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GUIDELINES FOR THE USE OF HIGH PERFORMANCE CONCRETE IN BRIDGES



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GUIDELINES FOR THE USE OF HIGH PERFORMANCE CONCRETE IN BRIDGES

1. INTRODUCTION

1.1. The Reinforced, Prestressed and Composite Concrete Committee (B-6) of the Indian Roads Congress was reconstituted in 2003 with the following personnel:

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 Secretary, IRC
 (R.S. Sharma)

Corresponding Members

Basa, Ashok
 Kand, C.V.

1.2. At its first meeting on 29th April, 2003, the Committee felt that in the light of the massive construction programme that was under execution in the highway sector, it was necessary to bring out guidelines on certain topics which were not adequately covered in the existing IRC Codes and Standards. The guideline for the use of High Performance Concrete was one of the two topics selected. It was decided that the guidelines would be generally in line with IRC:18 and IRC:21 with additional inputs from BS:5400, EURO and AASHTO codes, wherever necessary.

1.3. The initial draft of the guidelines was prepared by Dr. A.K. Mullick. The draft was discussed by the B-6 Committee at several meetings and finalized in its meeting held on 3rd September, 2004. The draft document was approved by Bridges Specifications and Standards Committee in its meeting held on 2nd December, 2004 and by the Executive Committee on 18th December, 2004. The document was considered by IRC Council in its 173rd meeting held on 8th January, 2005 in Bangalore and approved with certain modifications. The required modifications were accordingly carried out by the Convenor B-6 Committee before sending the document for publication.

2. SCOPE

High Performance Concrete (HPC) can be used both in super and substructure of bridges. The guidelines provide broad aspects for production of HPC including mix design. The guidelines on HPC should be read in conjunction with relevant IS and IRC Specifications and Codes of practice, besides International Codes/ Guidelines on the same topic, to gain confidence on its usage.

3. TERMINOLOGY

3.1. High Performance Concrete

Concrete, whose ingredients, proportions and production methods are specifically chosen to meet special performance and uniformity requirements that cannot be always achieved routinely by using only conventional materials, like, cement, aggregates, water and chemical admixtures, and adopting normal mixing, placing and curing practices. These performance requirements can be high strength, high early strength, high workability, low permeability and high durability for severe service environments, etc. or combinations thereof. Production and use of such concrete in the field necessitates high degree of uniformity between batches and very stringent quality control.

4. MATERIALS

4.1. Cement

Any of the types of cement as per Table 1 may be used with the approval of the competent authority.

4.2. Mineral Admixtures

Any of the following mineral admixtures

may be used as part replacement of Ordinary Portland Cement with the approval of the competent authority. Uniform blending with cement should be ensured by having dedicated facility and complete mechanised process control at the site to achieve specified quality.

4.2.1. Fly ash: Conforming to Grade I of IS: 3812-3. The proportion should not be less than 20 per cent, nor should exceed 35 per cent by mass of cement.

4.2.2. Granulated Slag: Ground granulated slag obtained by grinding granulated slag conforming to IS:12089. The proportion should not be less than 50 per cent, nor should exceed 70 per cent by mass of cement.

4.2.3. Silica Fume: Silica fume is very fine, non-crystalline SiO_2 , obtained as a by-product of Silicon or Ferro-Silicon alloy industries. It should conform to IS:15388.

4.3. Admixtures

Chemical admixtures and superplasticisers conforming to IS:9103 may be used. Compatibility of the superplasticiser with the cement and any other pozzolanic or hydraulic additives as covered in Clause 4.2 being used,

Table 1. Types of Cement

S. No.	Type	Conforming to
1.	Ordinary Portland Cement 43 Grade	IS : 8112
2.	Ordinary Portland Cement 53 Grade	IS : 12269
3.	Rapid Hardening Portland Cement	IS : 8041
4.	Sulphate Resistant Portland Cement	IS : 12330
5.	Low Heat Portland Cement	IS : 12600
6.	Portland Pozzolana Cement	IS : 1489 - Part I
7.	Portland Slag Cement	IS : 455

- Notes : (i) Use of Portland Pozzolana Cement may be permitted only in plain concrete members.
(ii) Under severe condition of Sulphate Content in subsoil water, special literature on precautions to be taken with regard to the use of special types of cement with low C_3A content may be referred to. Durability criteria, like, minimum cement content and maximum water cement ratio, etc. should also be given due consideration.

should be ensured by trials, so that the following problems are avoided.

