# *Use of Crushed Rock in Developing Abrasion Resistant Concrete for Vishnu Prayag Hydro-Electric Project*

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## ABSTRACT

The concrete surface of the spillway structures constructed across Himalayan rivers are generally subjected to erosion due to abrasive action of rolling boulders, shingles, debris etc. carried away by high speed flowing water during monsoon and heavy flood. This paper briefly discusses the laboratory investigations carried out at Irrigation Research Institute (IRI), Roorkee to examine the suitability of different protective materials for hydraulic structures. An attempt has been made to develop a high strength abrasion resistant concrete ($A_{20}M_{60}$) using crushed rock (quartzite) as fine aggregate, which has been successfully used to prepare the top layer of barrage floor of Vishnu Prayag Hydro-Electric project located in Chamoli district of Uttarakhand state. The study also indicated that high performance concrete using silica fume and superplasticiser with crushed rock appears to be more advantageous in terms of gain in strength beyond 75 MPa. On the other hand, natural river sand is found to be more suitable for lower range of strength.

***Keywords:*** Silica fume; Superplasticiser; Fly-ash; High performance concrete; Hydraulic structures

## 1. INTRODUCTION

The abrasive action of the high speed flowing water carrying suspended load in the form of boulders, shingles, debris etc. causes extensive damages in different parts of the hydraulic structures. The top layer of the spillway structures constructed across the high altitude rivers in the Himalayas is subjected to heavy erosion due to abrasive action of rolling boulders, shingles, debris etc. carried away with flowing water. It has been observed that barrages, weirs and other low head diversion structures are generally encountered to the onslaught of rolling boulders. In case of high dams, erosion is caused in the energy dissipation structures due to river bed boulders rolling back into the stilling basins. The rivers flowing through Himalayas have exceptionally steep slopes due to which large size boulders (50cm to 2m) have been observed to be rolling down over the spillway in some projects during flood and heavy monsoon. This has resulted extensive damage in different parts of the barrage and spillway structure (Garg et al., 1998).

Concrete tunnel linings are also susceptible to abrasion erosion damage, particularly when the water carries large quantities of sand, gravel, rocks and other debris. There have been many instances where the concrete in both temporary and permanent diversion tunnels has experienced abrasion erosion damage. Generally, the tunnel floor or invert is the most heavily damaged. Wagner (1967) has described the performance of Glen Canyon Dam diversion tunnel outlets.

It is always desirable to eliminate the cause of abrasion or erosion whenever possible, however, since this is always not possible during heavy monsoon period or flood especially in the project sites located in Himalayan region, a variety of material and material combinations is used for the repair of concrete. Some materials are better suited for certain repairs and judgment should be exercised in the selection of the proper material. The regular, periodic inspection of the completed and operating hydraulic structures is extremely important.

Thus systematic study of the abrasive characteristics of the material to be used as protective layer for spillway/barrage floor is very essential so as to preserve the designed life of the hydraulic structure. Generally epoxy mortar is used as a repairing material in places where small damages take place in such structures.

Experience shows that the erosion-resistance of the surface is directly related with strength of the material (generally concrete) used in such places. This can be achieved substantially by the use of suitable materials and methods adopted for development and placement of concrete during construction. Fly-ash with silica fume as pozzolana admixture is one such example, which can be used effectively for achieving abrasion resistant high strength concrete.

## 2. EVALUATION OF PROTECTIVE MATERIAL AND TESTING

### 2.1 High Performance Concrete

A high performance concrete (HPC) as defined by American Concrete Institute (ACI) is a concrete that meets special performance and uniformity needs that cannot be achieved routinely using conventional constituents and normal mixing, placing and curing practices. Such a concrete needs extra cementitious material such as silica fume or micro silica and high-water reducing superplasticiser. Developing high abrasion resistance concrete means including hardest available coarse aggregate and lowest practicable water-cementitious ratio. In addition, it means using cement equivalent to ASTM type I, which is OPC-53 grade in India. Because spillway is a complicated structure for construction, use of high performance concrete prevents differential wearing of the surface. Adding high range water reducing agent (HRWRA) makes strong bond between coarse aggregate and matrix (Nanda et al., 2010).

