Analysis of Distress Due to Alkali-Aggregate Reaction in Gallery Structures of a Concrete Dam

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ABSTRACT

A case study on the behaviour of penstock gallery structure of a concrete dam due to expansion caused by alkali aggregate reaction is presented. After nearly 25 years of operation, the reinforced concrete columns of the penstock gallery showed wide flexural cracks associated with snapping of mild steel reinforcement.A multi disciplinary investigation on material,geological and structural aspects identified alkali aggregate reaction in the concrete mass as the most probable cause related to the distress noticed.By imposing various ranges of horizontal and vertical displacements at different elevations and studying the combined effect of these displacements on the columns, the distresses noticed were correlated to the possible combination of vertical and horizontal displacements.Thus,a most probable combination was arrived at for further verification.In order to ensure that this order and combination of movement had indeed occured, recourse was taken to physical observations such as closing of expansion joints etc.The potential of residual expansion was assessed by carrying out long-term expansion tests on concrete core samples taken from the dam.As the potential for expansion was still existing, remedial actions were suggested taking into consideration the possible future expansion.

INTRODUCTION

Instances of distress of concrete structures due to alkali aggregate reaction (ASR) has been often reported, wherein, the manifestation of such deterioration in terms of cracking, bulging and deformation in the structure as well as the characteristics of the reaction have been adequately described. However, cases relating to the effect of such ASR deformations on the structural integrity and performance of reinforced concrete structures are not so widely reported. This paper presents a case study on the distress to penstock gallery structures of a concrete dam due to deformations caused by alkali aggregate reaction and on the remedial measures suggested.

MANIFESTATION OF DISTRESS AND PROBABLE CAUSE

The penstock gallery structure located on the toe of a 300 ft (91.5 m) high concrete gravity dam is comprised of RCC frames constructed integrally with the dam body(Fig 1). After nearly 25 years in operation, wide-spread distress was noticed in the dam and power house structures, in the form of cracks , vertical sliding of joints, jamming of gates,etc.Other associated problems noticed were: difficulties in operating the gantry crane in the power house because of the shift in the rail alignment; tripping of the generators because of the disturbance to the shaft alignment; and shearing of MS rails supporting the draft tube crane.

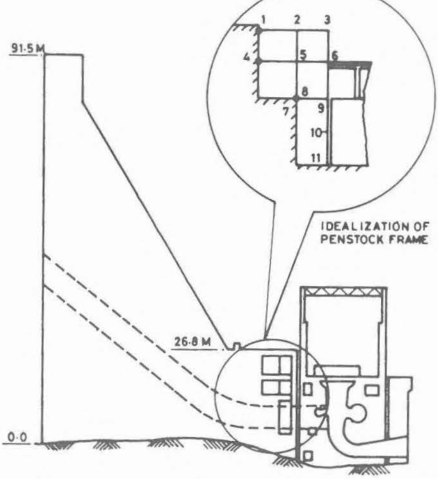

FIG.1 SECTION THROUGH ℄ OF PENSTOCK

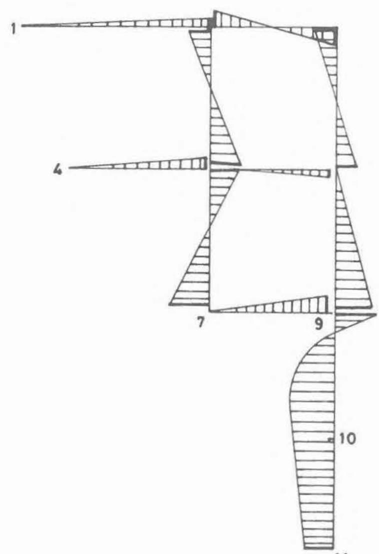

FIG 2 BENDING MOMENT DIAGRAM FOR PENSTOCK GALLERY

A summary on the major structural distress noticed in the penstock gallery and in the adjacent power house structure is given in the following lines:

- Multiple horizontal cracks on the face of columns marked 9-10-11(close to penstock) and extending to a height of 1m or so from the foot of columns.

