Challenges facing the hydro-electric dam projects in the Himalayas

S.C. Maiti and Raj K. Agarwal

The states of Himachal Pradesh, Uttarakhand, Jammu and Kashmir and those of the North-East are implementing several hydro-electric projects. The construction engineers working at these project sites come with various backgrounds and experience. The lack of uniformity in their preparedness is a challenge the hydro-electric projects in the Himalayas face. Training and retraining the engineers are essential to keep the site team updated with the advancing knowledge so that they have the right exposure to use the right construction materials and follow the relevant standards. There are several issues that need to be addressed so that the structures built by them last the designed service life. This paper highlights some of the issues that need to be considered while using construction materials such as cement, aggregates and steel.

Construction materials

One of the major challenges being faced by the dam engineers is the selection and use of materials for construction. The main construction materials are cement, water, sand, coarse aggregate, chemical and mineral admixtures.

Low alkali cements prevent alkali-silica reaction

According to the recommendations of the Codes of Practices, low-alkali Ordinary Portland Cement (OPC) should be used, because Himalayan aggregates are generally reactive.[1,2] Such aggregates react with alkali hydroxides in concrete, causing expansion and cracking over a period of many years. So, even when the laboratory tests indicate that the aggregates are not reactive, low-alkali OPC should be used as a precautionary measure. This is recommended because every cubic metre of aggregate cannot be tested.

However, not all cement plants are able to produce low-alkali OPC. Therefore, one must look for low-alkali OPC from the limited number of cement plants that are able to do so.

Use blended (low-alkali) cements to further reduce alkali-silica reaction

The Code of Practice and some American experts further stipulate the use of at least 25% good quality fly ash satisfying the requirement of IS 3812 (Part 1) or at least 50% ground granulated blast furnace slag (GGBS) as part replacement of the low-alkali OPC, to further prevent the durability risks associated with alkali- silica reaction.[1,3] The reactive alkali is about 17% and 50% of fly ash, and GGBS alkalis respectively.[4]

The Rihand dam power house suffered distress due to alkali-silica reaction despite using about 15% fly ash in concrete. The power house could not be operated, and the power generation was stopped. About 13,000 tonnes of fly ash was used in structural concrete. The OPC had a high-alkali content in the range 1.2 to 1.8% (as Na_2O equivalent).[5]

Fortunately, these days, several of India's cement plants are able to produce low-alkali OPC. The typical alkali content percentage (as Na_2O equivalent) in various cement samples tested for a dam project were 0.59, 0.59, 0.52, 0.97, 0.86, 1.29, 1.25, 0.96 and 0.91.[6]

The International Commission on Large Dams, or ICOLD, (French: Commission Internationale des Grands Barrages or CIGB) is an international non-governmental organisation dedicated to the sharing of professional information and knowledge of the design, construction, maintenance, and impact of large dams. It was founded in 1928 and has its central office in Paris, France. It consists of over 90 member national committees which have a total membership of about 10,000 individuals.

ICOLD recommends the following with regard to the use of fly ash or Portland Pozzolana Cement (PPC) or Portland Slag Cement (PSC) in concrete for combating the probable alkali-aggregate reaction.[7]

"There is now considerable experience of the use of the 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 limits of alkali (i.e. 0.9% as Na_2O equivalent for PSC containing more than 50% slag and 2.0% alkali as Na_2O equivalent for PSC containing more than 65% slag) have been observed.

In the case of Portland Pozzolana cements, the cement manufacturers should be able to match the characteristics of a particular cement and pozzolana to ensure adequate compensatory action under the conditions of the intended use, but, despite the accumulated experience with Portland pozzolana cements, the variability in their properties, does not yet permit the recommendation for their use in minimising the risk of alkali-silica reaction."

Use strong aggregates

Despite being in the mountains, dam sites do not always guarantee the availability of good quality aggregates. Sometimes only soft rocks are available at site. In such cases, strong rocks should be taken from a distance and crushed to produce coarse and fine aggregates meeting the requirements of the specifications. Mixed aggregates from the river bed may contain mica and other deleterious materials including sulphur. So such aggregates should be checked before using them in concrete. Sulphur, gets converted to sulphates and weak acids of sulphur. These chemicals attack concrete.