## 2.2 Testing Practices

Because of the massive size of most hydraulic structures, full-scale prototype testing is usually not possible. Model testing can identify many potential problem areas, but determining the ultimate effect of hydraulic forces on the structure requires some judgment. In some cases, it is desirable to evaluate a material after it has been subjected for a reasonable period of time to flows of a magnitude approaching that expected during operation of the facility.

Materials should be tested and evaluated prior to being used in hydraulic structures subjected to abrasion erosion damage. A variety of test methods including rubbing types of apparatus; dressing wheel; rolling steel balls under pressure (ASTM C 779); sandblasting (ASTM C 418) and modified Los Angeles rattler (ASTM C 131 and C 535) have been used to determine abrasion erosion resistance of concrete surfaces. These tests, designed to simulate heavy foot or wheeled traffic on concrete surfaces, are not intended to model abrasion by waterborne particles (ACI Committee 210).

The U.S. Army Corps of Engineers' test CRD-C6380, "Test Method for Abrasion-Erosion Resistance of Concrete (Underwater Method)," is a better model of the abrasive action of waterborne particles on a hydraulic structure. This test method is intended to qualitatively simulate the behavior of swirling water containing suspended and transported solid objects that produce abrasion of concrete and cause potholes and related effects.

The abrasion resistance test as given in IS: Code 9284-1979 is an indirect test, where sand is made to impinge on the surfaces through the action of compressed air and the loss of mass determined for two separate impressions on the same face. The relative abrasion resistance on different surfaces is determined by comparing the loss of mass in each case. This test however does not give an absolute value of abrasion resistance of given surface/material.

In this direction, laboratory studies have also been carried out to examine the effect of abrasion on different construction materials by high velocity water jet apparatus specially designed and developed at Irrigation Research Institute, Roorkee. The test procedure essentially covers the laboratory method of determining the relative resistance of different types of concrete used as protective layer for hydraulic structures subjected to abrasive action of high speed water borne particles.

## 3. PROPOSED METHOD OF TESTING

It is difficult to simulate the prototype conditions in the laboratory regarding flow pattern of water and abrasive charge etc. rolling on the spillway profiles of dams, barrages or turbine blades. At present there is no IS Code or guidelines available to study the abrasive action of high velocity water jet containing river bed material flowing over the concrete surfaces of dams and barrages or other surfaces. However, an effort has been made to design and develop an experimental set up which more or less

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The proposed apparatus consists of a chamber with an elevated platform for holding the specimen and receiving high velocity water jet (upto 30 m/sec), a sand feeding arrangement to feed sand upto 10000 ppm as shown in Fig. 1. It is connected to a centrifugal pump driven by electric motor with a capacity of 7.5 H.P., which pumps the water and delivers the same through a conical brass nozzle of 12.5mm inside diameter. The water is collected at the bottom and re-circulated by the pump. The water delivery pipe line is fitted with a pressure gauge from which any fluctuation in pressure is observed and subsequently the velocity may be noted. Figure 1 shows the experimental setup for high velocity water jet with sand feeding arrangement. This test method is not intended to provide a quantitative measurement of the length of service that may be expected from a specific concrete.

