Factors affecting Durability of Concrete

1.0 सामान्य/ General

Concrete should be durable as far as its strength and serviceability to the structure is concerned. It is now well recognized that concrete needs protection for longer durability. A concrete is said to be durable if it performs satisfactorily in the working environment during its anticipated exposure conditions during service.

Durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion and any other process of deterioration. Durable concrete envisages limits for maximum water cement ratio, minimum cement content, cover thickness, type of cement used and presence of amount of chlorides and sulphates in concrete.

One of the main characteristics influencing the durability of concrete is its permeability. A permeable concrete is prone to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances.

The importance of permeability of concrete has been realised in Indian Railways also and now by correction slip No.1 to 'Concrete Bridge Code', the permeability test has been made mandatory for all major bridges in all exposure conditions and for all RCC/PSC bridges when exposure condition is severe/very severe or extreme. It has further been stipulated that even in mild or moderate exposure condition, it is desirable to conduct permeability test for other than major bridges also.

Concrete durability is a subject of complex nature affected by many and varied factors. The factors that influence the durability of concrete include *the environment; the cover to embedded steel; the type and quality of constituent materials; the cement content and water-cement ratio of the concrete; the workmanship, to obtain full compaction and efficient curing; and the shape and size of the member*. (IS456)

2.0 सामान्य वातावरण के संपर्क में/ Exposure to General Environment

If properly prepared and placed in position, concrete has adequate durability under normal conditions of exposure. As per IS 456:2000, the general environment to which the concrete will be exposed during its working life is classified to five levels of severity, namely, mild, moderate, severe, very severe, extreme.

Concrete structures are generally placed in hostile environments that may generate many types of attacks, namely, physical, chemical, or a combination of the two.

2.1 एम्बेडेड स्टील की जंग का प्रभाव/ Effect of Corrosion of embedded steel: Concrete ordinarily provides an almost ideal environment for protecting steel against corrosion. Its high alkalinity causes the formation of thin protective passive film of ferric oxide surrounding embedded steel. This passive film gets broken during service due to ingress of chlorides, gases and water, which leads to carbonation and chloride attack, which makes the steel prone to corrosion. Therefore, it is necessary that concrete structures are designed to withstand carbonation and chloride attack.

2.1.1 कार्बोनेशन का प्रभाव/ Effect of Carbonation: Carbonation is the process in which CO_2 gas present in the atmosphere combines with hydrated concrete (alkaline hydroxides) and partly neutralizes the alkaline nature of concrete. The rate of carbonation depends on permeability of concrete, quantity of surplus lime and environmental conditions such as moisture and temperature. The ingress of moisture and oxygen infuse to the surface of steel initiates the electrochemical process and as a result rust is formed. The transformation of steel to rust increases its volume thus resulting in the concrete expansion, cracking and distress to the structure.

If the cover is more, the carbonation time will also be more. The most common method to detect carbonation is to spray a cut or broken concrete section with a phenolphthalein alcoholic solution. The solution remains clear on carbonated concrete, but turns pink at non-carbonated areas.

Alkalinity and acidity are measured on a pH value scale as given below.



2.1.2 क्लोराइड का प्रभाव/ Effect of Chlorides: All constituents may contain chloride and concrete may be contaminated by chlorides from external environment. Also, the sulphate attack in the concrete decomposes the chloride mineralogy thereby releasing chloride ion. Chlorides enter the concrete from cement, water, admixtures and aggregate. The higher the chloride content, the greater is the risk of corrosion of embedded metal.

Thus, in order to withstand chloride attack, following measures are necessary in design and construction stage for concrete structures:

a) The total chloride content by weight of cement in concrete needs to be controlled and shall not exceed the following values:

- For prestressed concrete work –
  - i) Under extreme and very severe environment — 0.06%
  - ii) Under severe moderate and mild environment — 0.10%
- For RCC works — 0.15%

b) Structures in aggressive environment (i.e. severe, very severe & extreme) are subjected to chloride attack. Therefore, provision of protective coating to concrete and steel is essential in aggressive environment.

2.2 सल्फेट का प्रभाव/ Effect of Sulphates: Sulphates are present in most cement and in some aggregate. Excessive amount of sulphate attack on concrete can cause expansion and deterioration of concrete. To

prevent this, the total water soluble sulphate content of concrete mix, expressed as SO_3, should not be exceeded 4 % by mass of the cement in the mix.

Sulphate attack generally attributes to corrosion of concrete by involving three mechanisms:

- Diffusion of sulphate ions into the cement matrix governed by porosity and permeability.
- Reactions between sulphate ions and hydration products of C_3A and C_3S of the cement which in turn forms expansive compounds such as ettringite [a mineral name for calcium sulfoaluminate, which is normally found in Portland cement concretes] and gypsum.
- Cracking of the matrix leading to strength loss and disintegration.