Avoid segregation by using well-graded aggregates

Concrete gravity dams are generally designed with low grade concrete, say M15, and bigger size coarse aggregates (150 mm and 75 mm maximum size) are used in proportioning the mix. This concrete has a tendency to segregate while travelling on a belt drive or while being placed. To prevent segregation, care must be taken to use well-graded and clean aggregates.

Use air-entraining agents to make cohesive concrete

Adding air-entraining admixtures (about 0.2% by weight of cement) helps produce cohesive concrete mix with such big size aggregates.

Control the heat of hydration – Keep cement content low, use blended cements

In concrete dams or other mass concrete constructions, low cement content is desirable, because the heat of hydration will be low when this is the case.

It is well known that OPC 43 and OPC 53 cements produce concrete with high heat of hydration. However, by lowering the cement fineness, that can be reduced. So in mass concrete applications, 33-grade OPC or PPC or PSC should be used. These cements are not ground as fine as OPC 53. Although, a BIS specification exists for low heat Portland cement, this cement is not readily available in the market. PPC (containing 25% fly ash) and PSC (containing 55% slag) produced by Indian cement manufacturers, have considerably low heat of hydration. So they are suitable for mass concrete structures in hydro-electric projects.

It is noteworthy that most of the structures in Koteshwar hydro-electric project (Uttarakhand) were constructed with PSC containing 55% slag (Figure 1). However, silica fume based high-performance concrete was used in the stilling basin and the spillway. Table 1 compares the heat of hydration for typical OPC, PPC and PSC samples.[6]

Prevent rebar corrosion

A dam's tunnel lining and power house structures are generally RCC constructions. In addition to protecting these structures from the deleterious alkali-silica reaction, their structural design should include the use of corrosion-resistant steel bars. Improved varieties of steel bars increase the durability and service life of such structures. Coating of reinforcement should also be considered to help achieve this goal. Polymeric coating materials are recommended for this purpose. Fusion-bonded epoxy coated bars are also used. In addition, steel companies produce corrosion-resistant rebars by modifying the metallurgy during the process of rebar manufacturing.

Improve abrasion resistance of concrete in spillway and tunnel lining

In addition to silica fume, fibre-reinforced concrete should also be considered for improving the abrasion resistance of structures such as spillways and tunnel linings. Polypropylene fibres can be satisfactorily used in such applications.

Watch out for reactive carbonate rocks

In the case of reactive carbonate rocks, experimental studies suggest that pozzolans are not effective in controlling the deleterious alkali-carbonate reaction. However, Portland slag cement with at least 55% slag does this job reasonably effectively. So recommendations for controlling this reaction include the use of very low alkali OPC (0.4% or low as Na_2O equivalent).[7,8] In addition, the dilution of aggregate has been suggested, so that the amount of potentially reactive rock does not exceed 20% of the coarse or fine aggregate or 15% of the total aggregate, when reactive carbonate is present in both coarse aggregate and fine aggregate.[9]

Table 1. Typical heat of hydration of cement

No.	Cement	Heat of hydration, KJ/kg	
		at 7 days	at 28 days
1.	OPC		
	33 grade	209	238
	43 grade	320	341
	53-grade	287	347
2.	PPC		
	(i)	251	295
	(ii)	181	214
	(iii)	199	230
3.	PSC (with more than 50% slag)		
	(i)	254	292
	(ii)	188	226
	(iii)	174	231
	(iv)	213	252
	(v)	196	244
	Requirement of low heat Portland Cement as per IS 12600:1989, Max	272	314

Use chemical admixtures

With the availability of accelerating admixtures, the speed of construction can be significantly improved. In cold conditions of the Himalayas, for example, chloride-free accelerators can reduce the setting time of concrete, and accelerate the rate of hardening. Using polycarboxylic ether-based superplasticiser, very high-workability, self-compacting concrete (SCC) can be produced. This concrete does not require compaction by vibrators. Moreover, its placing is faster than that of the conventional concrete.

