THE ASSESSMENT & MANAGEMENT OF ALKALI-SILICA REACTION IN THE GORDON RIVER POWER DEVELOPMENT INTAKE TOWER

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ABSTRACT

The Gordon River Power Development in south-west Tasmania includes an underground power station which receives water from Lake Gordon through a prestressed concrete Intake Tower and vertical shaft. The Intake Tower contains an 8.2m diameter steel cylinder gate to close off the Intake in an emergency or for maintenance work. The discovery in 1992 that the twelve guide shoes on this cylinder gate had lost precompression led to investigations which showed that the concrete Tower was expanding due to alkali-silica reactivity (ASR). This paper describes the testing and monitoring that has been undertaken in the assessment of the ASR and the consequences of the resultant expansion on the operation of the Intake. A prediction of the ultimate expansion has been made from accelerated laboratory testing of concrete prisms. This prediction is being used in the formulation of a long term management strategy for the Intake Tower so that the power station can continue to operate safely in the future.
Keywords: alkali-silica reactivity, concrete aggregates, hydroelectric power, maintainability, power plant intakes.

INTRODUCTION

The Gordon River Power Development of the Tasmanian Hydro-Electric Commission is located in the remote south-west corner of Tasmania. It was constructed between 1967 and 1977 and includes four dams, forming Lake Gordon and Lake Pedder, and the underground Gordon Power Station housing three 144MW generators. The associated infrastructure for the Power Development included an 85km sealed access road from the logging town of Maydena, the construction township of Strathgordon, other site access roads, and a canal connecting Lake Pedder to Lake Gordon.

The 140m high concrete arch Gordon Dam forms Lake Gordon whilst the 38m high Serpentine Dam (concrete faced rockfill), the 43m high Scotts Peak Dam (bitumen faced rockfill) and the 17m high Edgar Dam (concrete faced rockfill) extend the original Lake Pedder. Water from Lake Gordon reaches the underground power station via a 140m deep vertical intake shaft and a horizontal power tunnel and distributor manifold. Discharge from the power station is via a 1.6km long tailrace tunnel into the Gordon River.

The vertical intake shaft is concrete lined and has an internal diameter of 8.23m. On top of the shaft is a 76m high prestressed concrete Intake Tower, the foundations of which extend 32m into the Intake Shaft in the form of a thickened lining (Lea, 1982). Only the top 14m of this Tower projects above the normal full supply level of Lake Gordon. Near the base of the Tower an enlargement contains six equal rectangular openings which allow water to flow from the Lake into the Intake Shaft. Within the shaft these six openings can be closed off in an emergency by an hydraulically operated steel cylinder gate. This gate has guide shoes which bear onto vertical steel gate guides embedded in the concrete of the Tower. The discovery during routine checks in 1992 that the preload between the guide shoes and the gate guides had been lost led to investigations which finally confirmed the presence of alkali-silica reactivity in the concrete Intake Tower as well as in other concrete works of the Gordon River Power Development.