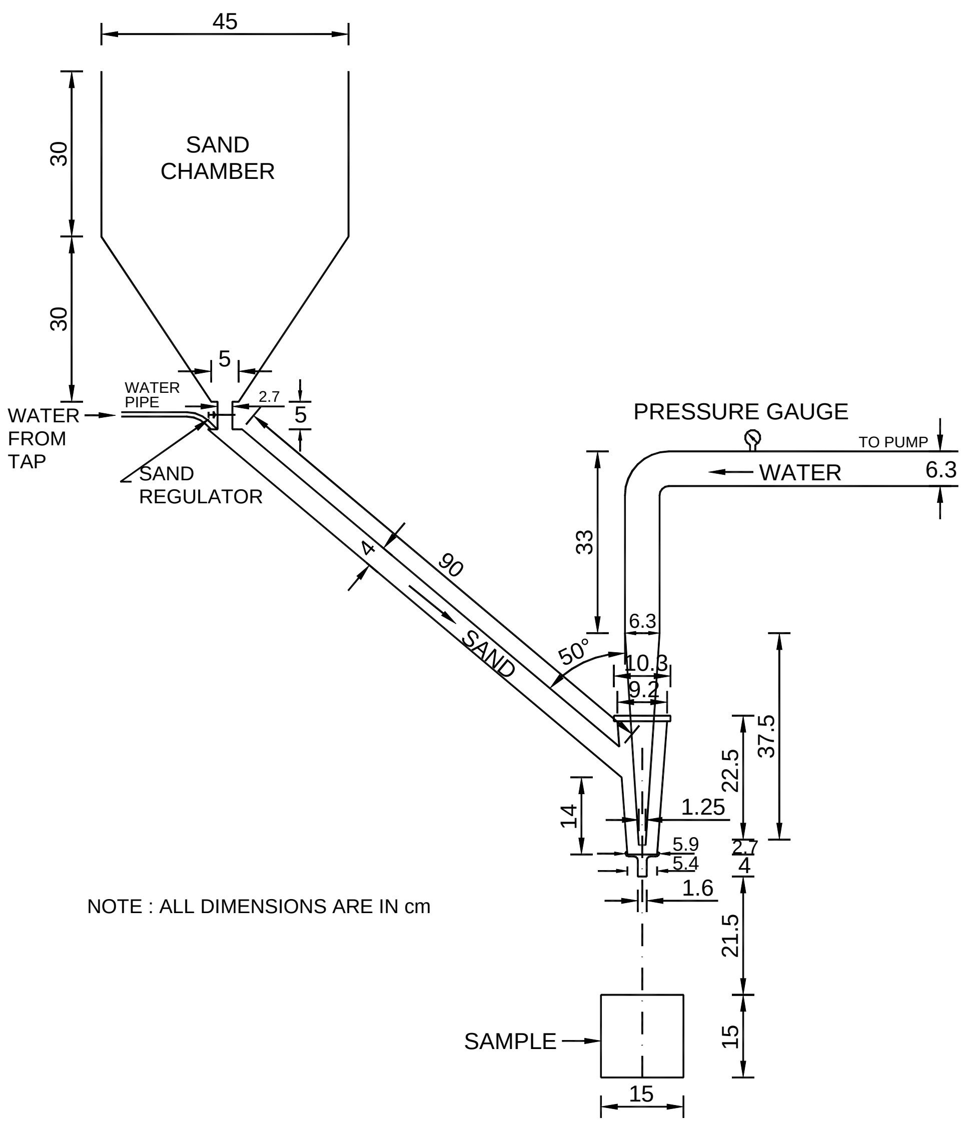


Fig. 1 – High velocity water jet apparatus with sand feeding arrangement developed in IRI Roorkee

The coarse sand as abrasive charging material (particle size < 4.75mm) is used with a water jet velocity at the rate 20m/sec and 30 m/sec and sediment load varying between 3,000 ppm to 10,000 ppm. The abrasion losses in terms of mass (and also volume) are measured with the help of high sensitive electronic balance.