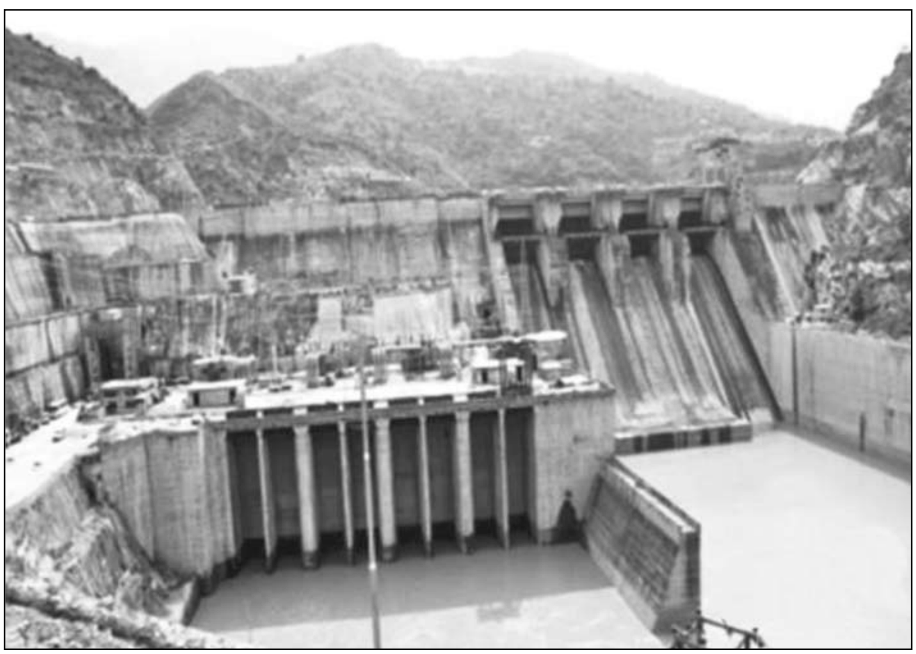

Figure 1. Koteshwar dam, Uttarakhand

Use corrosion inhibitors

As the name suggests corrosion inhibitors slow down the reinforcing steel corrosion, which is primarily caused by the presence of chloride in concrete. One of the effective corrosion inhibiting materials is sodium nitrite. Calcium nitrite is also used to prevent pitting corrosion of steel reinforcements exposed to chlorides in alkaline environment.[10]

Cement strength and concrete strength

Cements from various manufacturers behave variously in concrete. In other words, all cements produced by Indian manufacturers do not possess the same strength. Further, the 3-day compressive strength of OPC is not expected to be equal to that of PPC and PSC, despite having the same parent clinker. This is because, fly ash in PPC and slag (GGBS) in PSC react with the lime liberated due to the hydration of OPC. This reaction takes at least 3 or 4 days to start. But at 28 days, comparable concrete strength may be expected regardless of the cement used – OPC, PPC or PSC.

Understand the cement types

Cements produced by various companies vary in strengths because of the variation in raw materials such as limestone, clay and gypsum. Also, cement manufacturing conditions vary from plant to plant. However, experience suggests that the fineness (Blaine's) of cements should preferably be kept at an optimum level of say about 290 m^2/kg.

BIS has specifications for OPC, PPC and PSC. OPC is further classified into 3 grades 33, 43 and 53-grade, with the 28-day compressive strength being minimum 33, 43 and 53 MPa respectively. However, the BIS does not classify the blended cements similarly. PPC and PSC 28-day compressive strength requirements remain at 33 MPa, minimum. If the quality of clinker, fly ash and slag is good, the quality of PPC and PSC will also be good. The fineness of cement has a bearing on the early strength of OPC. More fine cement (say, fineness, 400 m^2/kg) will produce higher 3-day and 7-day compressive strengths. But at 28-day, the fineness advantage may be lost. The 28-day compressive strength of cement has a bearing on 28-day compressive strength of concrete. For a particular water-cement ratio, cements of higher compressive strengths help produce concrete of higher compressive strengths.

Figure 2. The spillway of 1000 MW Tehri hydro electric project uses 60 MPa concrete 8% silica fume

Use cement as soon as possible to avoid strength loss due to prolonged storage

The storage of cement at project sites is either in a godown or in a silo. Storing cement for about 3 months reduces its compressive strength by about 20%. In 6 months, the 28-day strength loss could be about 35%. Therefore, cement should be used as early as possible.