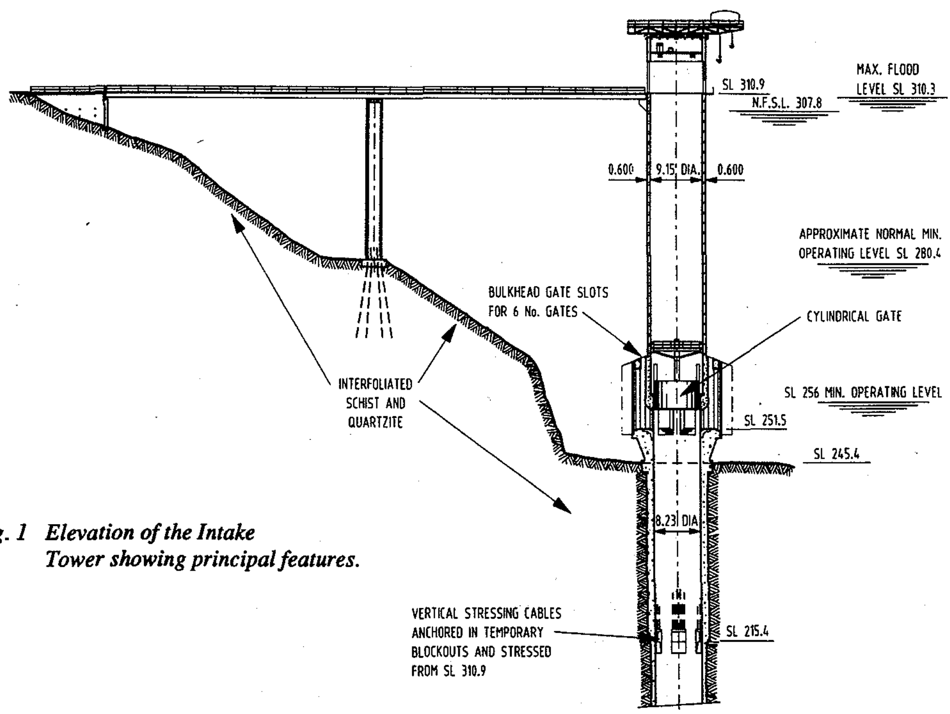

Fig. 1 Elevation of the Intake Tower showing principal features.

DESCRIPTION OF THE INTAKE TOWER

The Intake Tower is a heavily reinforced and prestressed concrete structure, Figures 1 &2. Where it projects from the Intake Shaft it is in the form of a conic frustrum, 6m high and increasing in outside diameter from 10.5m at the shaft collar to 15.5m. On top of this frustrum are six pillars, each 12m high and with a roughly elliptical cross-section of area about $8m^2$. Between the bottoms of these pillars are the six water entry openings, each approximately 3.8m square. On top of the six pillars the Tower extends for 57m as a cylinder with an internal diameter of 9.15m and a wall thickness of 600mm.

At the outer perimeter of the six pillars there are trashrack screens to prevent the entry of timber into the Intake Shaft and inside these screens there is provision for the

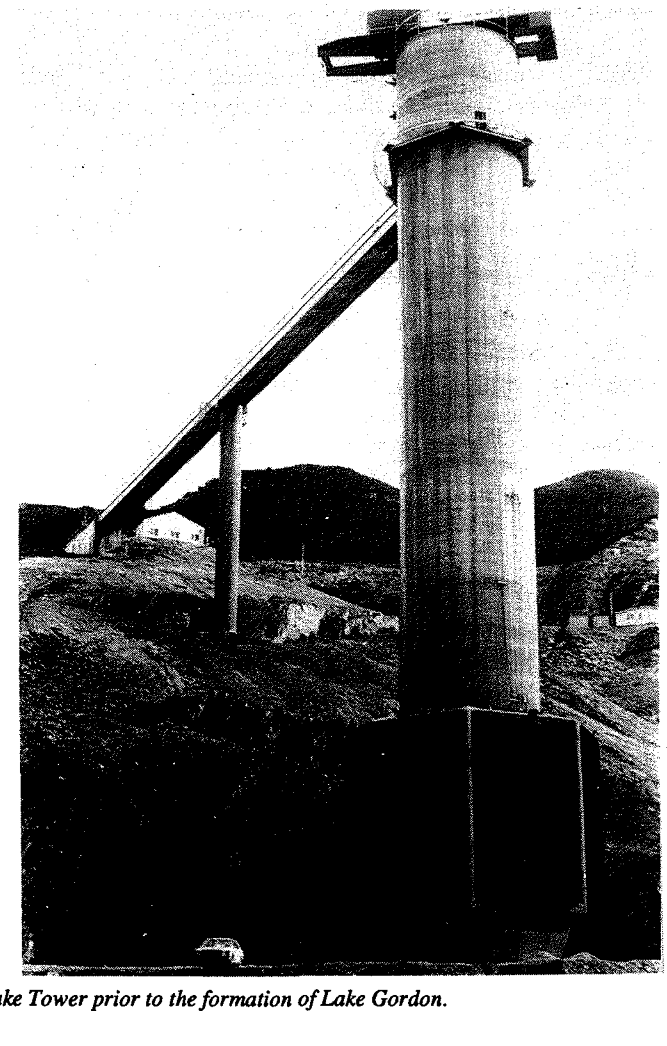

Fig. 2 The Intake Tower prior to the formation of Lake Gordon.

installation of six bulkhead gates which enable the Tower and shaft to be dewatered for maintenance work. A permanent rotating crane on top of the Tower enables the trashrack screens and bulkhead gates to be removed and replaced.