- Large dosage of superplasticiser required to achieve the desired workability,
- Excessive retardation of setting,
- Excessive entrainment of large air bubbles,
- Unusually rapid stiffening of concrete,
- Rapid slump loss, and
- Excessive segregation and bleeding.

4.4. Aggregates

4.4.1. General: All coarse and fine aggregates shall conform to IS:383 and shall be tested as per IS:2386 Parts I to VIII.

4.4.2. Coarse aggregate: Coarse aggregates shall consist of clean, hard, strong, dense, non-porous, equi-dimensional (i.e., not much flaky or elongated) and durable pieces of crushed stone, crushed gravel, natural gravel or a suitable combination thereof.

The maximum size of the coarse aggregate should not be greater than;

- one quarter of the minimum thickness of the member,
- 10 mm less than the minimum lateral clear distance between individual reinforcements,
- 10 mm less than the minimum clear cover to any reinforcement,
- Nominal maximum size of aggregate should not exceed 20mm.

4.4.3. Fine aggregate: Fine aggregate shall consist of hard, strong, clean, durable particles of natural sand, crushed stone or crushed gravel. Suitable combinations of natural sand and crushed stone or crushed gravel can be permitted. They shall not contain dust, lumps, soft or flaky particles, mica or any other deleterious materials in such quantities as would reduce the strength or durability of concrete. Fine aggregate of Zone II or III of IS:383 are preferable.

4.5. Water

Water should conform to provisions of Clause 302.4 of IRC:21-2000.

4.6. Concrete

4.6.1. Strength grades of concrete: The concrete shall be in grades designated in Table 2, where the characteristic strength is defined as the strength of concrete below which not more than 5 per cent of test results are expected to fall.

Table 2. Characteristic Compressive Strength

Grade designation	Specified characteristic compressive strength at 28 days (MPa)
M 40	40
M 45	45
M 50	50
M 55	55
M 60	60
M 65	65
M 70	70
M 75	75
M 80	80

4.6.2. The Cement content of concrete, inclusive of any mineral admixtures, shall be not less than 380 kg/m³.

4.6.3. The Cement content excluding any mineral admixtures shall not exceed 450 kg/m³.

4.6.4. The water/(cement+all cementitious materials) ratio should generally not exceed 0.33, but in no case more than 0.40.

4.6.5. Workability: The concrete mix proportions chosen should be such that the concrete is of adequate workability for placing conditions and congestion of reinforcement, to ensure proper placement without segregation or honey combing, and thorough compaction.

Suggested ranges of workability of concrete measured in accordance with IS:1199 are given below:

Degree or Workability	Slump (mm)
Low	25 - 50
Medium	50 - 100
High	100 - 150
Very High	150 - 200*

Note*: In the 'Very High' category of workability, measurement of workability by determination of flow as per IS:9103 will be appropriate.

4.7 Durability

4.7.1. Concrete should be durable to provide satisfactory performance in the anticipated exposure conditions during service. The materials and mix proportions specified and used, and the workmanship employed should be such as to maintain its integrity and to protect embedded metal from corrosion.

4.7.2. One of the main characteristics influencing the durability of concrete is its impermeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances. Impermeability is governed by the constituents and workmanship employed in making the concrete. A suitably low permeability is achieved by having an adequate cement content, sufficiently low water-cement ratio, dense packing of fine particles, by ensuring thorough compaction of the concrete, and by timely and adequate curing.

4.7.3. Total water-soluble sulphate (SO_3) content of the concrete mix, expressed as (SO_3) shall not exceed 4 per cent by mass of cement used in the mix.

