ALKALI-SILICA REACTION IN THE ITEZHITEZHI DAM PROJECT, ZAMBIA

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1. ABSTRACT

In the Itezhitezhi Dam Project, Zambia, substantial expansion of the concrete of the intake-towers to the diversion tunnels was noticed about 5 years after the concreting. The expansion of the towers was estimated to be in the order of 40 mm over a height of 30 m. Field inspection showed a typical map cracking pattern. Before erection, the aggregate was tested according to ASTM C227 and was found non-expansive.

However, laboratory investigations by thin-section microscopy confirmed expansive alkali-silica reactions in the coarse aggregate which was crushed granite rock.

The reactive substance is believed to be an opaline infilling of cracks of the weathered rock.

2. INTRODUCTION

The Itezhitezhi Dam Project in Zambia is an earthfill dam of 8.5 million m^3. The dam provides storage capapcity of $5 \cdot 10^9$ m^3 for the regulation of the Kafue river, which is used for power production in the Kafue Gorge Power Plant (located some 300 km downstream of the Itezhitezhi Dam). The dam was constructed in the period 1973-1976. The filling of the reservoir was completed in the middle of 1978. See location plan in Fig. 1.

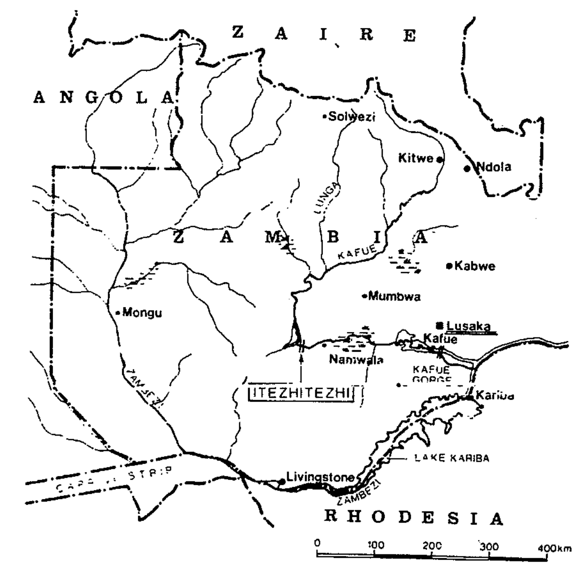

Fig. 1 Location plan

In 1980 a substantial swelling of the concrete in the intake towers to the diversion tunnels was noticed. Accurate measurements of the swelling were made. The swelling of the towers seemed to be in the order of 40 mm over a height of some 30 m. Bending of the towers was noticed, too. The surface of the concrete showed map-cracking, so alkali-silica reactions was suspected. Before use, the aggregates were tested according to ASTM C227, mortar bar expansion technique, and were found non-reactive. The alkali content of the cement vatied between 0.65 and 0.85% with an average of 0.72% (eqv. Na_2O).

3. INVESTIGATIONS

The Teknologisk Institut, Byggeteknik, Copenhagen was asked to carry out an investigation of the problem. The work was carried out in cooperation with VBB of Sweden and the Zambia Electricity Supply Cooperation, ZESCO.

The investigation included:

1. Field inspection of the dam construction
2. Continued levelling of the intake towers
3. Strength determination on the concrete (CAPO-test)
4. Measurement of the strain of a reinforcement bar
5. Drilling of cores
6. Thin-section investigation of cores
7. Expansion of cores in hot NaCl-solution
8. Compressive strength of cubes stored in water and NaCl.

4. RESULTS AND DISCUSSION

Site inspection

The investigation was carried out by the author for VBB in August 1981. The work comprised a visual inspection of the concrete, strength determination by CAPO-test on intake tower and regulation gate shaft, and measurement of strain of a reinforcement bar in the intake tower.