Prestressing of the Tower was by six groups of five prestressing cables, each about 97m long, extending from anchorage blockouts about 30m down the Intake Shaft, up through the six pillars to the top of the Tower. Each cable was stressed to an average load of about 2000kN. Reinforcement in the six pillars is typically 35mm diameter bars at 300mm centres, both ways at 75mm beneath the concrete surface and in the upper cylindrical section of the Tower, 25mm diameter bars at 300mm centres both ways and at both faces with once again 75mm concrete cover.

The steel cylinder gate is designed to close against station flow if there is some major leakage emergency in the underground Power Station. The gate is 8.22m outside diameter and 8.1m high. It is connected to a central hydraulic ram by a three arm framework, the hydraulic ram being supported by a similar three arm framework attached to the inside of the Tower. The gate seals at the top and bottom perimeters against hydraulically inflated circumferential rubber seals. These rubber seals are mounted in two circumferential steel housings embedded in the internal concrete surface of the Tower immediately above and below the six water openings.

The gate is guided by six vertical machined steel gate guides embedded along the internal edges of the six concrete pillars and in the tower above the pillars. Two sets of six guide shoes, at the top and bottom perimeters of the gate, bear onto the gate guides to maintain gate alignment during operation. Each guide shoe can be adjusted in a radial direction so that preload between a shoe and its gate guide can be changed. Such adjustment was used initially, together with the inherent flexibility of the gate shell, to round up the gate to within its diametrical tolerances.

CONCRETE SUPPLY FOR THE GORDON RIVER POWER DEVELOPMENT

Concrete for the Gordon River Power Development was produced at a batch plant established and operated by the HEC near the Gordon Dam. Aggregate was obtained from a quarrying and crushing operation using locally available quartzite rock and natural sand was obtained from McPartlan Pass about 30km from the batch plant. Cement was type A (GP) obtained in bulk from the Goliath Portland Cement Company in the north of Tasmania. Records of cement testing by the Goliath Company between 1969 and 1974 indicate total equivalent sodium oxide contents ($Na_2O + 0.66K_2O$) of between 0.53 and 0.58% for their type A cement.

The quartzite rock was tested in 1969 for potential reactivity of aggregates with cement alkalis in accordance with ASTM Test C227. These tests indicated no potential reactivity, the mortar bars made and tested in accordance with the ASTM procedure showing a shrinkage after one year of 120 microstrain and no surface cracking, mottling or exudation. Petrographic examinations at about the same time also indicated that the Gordon quartzite was largely free of potentially reactive minerals. The quartzite averaged 90% quartz with 10% of other minerals, mainly sericite. In the words of one petrologist at the time "the presence of minerals likely to participate in alkali-aggregate reaction in concrete was not recognised".

Fly-ash was used as a partial cement replacement for some of the concrete used on the Gordon Scheme, principally in concrete for the Gordon Dam. The main reason for its use for the dam was to increase concrete strength gain between 7 and 91 days, but reduction in heat evolution was an important secondary reason, contributing to temperature control and thus to the avoidance of cracking in the dam. The fly-ash was from Port Augusta in South Australia and was used generally to replace between 20% and 25% of the cement, although up to 35% replacement was employed for a period. The variation in the amount of fly-ash used was because of continuing testing and reassessment during the three year period of the Gordon Dam construction. Concrete containing fly-ash was used in some other Gordon structures, but was not used in the construction of the Intake Tower.

RECOGNITION OF ALKALI-AGGREGATE REACTIVITY IN THE GORDON CONCRETE

Some cracking in minor structures on the Gordon River Scheme was noticed in the late 1980's, that is about 15 years after construction, but it was not until 1991 that the characteristic map cracking of AAR was recognised. Subsequent petrographic examinations of drill core specimens from some affected structures and accelerated laboratory tests on mortar bar specimens by the CSIRO (Shayan et al, 1988) and on concrete prism specimens by the Queensland Department of Transport (Carse and Dux, 1990) confirmed the presence of alkali-silica reactivity in concrete made with the Gordon quartzite aggregate. The same concrete with fly-ash has not shown ASR in the accelerated tests and the Gordon Dam in particular has not shown any cracking that can be associated with ASR.