4.7.4. Total chloride content in concrete, expressed as chloride-ion, shall not exceed the following values by mass of cement used:

Type	Amount (per cent)
Prestressed concrete	0.10
Reinforced concrete	
(i) in severe condition of exposure	0.20
(ii) in moderate condition of exposure	0.30

4.8. Concrete Mix Design

4.8.1. General: Choice of materials, concrete mix design and field practices are quite critical, so that optimum performance can be extracted of each of the ingredients. The procedure of mix proportioning of normal grades of concrete may not be adequate. Relationships between the compressive strength of concrete and water-cement ratio (or water-cement+cementitious materials ratio, when part of the cement is replaced by mineral admixtures) and between water content and workability will have to be established by laboratory trials for the grade of concrete, the materials to be used, and the water-reducing efficiency of the superplasticiser.

4.8.2. Target mean strength: The target mean strength of the mix should be equal to be characteristic strength for the grade plus the current margin.

4.8.2.1. The current margin for a concrete mix shall be taken as 1.64 times the standard deviation of sample test results taken from at least 40 separate batches of concrete of nominally similar proportions produced at site by the same plant under similar supervision, over a period exceeding 5 days, but not exceeding 6 months.

4.8.2.2. Where there are insufficient data to satisfy the above, the target mean strength for the initial mix design shall be taken as given in Table 3. As soon as the results of samples are available, actual calculated standard deviation may be used and the mix designed accordingly.

Table 3. Target Mean Strength

Concrete Grade	Target Mean Strength (MPa)
M 40	52
M 45	58
M 50	63
M 55	69
M 60	74
M 65	80
M 70	85
M 75	90
M 80	95

4.8.3. Field Trial Mixes: Mix proportions arrived at by laboratory trials shall, in addition, be verified to be satisfactory under field conditions and necessary adjustments made. Field trial mixes shall be prepared for all grades of concrete, using samples of approved materials. Sampling and testing procedures shall be in accordance with para 4.11.

4.8.3.1. The concreting plant and means of transportation employed to make trial mixes and to transport them to representative distances shall be similar to the corresponding plant and transport to be used in the works. The optimum sequence of mixing of ingredients shall be established by trials. Mixing time may be longer than in normal grade concrete mixes.

4.8.3.2. The temperature of concrete at the time of placement shall not exceed 25°C. The temperature of concrete at the mixing stage should be lower, to allow for rise in temperature during transport. When considerable distance of transport is involved, particular attention should be paid to ensure retention of slump as targeted for placement.

4.8.4. Prototype testing: Further mock-up trials or prototype testing may be carried out to ensure that the concrete can be satisfactorily placed and compacted, taking into account the location of placement and provision of reinforcement, and adjustments made in concrete mix design and/or detailing of reinforcement accordingly.

4.9. Production of Concrete

4.9.1. Batching and mixing: Provisions of Clause 302.9.1 of IRC:21 shall apply. Fully automatic, computer controlled batching and mixing plant shall be used.

4.9.2. Curing: High Performance Concrete containing silica fume is more cohesive than normal mixes hence, there is little or no bleeding and no bleed water to rise to the surface to offset water lost due to evaporation. Plastic shrinkage cracking is possible, if curing is not proper. Initial

curing should commence soon after initial setting of concrete. Concrete should be covered with moist covers, opaque colour plastic sheets or suitable curing compound. Final moist curing should commence after final setting of concrete and continue for at least 14 days.

4.10. Quality Assurance

In order that the performance of the completed structure be consistent with the requirements and assumptions made during the planning and design, stringent quality assurance measures shall be taken. The construction should result in satisfactory strength, serviceability and long-term durability. In particular, it should be aimed to ensure uniformity and to lower the variability between batches of production, as evidenced by the standard deviation in test results.

The methods and procedures of Quality System shall be followed as per the guidelines contained in IRC:SP-47. Q-4 class of Quality Assurance shall be adopted for the 'Materials' and 'Workmanship' items.

