SUSTAINABLE DEVELOPMENT IN THE CONSTRUCTION OF CONCRETE DAMS IN INDIA

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ABSTRACT

The development in dam construction in India covering the use of right construction materials, distress observed due to deleterious alkali-aggregate reaction in some of the dams, current scenario in the use of blended cements with at least 25% flyash or with at least 50% ground granulated blast furnace slag and 5-10% silica fume (as necessary for the development of high strength and abrasion resistance of concrete) have been highlighted, with a few case histories. Recommendations have been made to use more and more factory-made blended cements in the construction of concrete dams, spillways, stilling basins, tunnel linings,desilting chambers and power house structures, towards a sustainable and durable concrete structures in hydro-electric projects, using green construction materials.

1. INTRODUCTION

Dam construction started in India as early as 1950's. Most of the dams in India are concrete dams. A few rock fill dams and two roller-compacted concrete dams are also constructed. In those days (1950-1960), good construction materials were not available in India. Only ordinary Portland cement (ASTM type I) with higher alkali content was produced by the cement plants. The coarse aggregates were mostly river pebbles. River bed sand was available as fine aggregate. The pozzolanic material was not much available, except burnt clay pozzolana. Thermal power plants were just started, producing power not sufficient to cope up with the demand of India's growing industries.

The concrete dams were constructed mostly for flood control and irrigation. The power generation was just a by-product. With the development process towards the end of the 20thcentury, along with rapid industralisation, more and more thermal power stations were constructed, without a concern for global warming. In this century, as it started, the country's attention was more and more for green power, and so, more and more hydro-electric projects were taken up specially in the Himalayan regions and hilly areas of the country. In the present scenario, concrete dams are under construction, but at a very slow rate.

2. THE ALKALI-SILICA REACTION IN CONCRETE DAMS IN INDIA

In two of the dams, cracks were developed due to alkali-silica reaction after about 30 years. One concrete dam suffered maximum deterioration due to this deleterious reaction. The power house structures cracked, and the power house was not operative for a number of years. Cracks were observed in the ogee crest of the spillway, 25mm wide and 100mm depth. The cracks in the columns of the penstock gallery were severe. One of the columns opened up at the crack, showed 9 of the 10 reinforcement bars of 45mm dia. had snapped at the end of the welded joints [1]. In those days the quality of OPCaswell as the quality of flyash were not good. The alkali content of OPC was high in the range of 1.2% to 1.8%. Although 15% flyash (total 13,000 tonnes) was used in concrete, cracks developed in many structures. Typical alkali-silica gel inside the concrete, and the cracaks in the aggregates (microscopic photographs) are shown in Fig.1 and Fig.2.

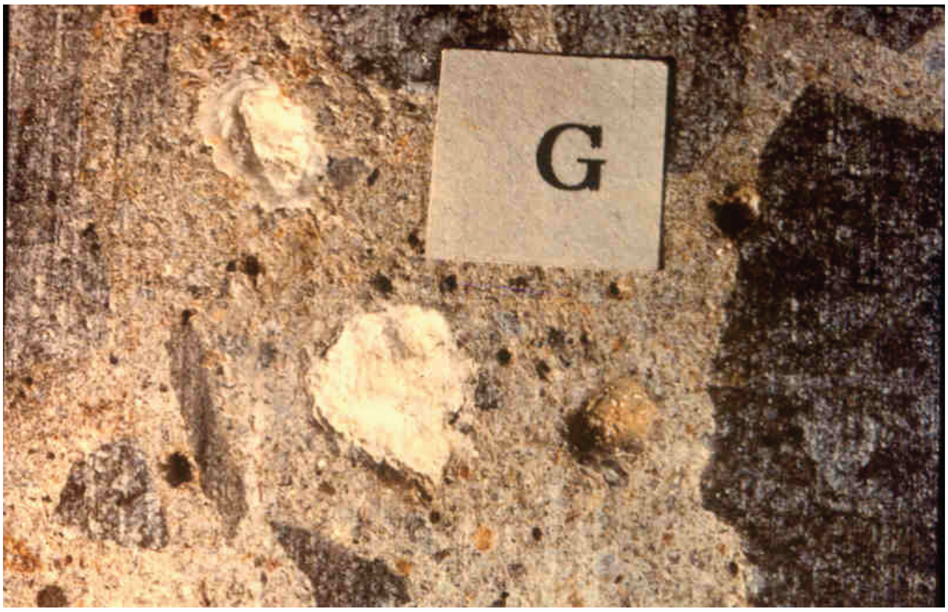

Figure 1 : Alkali silica gel inside the concrete

Figure 2 : Cracks in aggregates inside the concrete due to alkali aggregate reaction