In October 1992 routine checks on the operation of the cylinder gate in the Gordon Intake Tower resulted in significant water loss past the inflatable rubber seals and a loss of preload between the twelve gate guide shoes, which are attached to the cylinder gate, and the gate guides, which are embedded in the concrete of the Intake Tower. Similar checks in 1988 had not revealed any problems with the cylinder gate operation. Subsequent survey measurements showed that whilst the cylinder gate had not changed from its manufactured dimensions, the concrete Tower, housing the six gate guides and the inflatable seals, had expanded by between 6 and 10mm in diameter representing a diametral strain of between 750 and 1200 microstrain.

A number of causes for the observed expansion of the Tower were considered including loss of prestress, temperature changes, creep of the concrete, a low lake level which had persisted for some years prior to 1992 and alkali aggregate reaction. These considerations were assisted by a three-dimensional finite element analysis of the tower in which prestress loads, a change in water level and a change in temperature to simulate ASR expansion were modelled. Likely losses of prestress and temperature changes were determined to produce negligible effects. The lower lake level and a reduction in concrete modulus to a third of its initial value to represent creep, each only produced diametral strains of about 100 microstrain, about a tenth of the observed diametral strain. It was therefore concluded that only alkali aggregate reaction could explain the magnitude of the observed expansion. Petrographic examination of drill cores taken from the Tower subsequently showed the presence of ASR in the concrete and together with the already identified ASR in other Gordon structures it was concluded that the expansion of the Tower was principally due to ASR.

Further investigations and measurements were made during power station outages in October 1993 and October 1994 from which a trend of continuing concrete expansion was deduced. The absence of significant cracking in the structure, and particularly the absence of map cracking, is attributed to the heavy reinforcement and the vertical prestressing in the Tower. Precise survey observations of the level of the top of the Tower suggested that little vertical expansion had occurred. In this context a vertical strain of 1000 microstrain, which would be similar to the observed diametral strain, would have increased the height of the 70m tower by 70mm which would have been detectable by the survey measurements. It can be noted that the prestressing loads produce an average vertical compression in the upper cylindrical section of the Tower of about 3MPa. The structural competence of the Tower was assessed by making accurate measurements of the deflection of the top of the Tower while the tower-top crane rotated a 10t stop-log into four positions around the Tower. The small deflections were consistent with a concrete modulus of 30GPa which is a value that would be expected for the 28MPa concrete.

After three years of assessment it has thus been concluded that the Tower is currently structurally sound and should remain so for its design life of about 100 years. However the expansion threatens the satisfactory operation of the cylinder gate.

PREDICTION OF STRAIN TRENDS IN THE INTAKE TOWER

The results of diametrical strain measurements in the Intake Tower, at the level of the inlets, for the 1992, 1993 and 1994 measurements are shown in Fig. 3. It is apparent that extrapolation of a curve of strain trend from these three measurements cannot be reliably made.

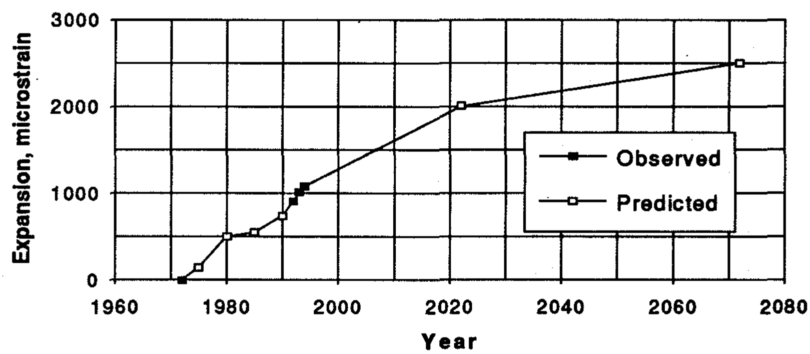

Fig. 3 Observed and predicted expansions for the Intake Tower

However, as part of the initial investigations into the ASR problem in the Gordon concrete, six concrete prisms were made by the Queensland Department of Transport and subjected to their accelerated ASR Test. In this test the prisms, 75mm x 75mm x 250mm long, are steam cured and then stored at 50°C and 100% relative humidity for an extended period and their length is measured every month. The prisms were made using Gordon fine and coarse aggregate, the same South Australian fly-ash used in the Gordon concrete in three of them, and Queensland Cement type GP fine. These tests commenced in October 1992 and were concluded in January 1994 when an expansion of 1100 microstrain had developed in the non-fly-ash specimens and 500 microstrain in the specimens with 20% fly-ash replacement of cement.