Master the details of mix proportioning techniques

The 28-day strength of concrete depends on the water-cement ratios as well as on the 28-day strength of cement. Adding superplasticiser can reduce the water-cement ratio, and at the same time, produce concrete of the desired workability. For high strength concrete, say M80 grade (for spillways) concrete, water-cement ratio is reduced to about 0.25 to 0.28 using a PCE-based superplasticiser. PCE superplasticisers have the capability of reducing the water content of concrete by more than 30%. Alongwith OPC, about 10% silica fume is also required for producing such high strength concrete. However, PPC and PSC are not able to develop such high strengths. With these cements, concrete grades up to M55 or M60 are possible. For producing M70 or M80 grades of concrete, OPC-53- grade is required.

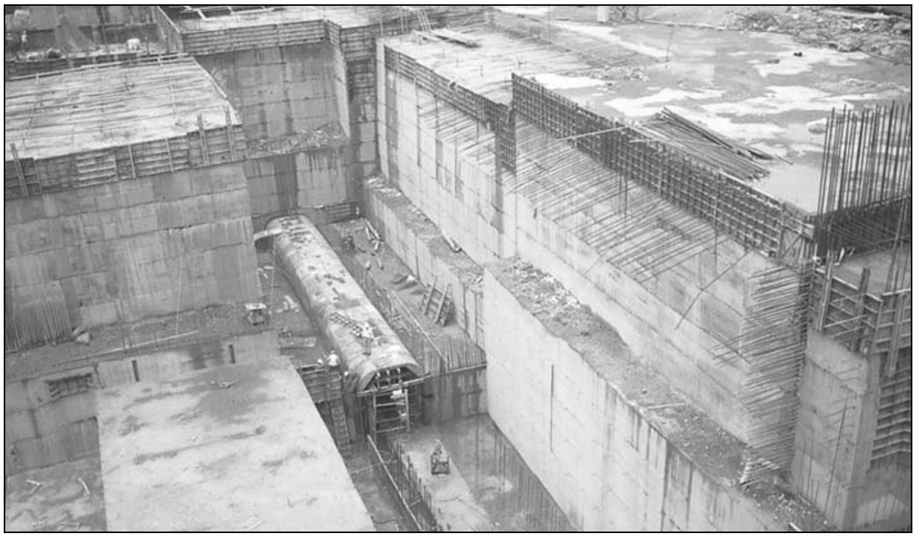

Figure 3. Typical view of the Kol dam (under construction)

The typical concrete mix proportions for M80 grade of concrete for Kol dam (Himachal Pradesh) spillway with 225 mm slump are as follows:

Mix Ingredients: kg/m^3

- OPC: 500
- Water: 137.5
- Silica fume: 50
- Coarse Aggregate (20 mm MSA) : 1063
- Sand: 698
- Superplasticiser: 8.25

Figure 3 shows a typical view of the Kol dam (under construction).

The silica fume high strength concrete of grade M60, M70 or M80 (required for spillways) will also have abrasion-resistance characteristics. The Southern Illinois University test results indicate more than 100% improvement in abrasion resistance, when 10% silica fume was introduced into the reference concrete (Figure 4).[11]

The typical M60 grade concrete mix proportions used in the spillway of Tehri dam (Figure 2) are as follows:

- Grade of concrete: M60
- Maximum size of aggregate: 20 mm
- Workability of concrete: 105 mm (slump)
- Mix ingredients: kg/m^3
  - Ordinary Portland cement: 470
  - Water: 155
  - Sand: 514
  - Coarse aggregate: 1272
  - Superplasticiser (naphthalene based) : 10.7
  - Silica-fume: 38