3. MATERIALS OF CONSTRUCTION FOR HYDRO-ELECTRIC PROJECTS

In the present scenario, ordinary Portland cement (OPC), the Portland pozzolana cement (PPC) consisting of 15-35% of pulverized fuel ash (PFA) or flyash produced by the thermal plants, and Portland slag cement (PSC) consisting of 25-75% of granulated blast furnace slag (g.g.b.s.), the by-product of steel industries, are available for any construction activity. The OPC should be used as less as possible, not only for its high release of carbon di-oxide in the atmosphere during its production, its production is slowed down. More and more PPCs are produced by the cement industries. The production of PSC is limited to the availability of the g.g.b.s. Out of the total production of cement in the country at present (420 million tonnes), OPC is about30% , PPC is about 60% and PSC is about 10%.

The coarse and fine aggregates available for the construction of concrete dams are generally from the rocks, available near the sites of construction. They are crushed to produce coarse and fine aggregates. The concrete admixtures (chemical) are available in sufficient quantities, as required, as a large number of admixture companies (including some foreign companies) are able to produce and supply the required chemical admixtures. The mineral admixture silica fume or the micro-silica is being imported.

4. USE OF PROPER CEMENT AND MINERAL ADMIXTURES IN CONCRETE FOR HYDRO-ELECTRIC PROJECTS

The Codes of practices stipulate use of proper cement and mineral admixtures (flyash, g.g.b.s. and silica fume) in concrete for hydro-electric projects. The Indian Standard Code of practice for plain and reinforced concrete IS 456 [2] stipulates 'use of low alkali OPC having total alkali content not more than 0.6%, as Na_2O equivalent. The Code of practice further adds "further advantage can be obtained by use of flyash conforming to IS 3812 (Part 1) [3] or granulated blast furnace slag conforming to IS 12089 [4] as part replacement of OPC (having total alkali content as Na_2O equivalent not more than 0.6 percent), provided flyash content is at least 25 percent or slag content is at least 50 percent".

In the early years of the present century, the government of India's emphasis was to use more and more flyash as they are hazardous materials at the thermal power stations. But the quality of flyash deteriorated over the time and good quality flyash as specified in IS 3812 (Part 1) is not sufficiently available to cater the needs of the construction projects. However, two roller-compacted concrete dams have been constructed in these years, with about 60% flyash in concrete. The 100m high concrete dam has been constructed with Portland slag cement, with slag content of about 55% and more concrete dams are currently under construction with PSC having similar amount of g.g.b.s. In one site, the crushed rock coarse aggregate is not satisfying the limiting Los Angeles abrasion value for wearing surfaces as stipulated in the Indian Standard specification IS 383 [5] and so, 5-8% silica fume is being used in concrete.

4.1 Use of blended cements in hydro-electric projects

In order to avoid the deleterious alkali-aggregate reaction in concrete dam projects, there are recommendations to use either PPC or PSC, with part replacement of OPC by flyash or by g.g.b.s. respectively. But since at present, the availability of good quality flyash is less, and there are variations in the properties of flyash from power stations to power stations, it is better to use Portland slag cement with at least 50% g.g.b.s. in it. The slag is a more consistent material than flyash. The ICOLD does not recommend the use of PPC in concrete for combating the deleterious alkali-aggregate reaction. The stipulations are as follows: "In the case of Portland pozzolanic cements, the cement manufacturers should be able to match the characteristics of the particular cement and pozzolana to ensure adequate compensatory action under the conditions of intended use, but, despite accumulated experience with Portland pozzolanic cements, the variability in their properties does not yet permit recommendations for their use in minimizing the risk of alkali- aggregate reaction [6]. On the other hand, on the use of Portland slag cement, the ICOLD bulletin states that, "there is now considerable experience of the use of Portland blast furnace slag cements with some types of reactive aggregates, and although the current recommendations probably are on the cautious side, there are no known instances of deleterious alkali reactions, when the stated limits of alkai i.e. less than 0.9% Na_2O equivalent with more than 50% slag in cement, and less than 2.0% Na_2O equivalent with more than 65% slag, have been observed".

Spellman [7] observed beneficial effect with 40%, 50% and 65% slag in Portland slag cement in terms of percentage expansion in mortar bars as per ASTMC227 [8] test with pyrex glass. He observed expansion less than 0.1% when 50% slag was used in the blend of (OPC + slag) (Fig.4). The alkali of cement was 1.15% as Na_2O equivalent.