- Wide horizontal cracks near mid height of column 9-10-11 maximum width at the gallery side and reducing in width as the cracks travel interior.
- Snapping of main reinforcement placed in column 9-10-11
- Spalling of concrete at the end section of beam 5-6
- Closing of expansion joints(design width 25mm) between gallery and scroll concrete.
- Relative horizontal shifts in the beams supporting generator floor.

For such distress in the concrete structures, temperature effects, deleterious chemical reactions and relative settlement of foundation merit prima-facie consideration. From the records it could be ascertained that the concrete was pre-cooled and the temperatures recorded were within the limits.This along with the fact that the movements are still continuing eliminated temperature effects as the cause.The dam was founded on granite rock which was considered as nearly ideal. Analysis of the dam section including a portion of the foundation rock was carried out using finite element techniques.It was observed that the deformations of the dam body were well within the expected values and this could not have caused the distress in the penstock gallery frame(PGF).A multi-disciplinary investigation on materials,geological and structural aspects identified ASR in concrete as the most probable cause.

ANALYSIS OF PGF FOR ASR EXPANSION IN DAM BODY

The penstock gallery is comprised of six blocks,each block having four frames. The frames are inter-connected with beams running parallel to the axis of the dam.There are twenty four such frames.As each of the six blocks is acting independently, the four frames connected to each block form a space frame configuration. Because the deformation characteristics of all the frames are identical and all the frames have same configuration and mechanical properties,a two dimensional analysis was considered adequate. Composite structures of this type under action of horizontal forces can be idealised as comprised of two systems, the dam section and the PGF.The stiffness of the dam section being very high compared to that of the frame, whenever an external load is required to be shared by the two systems, the dam section resists almost all the loads. However, because of the connection between the dam and the frame, any deformation of the dam at the connecting points is fully or partially transmitted to the frame. Using this principle, the analysis of the dam section and PGF can be carried out independently and subsequently the deformations superimposed to give the required force resultants.This approach has been used for determining the force resultants in the PGF.

Any volume change in the concrete mass of the dam will induce a relative movement at the joints connecting the PGF to the dam.This volume change has components in all the three orthogonal directions. For the two -dimensional analysis only vertical and horizontal componenets need to be considered. A quantitative estimate of these components enables the forces developed due to the relative movements of the joints to be determined. In the present study it is rather difficult to arrive at such values, because of a large number of unknown factors which influence the expansion phenomenon.The rate of expansion is dependant on the presence and proportion of alkali reactive aggregates,alkalies in the cement, the cement content in the concrete, relative humidity and temperature etc. Because of these unknown factors, an indirect approach was attempted.

An analysis was, therefore, taken up by imposing various levels of horizontal and vertical displacements at nodes 1,4,7 and 8 (Fig 1) representing the expansion in the dam body due to ASR. A systematic search was made to correlate the distress noticed and the possible combination of vertical and horizontal movements and thus the most probable combination was arrived at for further verification.Another interacting factor to be considered is the reaction from the turbine block.Though an expansion joint has been provided, over the years this has become nonfunctional. Because of various unknown factors involved , determination of the magnitude and nature of reaction from the turbine block is almost impossible. However, to take into account this interaction aspect a different approach was followed wherein the deflection of the column line was made to match an assumed deformation profile of block concrete. The results of this analysis are shown in Fig 2.

From this it may be concluded that the relative displacements due to ASR expansion can cause distress in the members of the PGF.In addition the reaction from the turbine block, which could be either passive or active can aggravate the distress in the column 9-10-11. The order of horizontal and vertical displacements imposed relative to node 11 (Fig 1) are 12.5 mm and 3 mm respectively.This will correspond to an average linear expansion rate of 0.035%.The expansion phenomenon discussed so far, relates to the main body of the dam.In addition, there is a possibility of this phenomenon occuring in the columns itself and in turbine block.Considering the possibilty of ASR phenomenon occuring in all the three areas,the associated structural problems related to the PGF are summarised as follows.