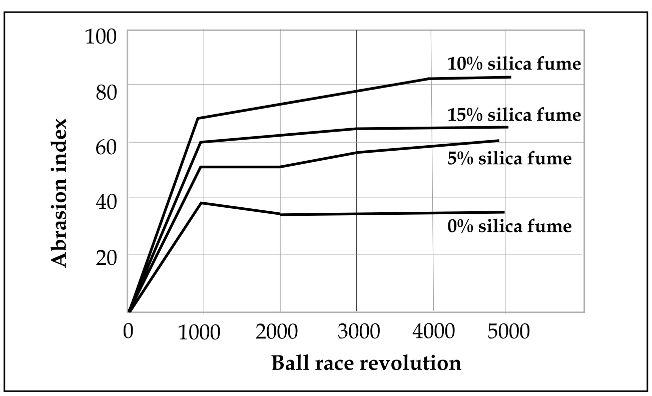

Figure 4. Abrasion index of silica fume concretes at 5 minutes testing period (Cement = 383 kg/m^3; w/C+sf) = 0.32 and 28 days curing)

Designers specify various grades of concrete for dam and other structures such as desilting chamber, tunnel lining and power house structures. For example, PPC or PSC based concrete is recommended for low strength concrete. PPC with 20 or 25% fly ash or PSC with 50 or 55% slag should be able to produce M15 grade of concrete. For other structures, M25 or M30 grades may be specified.

PPC or PSC will be sufficient for such grades of concrete. The high-workability concrete (pumpable concrete) can be produced using a naphthalene-based water reducing admixture. As mentioned earlier, any grade of concrete between M15 and M60 can be produced using normal PPC or PSC and a superplasticiser, by controlling the water-cement ratio. So, one should not look for high strength PPC or PSC. A typical concrete mix proportion for M55 grade concrete using PSC is given below:-

- Grade of concrete : M55
- Workability of concrete : 80mm
- Mixture proportion : kg/m^3
- Portland slag cement (with 55% slag) : 530
- Water: 195
- Sand (40%) : 651
- Coarse aggregate (20mm Max. size) : 977
- Superplasticiser (0.8%) (PC-based): 4.57
- Silica fume (8%) : 42
- w/(C+silica fume) = 0.34

The 28-day compressive strength was 59.55 N/mm^2 and 50-day compressive strength was 72.75 N/mm^2

Practice cold weather concreting methods

Some of the Himalayan region hydro-electric projects are in snow-bound areas. The cold weather there permits construction activity only for about 6 months in a year.

For cold weather concreting, the ACI Committee report 206 R should be followed.[12] If concrete is protected from freezing until it has attained a compressive strength of at least 3.5 MPa, it will not be damaged by exposure to freezing temperatures. However, a heated enclosure is recommended to protect the concrete from low temperature exposures. The enclosure must be windproof and weatherproof. A low slump concrete is desirable so that bleeding is minimised and early setting is possible. Circulating steam in pipes is recommended for heating the aggregates. Heating of mixing water up to 60^{o}C is also advised. However, mixing with very hot water may flash set cement producing cement balls in the truck mixers.

Ordinary Portland cement (43-grade) is a preferred choice, to utilise the heat of hydration and to maintain concrete temperatures.

It is necessary to cover the concrete with an insulated material, to utilise the natural heat of hydration of cement and to maintain the temperature at the recommended level. The insulation must be kept in close contact with the concrete. Some of the insulating materials are polystyrene foam sheets, urethane foam and foamed vinyl blankets, mineral wool, cellulose fibers, straw and commercial blankets.

Newly placed concrete must be protected from drying out, so that adequate hydration can be achieved. As long as the forms remain in place, the adjacent concrete surface will retain adequate moisture. Exposed horizontal surfaces, particularly finished floors are prone to rapid drying out in a heated enclosure. Concrete may be water-cured, when no freezing is expected. Otherwise, the use of curing compounds or an impervious cover is the preferred procedure for curing.

In very cold weather conditions, non-corrosive accelerating admixtures should be used in concrete. Calcium nitrite and Sodium nitrite are chloride-free accelerators, as well as anti-freezing admixtures. Concrete mixes containing nitrites are found to develop significant strength even at temperatures down to -10^{o}C [13].