## 4. ABRASION STUDY ON HIGH PERFORMANCE CONCRETE DEVELOPED IN THE LABORATORY

In order to protect the surface of the hydraulic structures, different materials are used, which include epoxy resin, acrolytic mortar, iron aggregate, coating of polyurethane mortar, silica fume- flyash concrete, steel fibre reinforced concrete etc. In the present study, three different types of high performance concrete were developed and subsequently tested for examining its abrasive characteristics under high speed water jet with a velocity of 30 m/sec and sediment load 10,000 ppm. Table-1 shows the mix ingredients for silica fume-flyash concrete, steel fibre reinforced concrete (SFRC) and conventional concrete. The abrasion loss in cc/hr as observed during experimentation on high velocity water jet apparatus has also been shown. In case of silica fume-flyash concrete, the superplasticiser has been used as usual, which is 1.25 percent of cementitious material (i.e. cement + flyash + silica fume).

Table 1 - Mix Ingredients of Different types of Concrete Developed in the Laboratory and Observed Abrasion Loss

**Type of Cement- OPC- 43 grade** : 56 MPa (28 days Compressive strength)

Workability for silica fume-fly ash concrete : 50mm to 80mm (in terms of slump)

| Quantity of Mix Ingredients per Cubic Meter (kg) | | | | | | | | Compressive Strength (MPa) | | Abrasion Loss (cc/hr) Period of Test- 4 hrs. |
|---|---|---|---|---|---|---|---|---|---|---|
| **Cement** | Water | Super-plasti-ciser | Pozzolanic Admixture: Fly-ash | Pozzolanic Admixture: Silica fume | Fine Aggre-gate (Natural Sand) | Coarse Aggregate (mm): 20-10 | Coarse Aggregate (mm): 10-4.75 | 28 days | At the time of abrasion test | |
| [A] Silica Fume – Flyash Concrete (MSA 20mm); Test at the age of 13 and 15 months respectively | | | | | | | | | | |
| 522 | 168.0 | 7.25 | 39.2 | 26.1 | 482 | 952 | 208 | 76.9 | 94.8 | 10.0 |
| 522 | 168.0 | 7.67 | 52.2 | 39.2 | 443 | 959 | 210 | 67.3 | 90.2 | 10.15 |
| [B] Silica Fume – Flyash Concrete (MSA 10mm); Test at the age of 6 months | | | | | | | | | | |
| 531 | 186.0 | 7.60 | 45.5 | 30.4 | 482 | - | 929 | 66.5 | 77.2 | 10.38 |
| 528 | 192.0 | 8.00 | 64.0 | 48.0 | 466 | - | 929 | 68.3 | 79.2 | 9.75 |
| [C] SFRC (Flat type Corrugated), 4% by total mass, 87 kg/m$^3$, Test at the age 6 months | | | | | | | | | | |
| 462.5 | 185.0 | - | - | - | 523 | 1006 | 195 | 52.8 | 67.5 | 9.96 |
| [D] Conventional Concrete, Test at the age of 13 months, slump 40mm | | | | | | | | | | |
| 528.6 | 185.0 | - | - | - | 498 | 981 | 189 | 45.7 | 67.5 | 11.54 |

## 5. DEVELOPMENT OF HIGH PERFORMANCE CONCRETE

Vishnu Prayag Hydro-Electric Project (400MW) is located across river Alaknanda in Chamoli district of Uttarakhand. This has highest operating head with 915m. The project envisages construction of diversion barrage of size 17m x 63m long with three radial gates, separate intake to power tunnel/sedimentation chambers; a 11.343 km long and 4m horseshoe-shaped (concrete lined) power tunnels with a design discharge 50 cumec; 143m high and 8m dia. restricted orifice type underground surge shaft; 1517m long steel lined pressure shaft (dia. 3.5m, 3.4m, 3.3m, 2.5m, 1.85m), an Underground power house complex with machine hall cavern 122m long x 18.5m wide x 38.6m high with 4x100MW Pelton turbo-generators; transformer hall gallery of 103m long x 14m wide x 22.5m high with single phase power transformer and 1.924 km long tail race tunnel with 5.6 wide and 5.7 high D-shaped tunnel. The sedimentation chamber (two continuously flushing desanding chamber 160m long x 16m wide) has been designed to exclude sediments greater than 0.15mm.