On the basis of the investigation the following conclusions were drawn:

Intake towers

The concrete of the intake towers showed clear signs of expansive alkali-silica reaction in form of a typical coarse map-cracking pattern. The reaction seems to be severe and some of the reinforcement bars are under tension due to the swelling of the concrete. Measured strain on one vertical ø 16 mm rebar was 0.18%. A typical crack width was 0.5 mm. See Fig. 2.

The concrete of the intake towers showed no signs of other types of deteriorations. The average compressive strength was 31.6 MN/m^2.

There was no signs of rebar corrosion.

Regulation gate shaft

The concrete of the regulation gate shaft was in a general good condition with only mild signs of alkali-silica reaction in form of gel patches on pulled - out cones of concrete.

The average compressive strength was 23.3 MN/m^2.

Spillway structure

The concrete of the spillway structure showed no signs of alkali-silica reactions.

Diversion tunnels outlet

Inspection of the diversion tunnel outlet gave no clear indications of alkali-silica reactions.

Quarry

Inspection of the quarry from where the major part of the coarse aggregate was taken, indicated that this quarry was most probably not the source of the alkali-silica-reactive aggregate. However, some aggregates were taken from the excavation of the diversion tunnels. The walls of the tunnels showed weathering and cracking. There were signs of silica filling of cracks. Coarse aggregates taken from this rock source, were suspected to cause the problem.

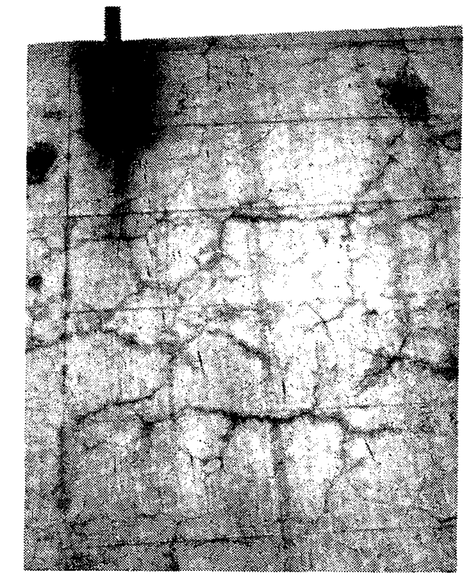

Fig. 2. Upstream outer face of intake tower. Heavy map-cracking is visible.

The intake towers

Continued levelling of the intake towers in the period 1980-1982 showed expansion of less than 10 mm. The expansion seemed to level off during the end of 1981. During 1982, some shrinkage took place. See Figs. 3 and 4.

Compressive strength of concrete cubes

Some concrete test cubes made of the same concrete as the intake towers during the construction of the dam have been continuously water stored. Some of the cubes were transferred to saturated NaCl-solution at 50°C and stored for 6, 8 and 13 months, respectively. The purpose was to accellerate alkali-silica reaction. The compressive strength was determined and compared to cubes stored in pure water. The cubes kept in NaCl-solution showed up to 30% reduction in strength and developed cracks.

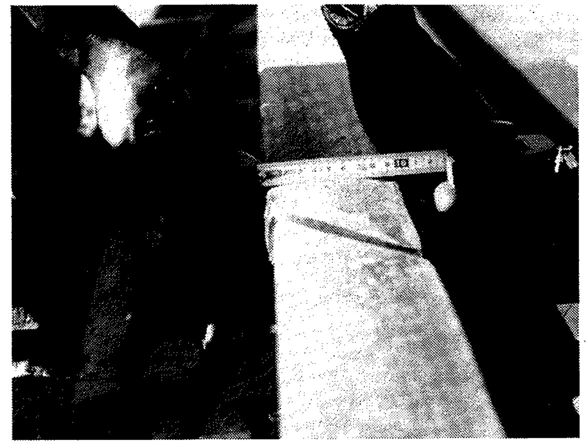

Fig. 3.
Gantry crane rail is displaced due to swelling of the intake tower.