2.3 क्षार सिलिका (कुल) प्रतिक्रिया का प्रभाव/ Effect of Alkali-Silica (of Aggregate) reaction: A variety of rock types have been identified as being deleteriously reactive and cause expansion and damage to concrete. The most common reaction is the one between some forms of silica present in certain aggregates, and the alkalis of Portland cement. A silica gel containing calcium and alkalis is formed that tends to absorb water from the surrounding environment and to swell, further causing stresses that result in concrete cracking.

2.4 सतह घिसाव के कारण कंक्रीट का क्षय/ Deterioration of Concrete due to surface wear: Concrete loses mass progressively under many circumstances when subjected to wear due to Abrasion, Erosion, and Cavitation.

- Abrasion refers to wearing away of concrete surface by sliding, scraping, or percussion.
- Erosion refers to wearing away of surface by the abrasive action of fluids containing solid particles in suspension
- The cavitation refers to the formation of vapour bubbles and their subsequent collapse due to sudden change of direction in rapidly flowing water.

2.5 भौतिक कारकों का प्रभाव/ Effect of Physical Factors: Throughout the service life of concrete structures, the concrete is subjected to thermal and hygrometric variations caused by the heat of hydration of cement and the changes in temperature and humidity of the environment. Daily and seasonal climatic variations strongly affect the mechanical behaviour of concrete structures.

3.0 एम्बेडेड स्टील पर कंक्रीट कवर का प्रभाव/ Effect of Concrete cover to embedded steel: The primary purpose of the concrete cover is to protect the reinforcement from a hostile environment. It must be compact, strong and thick (minimum cover thickness as specified by standards). Cover thickness should be related to the environmental aggressiveness but this requirement is very often neglected.

Min. nominal cover to meet durability requirements for normal weight aggregate concrete should be provided to all reinforcement, including links depending on the different conditions of exposure.

Exposure	Nominal Cover in mm (minimum)
Mild	20 mm
Moderate	30 mm
Severe	45 mm
Very Severe	50 mm
Extreme	75 mm

4.0 घटक सामग्री के प्रकार और गुणवत्ता का प्रभाव/ Effect of the type and quality of constituent materials

Aggregates: Aggregates represent about 75% of the hardened concrete by mass and therefore affect the concrete properties. For reinforced concrete and pre-stressed concrete works a nominal maximum size of 20 mm is generally considered satisfactory. Aggregates shall comply with the requirements of IS 383.

In general, marine aggregate shall not be used for reinforced concrete and pre-stressed concrete bridges. However, in special cases, use of marine aggregates may be permitted by the engineer subject to the following: -

- The marine aggregates shall be thoroughly washed.
- Generally, limits for chloride content and sulphate content in aggregates after washing will be as under:

	Fine Aggregate	Coarse Aggregate
i) Chloride contents (Cl) max.	0.04% by wt. acid soluble	0.02% by wt. acid soluble
ii) Sulphates (SO_3) max	0.4% by wt. acid soluble	0.4% by wt. acid soluble

- After washing and drying, the aggregates should conform to IS: 383. The designer should take into account grading of aggregates after washing.

Water: Water for washing of aggregates and for mixing and curing concrete shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel. The pH value of water shall generally be not less than 6. Water found satisfactory for mixing is also suitable for curing concrete. However, water used for curing should not produce any objectionable stain or unsightly deposit on the concrete surface. The presence of tannic acid or iron compounds is objectionable.

Concrete mix proportions:

Mix Proportion – The mix proportions shall be selected to ensure that the workability of the fresh concrete is suitable for the conditions of handling and placing, so that after compaction it surrounds all reinforcements. When concrete gets hardened, it shall have the required strength, durability and surface finish.

Design mix concrete is preferred to nominal mix. Nominal mixes, when used, are likely to involve higher cement content. Concretes of grades richer than M 20 shall only be design mix concretes.

Batching – In proportioning concrete, the quantity of both cement and aggregate should be determined by mass. Water should be either measured by volume in

calibrated tanks or weighed. Any solid admixture that may be added, may be measured by mass, liquid and paste admixtures by volume or mass. Batching plant where used should conform to IS: 4925. All measuring equipment should be maintained in a clean serviceable condition, and their accuracy periodically checked, Coarse and fine aggregates shall be batched separately.

Mixing – Concrete shall be mixed in a mechanical mixer. The mixer should comply with IS: 1791. The mixing shall be continued until there is a uniform distribution of the materials in the mass, in colour and consistency. If there is segregation after unloading from the mixer, the concrete should be remixed.

Workability of the concrete – Should be controlled by direct-measurement of water content with/ without admixtures. Workability should be checked at frequent intervals (refer to IS: 1199).