On the basis of abrasion study on different type of concrete developed in the laboratory, it was planned to develop high performance concrete using silica fume and superplasticiser for its use in the construction of barrage floor of the above hydro-electric project.

The concrete mix design for grade $A_{20}M_{60}$ at slump (65±10)mm was carried out using ordinary Portland cement-53 grade, Micro Silica grade 920-D as mineral admixture and Superplasticiser as chemical admixture on the basis of 28 days compressive strength. In the present study, the fine aggregate/coarse aggregate were prepared by crushing the quartzite rock obtained from nearby quarry site of the project. The mix design was also carried out using natural river sand. In order to simulate the field condition as far as possible, the temperature of the concrete was maintained below 30 $^0$C by using cold water during experimentation.

From the results obtained for compressive strength of 150mm size concrete cubes, free water-cementitious ratio Vs compressive strength curve has been developed for crushed and natural sand separately as shown in Fig. 2. The laboratory 28 days target strength 73.0 N/mm$^2$ corresponding to grade $M_{60}$ was achieved at free water-cementitious ratio 0.311 with crushed rock sand and 0.317 with natural river sand. The quantities of mix ingredients are given in Table-2 (a). (IRI, Roorkee Technical Memorandum, 2001)

Table 2(a) - Concrete mix design for top layer of barrage floor, Vishnu Prayag hydro-electric project ($A_{20}M_{60}$)

| Type of Fine Aggregate | W/(C+P) ratio | Quantity of Mix Ingredients per Cubic Meter (kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Cement (C) | Silica fume (P) | Water | Super-plasticiser* | Fine Aggregate | Coarse Aggregate (mm) | |
| | | | | | | | 20-10 | 10-4.75 |
| Crushed rock sand | 0.311 | 479 | 36 | 151.4 | 10.3 | 596 | 794 | 337 |
| Natural river sand | 0.317 | 464 | 35 | 150.3 | 9.98 | 603 | 804 | 341 |

* 2.0 percent by weight of cementitious material.

Table 2 (b) shows the comparison of the cementitious materials used for natural sand and crushed rock sand at different compressive strength. It is interesting to note that use of crushed rock as fine aggregate may be more advantageous in terms of saving the cement when higher strength (> 80MPa) is required.