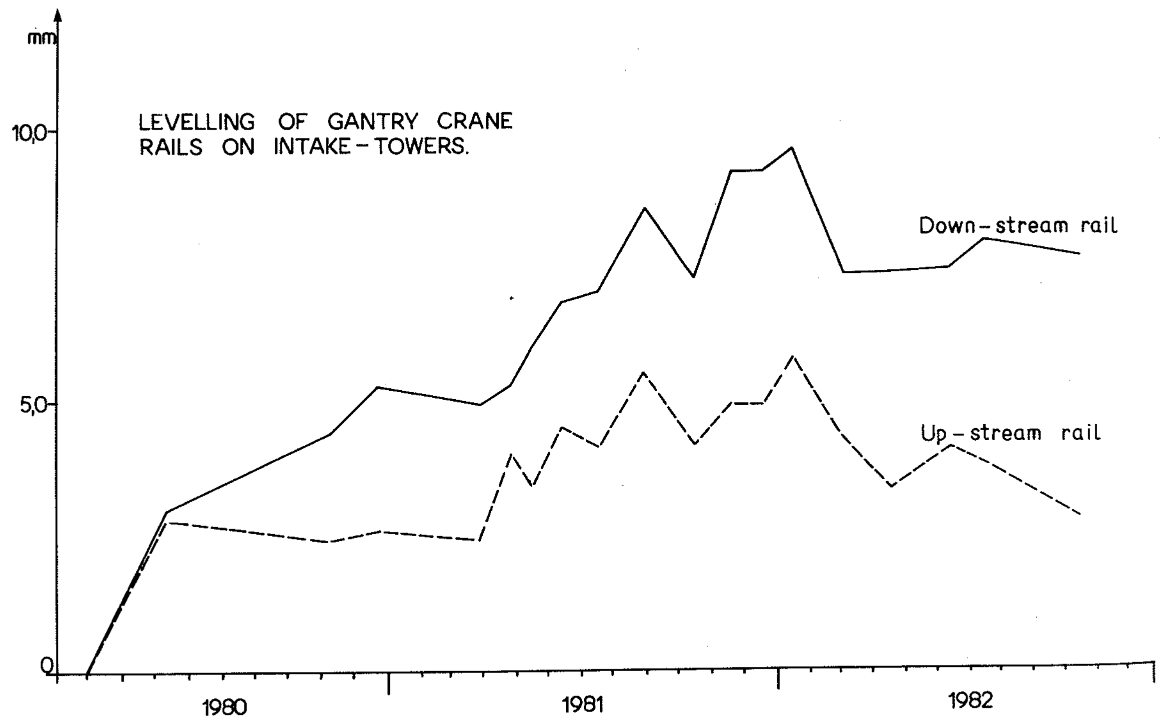

Fig. 4. Expansion of intake towers, 1980-1982.

Thin-section examination

Visual examination of concrete cores taken from the intake tower showed that the concrete was made with red granite as coarse aggregate. At certain places the concrete cores were covered with white extrusion products and air pores were filled, too. The white product looked like alkali-silica gel and seemed to be related to coarse aggregates.

Thin-sections were prepared of selected samples of the concrete cores. The samples were treated with alcohol to remove water and then vacuum-impregnated by yellow coloured, fluorescent epoxy-resin. After sectioning the hardened epoxy-resin was visible in all cracks and voids in fluorescence microscopy. The sections were approx. 35 x 50 mm and 20 µm thick. The thin-sections were examined by polarizing- and fluorescence microscope.

The coarse aggregate was mainly of granitic type with rather weathered feldspar grains. The grain boundaries were pigmented and porous. Veins in the granite were filled with a brown isotropic material believed to be opal. Some grains showed cracks radiating into the cement paste. Some of the cracks were filled with a transparent, colourless or brown, isotropic material with shrinkage cracks. This material had optical proporties identical to the alkali-silica gel commonly found in concrete containing reactive silica like flint or opal. Reacted stones with crakcs and gel were observed in concrete sections from the intake tower. The thin-section from the spillway concrete had no reactive stones.