A regression analysis was performed on the concrete prism expansion results representing the concrete mix used in the Intake Tower. Using this relationship, Table 1 contains a prediction of the anticipated concrete expansion due to alkali-silica reaction within the Intake Tower over a life of 100 years and Fig. 3 presents this data graphically.

Table 1 Predicted expansion of the Intake Tower

Year	1972	1975	1980	1985	1990	1992	1993	1994	2022	2072
Expansion	0	140	500	550	740	912*	1008*	1082*	2000	2500
(Microstrain)						* Observed values				

From Table 1 the ultimate ASR strain is conservatively predicted as 2500 microstrain at a field age of 100 years i.e. 2½ times its present maximum value as measured in October 1994. It can be noted that the laboratory conditions are more severe than the field conditions with a laboratory temperature of 50°C (7-12°C in the field), Na_2O equivalent alkali level of 5.2kg/m^3 (2.3 to 3.2 in the field) and the field concrete being heavily reinforced and prestressed. As a consequence 22 years in the field are required to reach the one year accelerated ASR strain.

MANAGEMENT OF THE ASR PROBLEM

The 432MW Gordon Power Station plays a major role in the Tasmanian electricity generating system. Its annual contribution of energy to the system over recent years has averaged 13% and has been up to 18%. Any extended loss of this power station could thus be serious for the Tasmanian economy. Whilst complete loss of the Intake Tower due to ASR is now seen to be very unlikely, even in the long term, the inability of the cylinder gate to operate correctly could have serious consequences in the event of a major water leakage in the underground power station. Such incorrect operation could be due to the gate seals not working. However, more seriously, incorrect operation could also be due to damage to the gate due to vibration because the gate guide shoes are loose or to damage to the support brackets for the three arm framework supporting the hydraulic gate operating ram due to tower expansion.

The short term management of the ASR problem in the Intake Tower has thus aimed at designing modifications to the inflatable rubber gate seals, to the adjustable gate guide shoes and to the support brackets for the hydraulic ram support framework. To carry out such design modifications the above deduced indications of the ultimate expansion of the Tower and the time trend for this expansion are crucial items of design data.

In the longer term the continuing management of the ASR problem will include periodic measurements of the expansion of the Tower to verify or modify the current predictions of ultimate expansion and its timing. Cracking in the structure will also be monitored and the likelihood of corrosion of reinforcing steel or of the prestressing cables will be assessed from time to time. Methods of sealing such cracks have currently been assessed but as it could be quite some years before corrosion becomes a potential problem, if in fact it ever does, new techniques or materials might by then have been developed.

CONCLUSIONS

Visual inspection, petrographic examinations and laboratory accelerated mortar bar and concrete prism tests have confirmed the presence of alkali-silica reaction in concrete made for the Gordon River Power Development using Gordon quartzite aggregate. One significant structure that has been affected by ASR is the 76m high Gordon Power Station Intake Tower. Although the 20 year old Tower is showing minimal cracking, which is attributed to its heavy reinforcement and prestressing, the ASR induced diametral expansion has affected the operation of the emergency cylinder gate that it contains. As a consequence the gate does not currently seal properly and further expansion could threaten its mechanical integrity.

The importance of the Gordon underground power station to the Tasmanian electricity generating system has required a management plan to be formulated to deal with the ASR problem in the Intake Tower. In the short term this plan requires modifications to be made to the cylinder gate so that the Tower expansion can be accommodated. In the longer term the continuing expansion of the Tower will be monitored, crack surveys will be carried out periodically and methods of sealing the Tower concrete to prevent corrosion of reinforcing steel via ASR cracks will be investigated in case such sealing becomes necessary in the future.

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