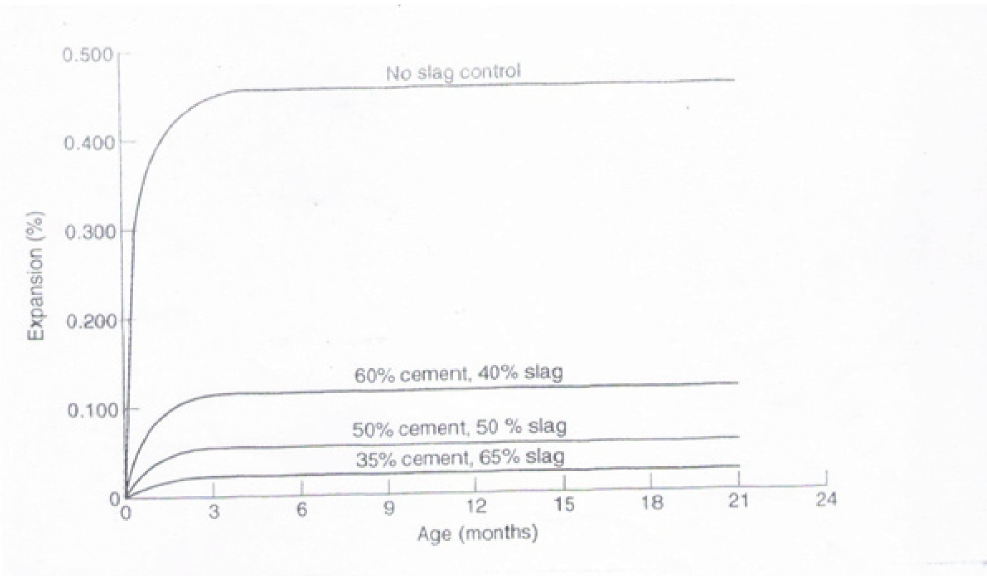

Figure 4 : Linear expansion of mortar bars with pyrex glass showing less than 0.1% expansion with 50% slag in cement

The PSC with 55% slag has been used to combat the alkali-silica reaction in 17 km tunnel lining in a hydro-electric project in Himachal Pradesh.

5. CONSTRUCTION METHODOLOGY FOR HYDRO-ELECTRIC PROJECTS IN THE CURRENT SCENARIO

Looking into the availability of consistent products, the Portland slag cement is the best failsafe material, using slag from blast furnace steel plants. The cement made from this product arrests the alkali silica reaction and also is resistant to the sulphates and chlorides present in ground water.

The concrete dams are to be constructed with the available crushed rock aggregates at the sites of construction. The cement and the admixtures (mineral as well as chemical) are to be transported to sites of construction. Indian Standard Code of practice for plain and reinforced concrete [2] stipulates use of (low alkali OPC + flyash /g.g.b.s.) as binding material to combat the deleterious alkali silica reaction in concrete. But since low alkali OPC (alkali less than 0.6% as Na_2O equivalent) is not much available in the country, PPC or PSC has to be used, with minimum 25% flyash in PPC and with minimum 50% g.g.b.s. in PSC. ICOLD [6] does not recommend use of PPC, because of its variable characteristics. Therefore, factory-made PSC with at least 50% g.g.b.s. is the best choice. In the cement factory, OPC and g.g.b.s. are chosen with compatible characteristics. The control in the factory is much better, than mixing the two materials i.e. OPC and g.g.b.s., at the site concrete mixer.

At some construction sites, aggregates may not be strong enough and might have high Los Angeles abrasion value, unsuitable for wearing surfaces. In that case, 5-8% silica fume is required to be mixed in concrete. This is specially for tunnel lining, desilting chambers etc. For spillways and stilling basins, 8-10% silica fume will be required, as they are to be of high strength concrete i.e. 55-80 MPa compressive strength. The superpasticizers (Polycarboxylate ether based) shall provide the required workability of concrete. Sometimes, precast concrete tunnel lining is specified. In that case, usual steam curing of concrete will be required, to achieve the early strength of concrete. The dam concrete will be as usual of low strength (15MPa) and with lower slump of 25-50mm. Superplasticizer is not required for such concrete. Very low percentage of air entraining admixtures (0.1 to 0.2% by weight of cement) should be used in concrete to make it cohesive, with higher maximum size of aggregate of 80 or 150mm.

