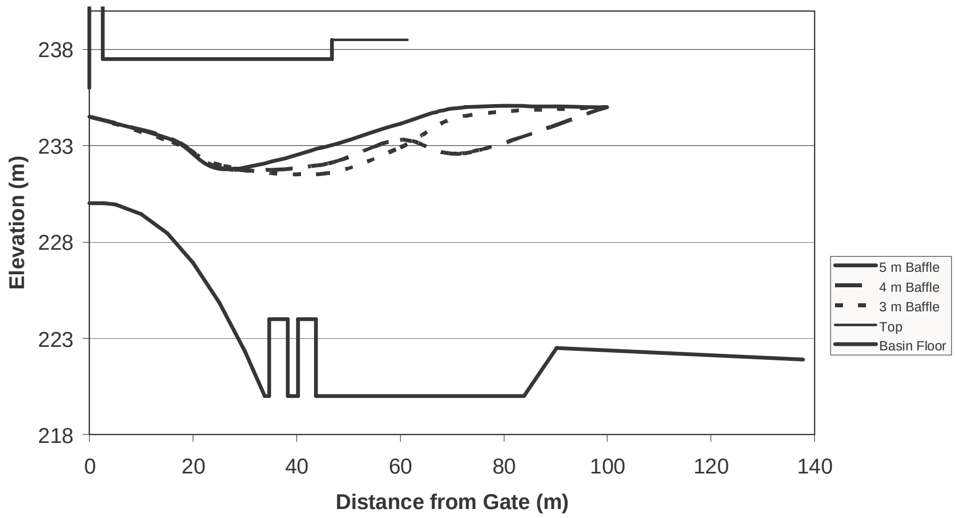


Figure 6: Model Test Results. 75% gate opening and current tailwater level

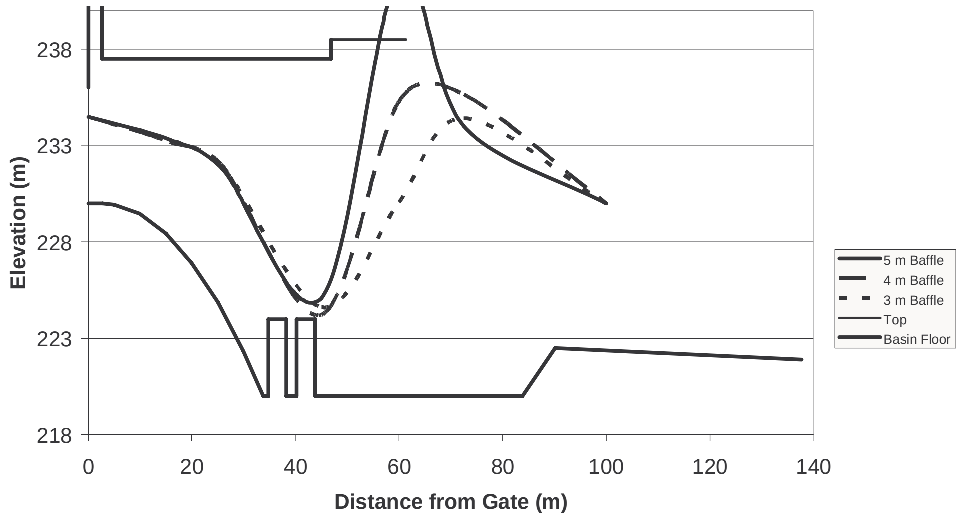


Figure 7: Model Test Results. 75% gate opening and future tailwater level

<u>Underwater Survey</u>

The diving survey was undertaken by a specialist diving company from Kazakhstan. Their survey consisted of taking a video as well as taking physical measurements of the defects and the intended location of the caisson gate.

The survey showed:

- significant cavities in the floor of the basin at the top of the sloping section with reinforcement exposed;
- cavities in the adjacent walls;

- irregularities in the concrete profile adjacent to the service gate bottom sealing plate and small cavities;
- local cavities elsewhere in the sloping section, at the base of the splitter wall and at the base of the baffle blocks;
- irregularities of up to about 300 mm in the profile of the stilling basin wall at the caisson gate location.

Conclusions from Investigations

As a result of the investigations it was confirmed that:

- the profile of the stilling basin floor was causing cavitation and the proposed positive pressure profile was appropriate;
- infilling of the partial splitter wall and columns improved hydraulic conditions;
- the existing (5 m high) baffle blocks needed to be reduced in height as they were forcing a hydraulic jump/causing too much disturbance in the upstream part of the basin resulting in the flow hitting the slab above the basin and causing gate vibration through pressure variations behind the gate as the air flow is temporarily occluded;
- adequate stilling could be achieved in the basin if the blocks were reduced to 3 m in height;
- the impacting flow on the side walls from deflection off the baffle blocks was causing vibration of the side walls, and this could be reduced by changing the profile of the outer part of the block face.

CAISSON GATE

To undertake the works in the outlets it is necessary to dewater the basin. As there was no existing stoplog provision for closing off the basin from the downstream end, and as coffer-damming was impractical, a new downstream gate was required. This needed to be located downstream of the baffle blocks, yet within the area bounded by the splitter wall between the outlets and power station tailbay. At this point the basin is about 14.5 m wide. The water depth may be up to 13 m during the remedial work period. In addition to the new gate, bearing and sealing surfaces also needed to be provided before the basin could be dewatered.

A solution was proposed in the tender documents and the contractor was required to provide the detailed design. The solution was to provide a gate that could be floated into the basin with water-tight chambers that could be flooded to sink the gate into position. The proposal for bearing and sealing was to bolt a suitable arrangement onto the surface of the structure.

The contractor adopted the floating gate proposal. Providing a suitable bearing sealing arrangement proved far more problematic. The contractor was concerned about bolting onto the pre-cast concrete panelled surface so he opted for a supporting system consisting of props bearing on the baffle blocks and removable arms bearing onto plates cast into holes cut into the concrete walls. In his original design the sealing was to be rubber seals placed on the concrete. This was subsequently modified to a grouted 'sausage' held in an adjustable channel when the irregularity of the concrete surface was realized from the diving survey. The gate was manufactured in 5 sections to facilitate transporting to site, and put together in an earth bunded drydock adjacent to the downstream river channel (Photograph B).

Photograph B: Caisson Gate

CONCLUSIONS

1. The vibration survey, hydraulic model test and diving survey all proved essential for investigating the outlets, in particular:
   - The vibration survey showed that with the existing configuration unstable conditions were occurring in the outlets below the design discharge;
   - The hydraulic model test showed that the water levels in the basin would exceed the levels of the structure walls in the future if the basin was modified without reducing the baffle block heights;
   - The diving survey showed that the structure surface was unsuitable for a conventional rubber seal.
2. The absence of any provision for dewatering the basin has made the remedial works far more complex and difficult. It is recommended that at least either grooves or anchorage provisions be provided for suitable stop-logging arrangements in new build where dewatering it not otherwise practical.