4.11. Sampling and Testing

Provisions of Clause 302.10 of IRC:21 shall apply.

4.12. Acceptance Criteria

Provisions of Clause 302.11 of IRC:21 shall apply.

4.12.1. Acceptance testing on site shall not be restricted to tests for compressive strength of concrete alone. Where durability of concrete is the main reason for adopting High Performance Concrete, Rapid Chloride Ion Permeability test as per ASTM C-1202 or AASHTO T-277 shall be carried out. The permissible value of chloride- ion permeability shall be less than 800 coulombs.

4.12.2. Additional durability tests, such as, Water Permeability test as per DIN:1048 Part 5-1991 or Initial Surface Absorption test as per BS:1881 Part 5

can also be specified. The permissible values in such tests shall be decided taking into account the severity of the exposure conditions.

5. BASIC PERMISSIBLE STRESSES IN CONCRETE

The properties and basic permissible stresses for concrete of grades upto M 60 shall be as given in Table 9 of IRC:21. For concrete of grades higher than M 60, properties of concrete, permissible stresses and design parameters given in IRC:18 and IRC:21 will not be applicable. Appropriate values may be obtained from specialized literature and/or International Codes of Practice.

REFERENCES

In this publication reference to the following IRC, IS, BS, DIN Standards ASTM and AASHTO has been made. At the time of publication, the editions indicated were valid. All Standards are subject to revision and the parties to agreements based on these guidelines are encouraged to investigate the possibility of applying the most recent editions of the Standards indicated below:

Codes and Specifications:

1. IRC:18-2000 Design Criteria for Prestressed Concrete Road Bridges (Post-Tensioned Concrete) (Third Revision)
2. IRC:21-2000 Standard Specifications and Code of practice for Road Bridges, Section-III Cement Concrete Plain & Reinforced, (Third Revision)
3. IRC:SP:47-1998 Guidelines on Quality Systems for Road Bridges (Plain, Reinforced, Prestressed and Composite Concrete)
4. IS 383:1970 Specification for Coarse and Fine Aggregates from Natural Sources for Concrete
5. IS 455:1989 Specification for Portland Slag Cement
6. IS 1489-Pt.1:1991 Specification for Portland Pozzolana Cement-part 1 Flyash based

7. IS 1199:1959 Methods of sampling for analysis of concrete.
8. IS 12089:1987 Specificaion for Granulated slag for Manufacture of Portland Slag construction
9. IS 2386:1963 pt. 1-8 Methods of test for aggregates for concrete
10. IS 3812:2003 Specification for Flyash for use as Pozzolana and Admixture
11. IS 15388:2003 Specifications for Silica fume
12. IS 8112:1989 Specification for 43 Grade Ordinary Portland Cement
13. IS 9103:1999 Concrete admixtures-specification
14. IS 12269:1987 Specification for 53 grade Ordinary Portland Cement
15. IS 12330:1988 Specification for Sulphate Resisting Portland Cement
16. IS 12600:1989 Specification for Low heat Portland Cement
17. IS 8041:1990 Specification for Rapid hardening Portland Cement
18. BS 1881 pt. 5-1970 Testing Concrete methods for testing Hardened concrete for other than strength (current, partially replaced)
19. DIN 1048 pt. 5-1991 Testing concrete testing of Hardened concrete (specimens prepared in mould)
20. ASTM C 1202: 1997 Test method for electrical indication of concretes ability to resist chloride ion
21. AASHTO T 277-831 Rapid Determination of the Chloride Permeability of Concrete

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 9. Saini, S., Dhuri, S.S., Kanhere, D.K. and Momin, S.S., High Performance Concrete for an Urban Viaduct in Mumbai, ibid, pp. 634-640.
 10. Rashid, M.A., Considerations in Using HSC in RC Flexural Members, Indian Concrete Journal, May 2004, pp. 20-28.
 11. FHWA Manual High Performance Concrete- Structural Designers Guide, Deptt. of Transportation, March 2005.
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