5.0 कंक्रीट की सीमेंट मात्रा और पानी-सीमेंट अनुपात का असर/ Effect of cement content and water-cement ratio of concrete

It is necessary to use cement of appropriate grade and type for specific applications and environment conditions. The cement used shall be any of the following, with the prior approval of the engineer:

a. 33 Grade OPC conforming to IS: 269
b. 43 Grade OPC conforming to IS: 8112
c. 53 Grade OPC conforming to IS: 12269
d. Rapid hardening OPC conforming to IS: 8041
e. High strength Portland cement conforming to IRS: T-40
f. Portland Slag cement conforming to IS:455
g. Portland Pozzolana cement conforming to IS:1489 (Part-I) - 1991 (using flyash)
h. Sulphate Resistance cement conforming to IS:12330

Water-cement ratio is the most important specification, which controls strength, durability and permeability of concrete. For a durable concrete, use of lowest possible water-cement ratio is the fundamental requirement to produce dense and impermeable concrete.

IS 456:2000 specifies as follows the minimum cement content, maximum water-cement ratio and minimum grade of concrete for different exposures with normal weight aggregates of 20 mm normal maximum size.

S. No.	Exposure	Plain Concrete			Reinforced Concrete		
		Min. Cement Content kg/m^3	Max. Free W/C ratio	Min. Grade of Concrete	Min. Cement Content kg/m^3	Max. Free W/C ratio	Min. Grade of Concrete
i)	Mild	220	0.60	-	300	0.55	M20
ii)	Moderate	240	0.60	M15	300	0.50	M25
iii)	Severe	250	0.50	M20	320	0.45	M30
iv)	Very Severe	260	0.45	M20	340	0.45	M35
v)	Extreme	280	0.40	M25	360	0.40	M40

NOTES
1. Cement content prescribed in this table is irrespective of the grades of cement and it is inclusive of additions mentioned in 5.2. The additions such as fly ash or ground granulated blast furnace slag may be taken into account in the concrete composition with respect to the cement content and water-cement ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit of pozzolona and slag specified in IS 1489 (Part I) and IS 455 respectively.
2. Minimum grade for plain concrete under mild exposure condition is not specified.

IRS Concrete Bridge Code 1997 specifies as follows the limits for maximum water-cement ratio, minimum grade of concrete and minimum cement content for design mix based on environmental conditions.

(Source: IRS Concrete Bridge Code 1997)

Environment	Maximum Water-cement ratio			Minimum Grade of Concrete			Minimum Cementious Material Content in kg/m^3		
	PCC	RCC	PSC	PCC	RCC	PSC	PCC	RCC	PSC
Mild	0.55	0.45	0.40	M-20	M-25	M-35*	300	350	400
Moderate	0.50	0.40	0.40	M-25	M-30	M-35*	350	400	400
Severe	0.45	0.40	0.40	M-25	M-35	M-45	380	400	430
Very Severe	0.45	0.38	0.35	M-30	M-40	M-50	400	430	440
Extreme	0.40	0.35	0.35	M-30	M-45	M-50	400	430	440

1. *Min. grade of concrete shall be M-40 for pre-tensioned prestressed concrete structures.
2. Maximum cementitious material content shall be limited to 500kg/m3.

6.0 कारीगरी का प्रभाव, पूर्ण संघनन और कुशल इलाज प्राप्त करने के लिए/ Effect of the workmanship, to obtain full compaction and efficient curing

Adequate compaction without segregation should be ensured by providing suitable workability and by employing appropriate placing and compacting equipment and procedures. Overworking the surface and the addition of water/cement to aid in finishing should be avoided.

Curing is the process of preventing the loss of moisture from the concrete while maintaining a satisfactory temperature regime. The prevention of moisture loss from the concrete is particularly important, if

- the water-cement ratio is low,
- the cement has a high rate of strength development,
- the concrete contains granulated blast furnace slag or pulverized fuel ash.

Exposed surfaces of concrete shall be kept continuously in a damp or wet condition by covering with a layer of sacking, canvas, hessian or similar materials and kept constantly wet for at least seven days from the date of placing concrete in case of ordinary Portland cement and at least 10 days where mineral admixtures or blended cements are used. The period of curing shall not be less than 10 days for concrete exposed to dry and hot weather conditions. In the case of concrete where mineral admixtures or blended cements are used, it is recommended that above minimum periods may be extended to 14 days.

7.0 स्ट्रक्चरल मेम्बर की आकृति और आकार/ Shape and size of structural member

The shape or design details of exposed structure should be such as to promote good drainage of water and to avoid standing pools and rundown of water. Precaution should be taken to minimize any cracks and may collect or transmit water. Adequate curing is necessary to avoid the harmful effect of early loss of water. Members shall be designed and detail in a way to ensure flow of concrete and proper compaction during concreting.

References:

1. ***IS 456:2000***
2. ***Report No. BS-14 (revised), January 2001, issued by RDSO, Lucknow.***
3. ***IRS Concrete Bridge Code 1997 incorporating A&C Slip No.7, Year: 2003, issued by RDSO, Lucknow.***
4. ***Concrete Technology October 2007 (corrected & reprinted: January 2014), IRICEN, Pune.***
5. ***Report No. BS-88, March – 2008, issued by RDSO, Lucknow.***

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✆ **: 0751 - 2470869 & Fax: 0751 – 2470841 E-mail - dircivilcamtech@gmail.com**

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