The sand fraction of the aggregates contained mainly angular particles of quartz and feldspar. There was in no case any signs of alkali-silica reactivity in the sand. As the number of sand grains in the thin-sections are high, it can safely be concluded that the sand is not reactive in any of the samples investigated.

The cement was a coarse-grained portland type cement. Calcium-hydroxide was seen at medium sized crystals in the paste and at the interface between paste and aggregates (bleeding-voids).

Some round air voids contained alkali-silica gel. See Figs. 5 and 6.

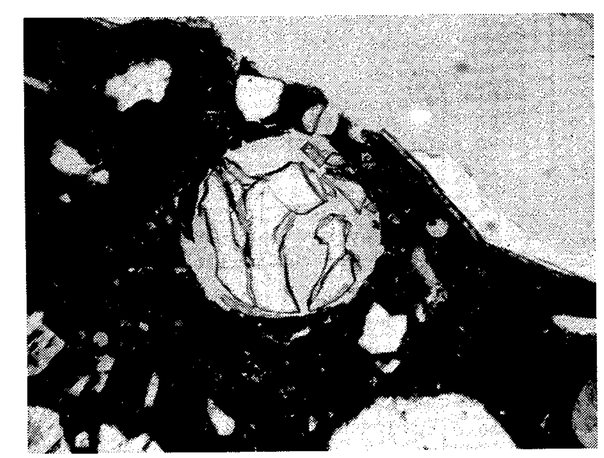

Fig. 5. Thin-section showing alkali-silica gel in an air void in the cement paste. Magnification 60x. Transmitted light.

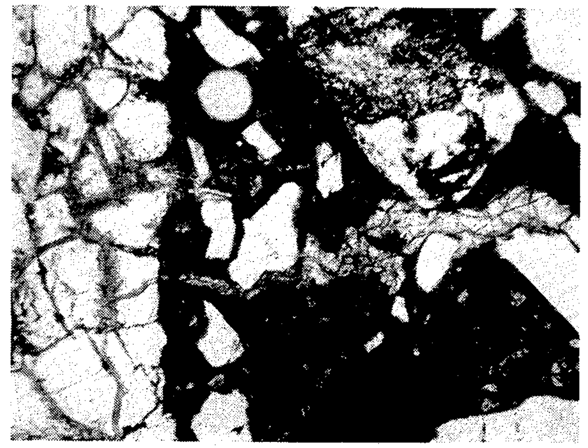

Fig. 6. Thin-section. Reacted granite with stained crystal boundaries, and veins filled with brown isotropic material. In the cement paste a gel-filled crack is seen. Magnification 60x. Transmitted light.

Expansion of cores

In order to test if the concrete samples from the intake tower and spillway have any reactive silica still left unreacted, about 10 cm long cores from each of the above samples were stored in saturated NaCl solution at 50°C. At weekly intervals, the expansion of the cores was measured. After 8 weeks the expansion had reached a steady value. The following table shows the mean value of expansion after 8 weeks.

Sample	Expansion %
Intake tower	0.04
Intake tower	0.09
Spillway	0.02

Table 1.
Expansion of cores when placed in 50°C saturated NaCl solution.

The results indicate that the core from the spillway had very little, if any, reactive silica in it. The cores from the intake tower had reactive silica causing expansion.

The probable reasons for the failure of the preliminary testing following ASTM C227, mortar bar expansion test, when the aggregates were tested before the concreting are i) the test carried out only upto 3 months, ii) that the alkali content of the cement was not very high. In the structure some concentration of alkalies must have taken place, probably by migration.

5. CONCLUSION

The granitic coarse aggregate, used to make concrete for the intake towers of the Itezhitezhi Dam, was found to be alkali-reactive. The reactive material seemed to be a secondary opaline infilling in the cracks of weathered rocks. Expansion of the 30 m high towers was of the order of 40 mm. The expansion of the towers seems to have ceased by 1982. Repair is deemed unnecessary at this stage.