Address the environmental issues

During the implementation of hydro-electric projects, the many environmental issues that arise must be attended to. The pollution of river water due to construction must be as less as possible. A recent report suggests that “every day nearly, 2,900 million litres of sewage is being discharged in to the holy river “Ganga”. Some of the hydro-electric projects on the tributaries of Ganga in Uttarakahand are also facing, environmental issues. To combat river pollution, the Government of India recommends focusing on three key areas: untreated sewage, industrial pollution and the need to maintain the ecological flow of the Ganges. The people displaced because of hydro-electric projects must also be rehabilitated at an alternative place with the facilities they had in their first place. Many trees are removed due to construction activities. Re-planting of trees should be carried out as early as possible. The survival of the replanted trees should also be ensured.

Concluding remarks

The construction materials field is making rapid advancements. Many of the old practices are getting replaced with new ones. Concrete as a construction material has undergone remarkable advancements in the last few decades. Aggregates’ reaction with cement has led to the understanding of alkali-silica reaction which in turn has led to the material specifiers specifying low alkali cement for dam construction. The use of blended cements improves the durability of construction with an added advantage of low heat of hydration in mass concreting jobs.

The method of cold weather concreting includes the option of preheating the aggregates, using chemicals for accelerated strength development, incorporating air entraining agents for producing cohesive concrete with large size aggregates. Anti freezing chemicals and corrosion – inhibiting chemicals are also included in the modern concretes for dam construction. Dam engineers have the option of using coated reinforcing steel bars to increase the durability of reinforced concrete constructions.

Dam construction projects bring with them several environmental and social issues including the cutting of trees, pollution of river water and rehabilitation of project affected people. By accepting training and retraining opportunities, dam engineers can help themselves in successfully implementing such projects despite the many technical, environmental and social challenges.

References

1. ______Indian standard Code of practice for plain and reinforced concrete, IS 456:2000, Bureau of Indian Standards, New Delhi.
2. BRE Digest 330, Alkali aggregate reactions in concrete. March 1988.
3. Malvar, L.J. and others. Alkali-silica reaction mitigation : State of the art and recommendations, ACI Materials Journal, September–October 2002, pp.480-489.
4. BS 5328 : Part 4 : 1970 Specification for the procedures to be used in Sampling, Testing and Assessing Compliance of Concrete, British Standards Institution.
5. Rihand Dam Expert Committee Report, Vol. 1, June 1986, Published by Irrigation Department, Uttar Pradesh.
6. Maiti, S.C, Agarwal, Raj K. and Rajeeb Kumar. Concrete for hydro-electric projects: Combating alkali-aggregate reaction. Indian Concrete Journal, Vol. 79, No. 1, January 2005, pp 33-39.
7. ICOLD. Alkali-aggregate reaction in concrete dams. Review and Recommendations. International Commission on large dams. Bulletin No. 79, 1992, 158pp.
8. ______Guide to durable concrete, American Concrete Institute Committee 201, Detroit, U.S.A.
9. ______Concrete dams – Control and treatment of cracks, 1997, ICOLD Bulletin 107, International Commission on Large Dams, Paris.
10. Edmeades, R.M. and Hewlett, P.C. Cement Admixtures in Lea's Chemistry of Cement and Concrete. Fourth Edition, 1998, pp.841-905.
11. Ghafoori,N and Diawara,H. Abrasion resistance of fine aggregate replaced silica fume concrete. ACI Materials Journal, September-October 1999,pp 559-567.
12. ______ACI 306R-88 Cold weather concreting. Manual of Concrete Practice. American Concrete Institute, 2006
13. Korhonen, C.J, Cortez, E.R. and Charest, B.A. Strength development of concrete cured at low temperature. Concrete International, 14, No.2, 1992, pp. 34-39.

Dr. S.C. Maiti holds a PhD (structural engineering) from IIT Kharagpur and is former Joint Director of National Council for Cement and Building Materials (NCCBM), New Delhi. He is currently a Technical Consultant at Ultratech Cement Ltd. He has been a member of the panel for revision of IS 456:2000. His areas of interest are cement and concrete, advances in concrete technology, concrete mix design and quality assessment of concrete structures.

Raj K. Agarwal is Managing Director of Marketing & Transit (India) Pvt. Ltd., New Delhi. He has been interacting with the project authorities of hydroelectric projects in the country for the last 15 years, and providing guidance for the use of proper construction materials in order to achieve durable concrete structures. He has pubilshed several papers and has participated in ICOLD and International seminars.

■