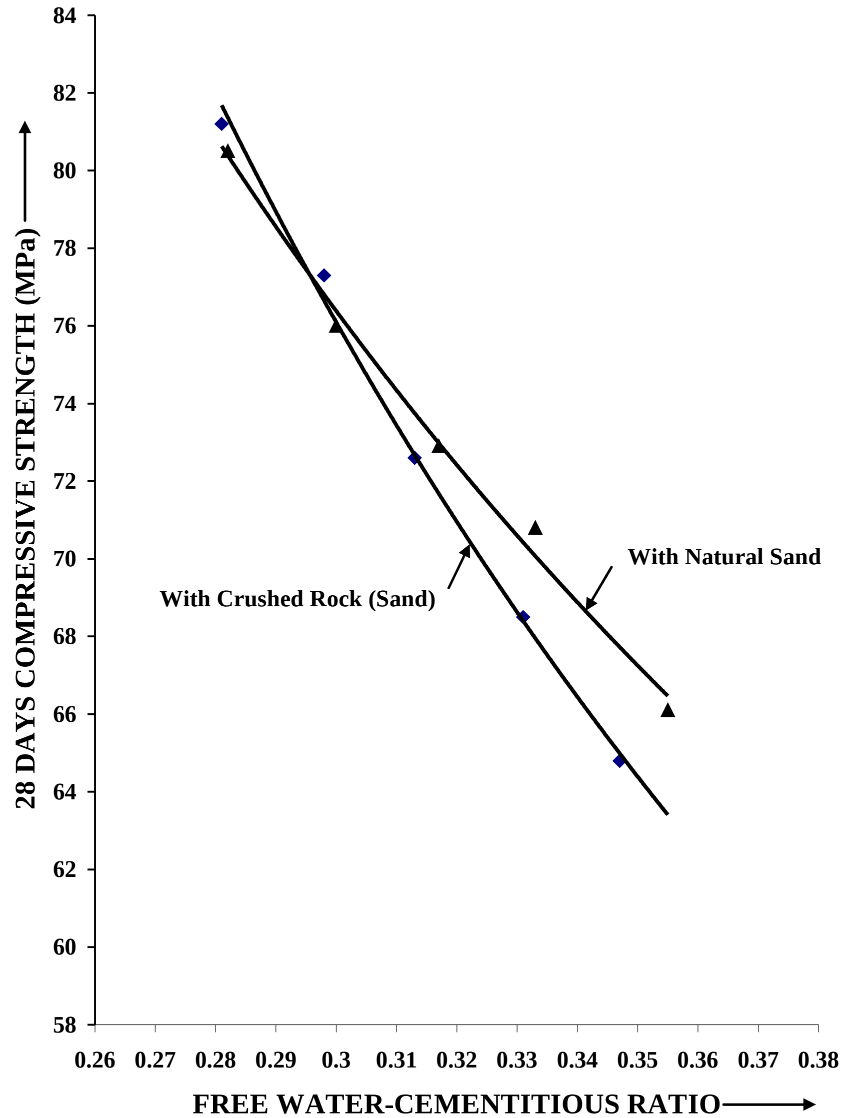


**FIG.-2 : 28 DAYS COMPRESSIVE STRENGTH Vs FREE WATER-CEMENTITIOUS RATIO**

Table 2(b) - Comparison of the cementitious materials for natural sand and crushed rock

| Sl. No. | 28 days Compressive strength, MPa | Quantity of Cementitious Material (kg/m$^3$) | | | | Difference (kg/m$^3$) | |
|---|---|---|---|---|---|---|---|
| | | With Crushed rock | | With Natural sand | | | |
| | | Cement A | Silica fume B | Cement C | Silica fume D | Cement (A-C) | Silica fume (B-D) |
| 1 | 64 | 432 | 11 | 404 | 10 | 28 | 1 |
| 2 | 68 | 463 | 12 | 440 | 11 | 23 | 1 |
| 3 | 72 | 494 | 13 | 478 | 12 | 16 | 1 |
| 4 | 76 | 526 | 13 | 517 | 13 | 9 | 0 |
| 5 | 80 | 558 | 14 | 556 | 14 | 2 | 0 |
| 6 | 84 | 590 | 15 | 597 | 15 | -7 | 0 |

## 6. CONCLUSIONS

The objective of the present study was to obtain useful data on the basis of experiment carried out with the help of specially developed high velocity water jet apparatus on different types of concrete generally used for construction or repair works of hydraulic structures subjected to sediment led high speed flowing water. Following major conclusions may be drawn on the basis of present study-

- The silica fume-flyash concrete or steel fibre reinforced concrete may be used effectively at suitable places for the construction of hydraulic structures subjected to high speed flowing water carrying sediments as abrasive material.
- Where natural river sand is not available as per construction requirement for manufacturing of mass concrete, the use of crushed rock may be made effectively for development of abrasion resistant concrete.
- High performance concrete using silica fume and superplasticiser with crushed rock appears to be more advantageous in terms of gain in strength beyond 75 MPa. However, natural river sand is found to be more suitable for lower range of strength.
- The performance of high strength concrete using silica fume and superplasticiser with crushed rock (quartzite in present case) as fine aggregate used for the construction of top layer of barrage floor in one of the Hydro-Electric Project located in Himalayan region has been reported to be satisfactory during the last five years.

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