6. ABRASION RESISTANCE OF CONCRETE IN SPILLWAYS AND STILLING BASINS

Silica fume is well known in increasing the abrasion resistance of concrete. In two of the Indian concrete dam projects (completed during 2004-2010), 8-10% silica fume (% by weight of cement) has been used in their spillways, and the projects are performing satisfactory. Typical photograph of the spillway of a concrete dam made with 60 MPa concrete and with 8% silica fume is shown in Fig. 5. The Southern Illinois University test results [9] indicate more than 100% improvement in abrasion- resistance when 10% silica fume was included in concrete (Fig 6). The test was conducted as per ASTMC779 [10]

Figure 5 : The spillway of 1000MW Tehri hydro-electric project,60MPa concrete with 8% silica fume

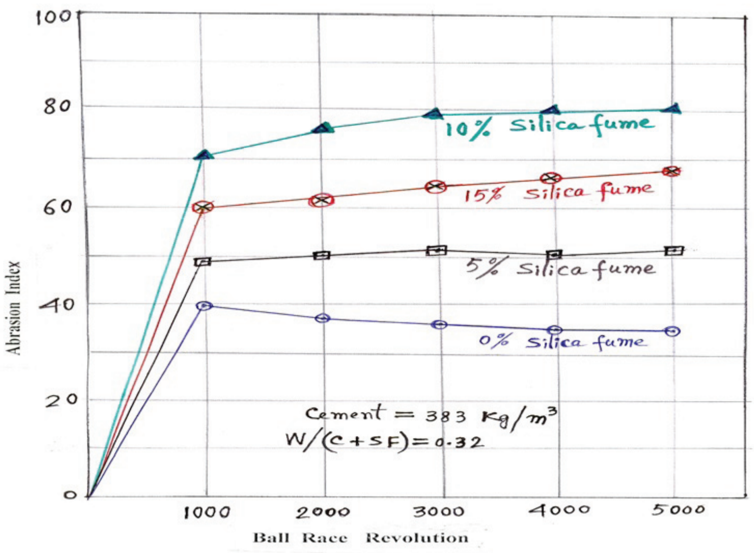

Figure 6 : Abrasion index of silica fume concrete

The stilling basins of concrete dams have to be strong enough to resist the abrasion and impact of the boulders, stones and other abrasive materials. Generally concrete of 55 or 60 MPa compressive strength is being used in the stilling basins. The top 150-200mm concrete should include steel or polypropylene fibres for resisting impact and abrasion. On the stilling basin of one of the hydro-electric projects in India, steel girders were fixed on the top concrete to resist the impact and abrasion. In another project, the stilling basin consisting of concrete blocks (size :26m x 26m x 1m, 19m x 19m x 1m and 24m x 21m x 1m) of 55 MPa strength, were constructed using PSC and 11% silica fume. During construction period, thermal cracks developed in concrete after 3 days. In order avoid such cracks, the quantity of silica fume in concrete was reduced to 8% by weight of cement.

7. CONCLUSIONS AND RECOMMENDATIONS

Based on the distress observed due to alkali-silica reaction in some of the concrete dams in India, Indian Standard Code of practice for plain and reinforced concrete recommends use of low alkali ordinary Portland cement plus at least 25% flyash or at least 50% ground granulated blast furnace slag in concrete, in hydro-electric projects The availability of good quality flyash from thermal power plants is less. The International Commission on Large Dams does not recommend Portland pozzolana cement in concrete for minimizing the risk of alkali- aggregate reaction, due to its variable properties.

Therefore, best option is to use factory made Portland slag cement with at least 50% ground granulated slag in it. Beneficial effect in terms of expansion in mortar bars has been observed, when 50% or more slag was used in the blend. Use of such green cement in concrete shall provide a sustainable and durable concrete structures in hydro-electric projects.

Due to availability of weak aggregates in some of the construction sites, 5-8% silica fume is being used to increase the abrasion resistance of concrete in tunnel linings. In some of the spillways of concrete dams, 8-10% silica fume had been used in concrete of compressive strength, 60 to 80 MPa, for the development of high-strength and abrasion- resistance. The Southern Illinois University test results indicate more than 100% improvement in abrasion-resistance, when 10% silica fume was used in concrete.

In India, using Portland Slag Cement with 55% g.g.b.s, 60 MPa strength of concrete has been achieved. The International commission on large dams should recommend the use of Portland slag cement in hydro-electric projects throughout the world. This will ensure durability of concrete structures combating the deleterious alkali-silica reaction and arresting other evils present in water, deleterious to concrete and simultaneously saving the environment from the pollution of carbon dioxide to a great extent.

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