Expansion of Concrete in	Associated structural Problems
Dam	Relative displacement in the penstock gallery frames.
Columns	Additional tensile stress in reinforcing steel.
Turbine block	Lateral thrust on the columns.

ASR EXPANSION POTENTIAL

In order to ensure that the order of expansion considered had indeed occured, recourse was taken to physical observations such as closing of expansion gap ,shift of beams supporting turbine floors, etc..In addition, the order of expansion was checked with long-term expansion tests on concrete core samples immersed in water and KOH solution, both at room temperature and 60 C .The rate and the order of expansion as obtained from the laboratory studies are given in Fig 3. The results show that an expansion of the order of 0.1% is realistic.Further it was concluded that potential for further expansion still existed.This is also corroborated by the site observations.

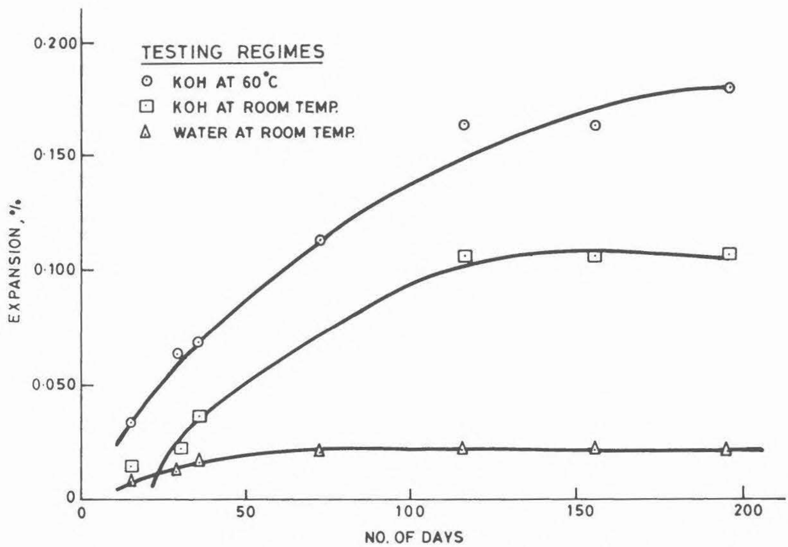

FIG.3 EXPANSION OF CONCRETE CORES IN DIFFERENT TESTING REGIMES (LONG TERM STUDIES)

RECOMMENDATIONS FOR REMEDIAL MEASURES

There is no known method or solution to stop or to minimise the expansion phenomenon.Under these circumstances, any solution to the problem should suggest methods which will minimise its effect on the behaviour of columns in the PGF. The interaction between the PGF and the dam profile can be minimised by introducing releases at the nodes 1,4 and 8.The beams may be detached from the dam profile and made to rest on corbels with suitable bearing seats which will ensure that any further change in the dam profile is accomodated within the seating provided. This arrangement will take care of horizontal displacements.It appears difficult to accomodate the vertical component of the movement.One possible approach is to have some arrangement at the bearing seats, suggested earlier ,by which the vertical expansion is compensated.The third aspect is the non functioning of the expansion joint between the turbine block and the PGF and hence creating a pressure on the column face.This can be taken care of by cleaning the joint and by chipping off concrete to the required depth and thus making the expansion joint functional.The last aspect to be considered is the expansion of concrete within the column itself.The fractured columns can be structurally rehabilitated by procedures available in the literature.However this does not solve the expansion problem and the consequent increase in the steel stress.One possible approach is to release the current level of stresses by cutting the reinforcing steel and rehabilitating them by re-welding the same bars and if necessary with lap joints.

ACKNOWLEDGEMENT

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