Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 5, Issue 09, September -2018

QUALITY CONTROL CONCRETE IN AGGRESSIVE SALINE EXPOSURE ENVIRONMENT

Dr Mahipal Burdak

Structural Consultant Engineer, Dara Construction Company Jodhpur

Abstract- *For many years, the deterioration of concrete structures in a severe marine environment, mostly in the form of chloride-induced corrosion of embedded steel, has been a big problem and challenge for the construction industry. To meet this challenge, there is consolidated effort in the form of research and development of quality control of concrete. Extensive experience demonstrates that the durability of concrete structures is closely related not only to design and material but also to construction issues. Although to a certain extent a probability-based approach to the durability design can take the wide variability of construction quality into account, a numerical approach to the durability design alone is not sufficient for ensuring a proper durability. For concrete structures in severe environments, construction quality and variability is a key issue, which must be firmly grasped to achieve a more controlled durability.*

In order to comply with the overall durability requirement of the given structure, a proper quality control of both the specified chloride diffusivity and the concrete cover must be carried out during the concrete construction. For both of these durability parameters average values and the standard deviation must be obtained. If cathodic prevention or preparation for such a protective measure has also been specified, regular quality control of the electrical continuity within the rebar system must also be carried out during concrete construction. This paper reviews the necessary test method and procedure for measurement and control of the above durability parameters. The present paper deals with filed study of aggressive environment exposed structure and non destructive analysis.

Key Words: *Durability design, Chloride Diffusivity, Quality Control, and Electrical Resistivity.*

I. INTRODUCTION

Even before the concrete is placed in the formwork, the quality of concrete may show a high scatter and variability. Depending upon the number of factors during concrete construction, the achieved quality of the finely placed concrete normally shows an even higher scatter and variability. The high scatter of achieved chloride diffusivity in the deck of the new concrete harbor structure according to the Rapid Chloride Migration (RCM) method is shown.

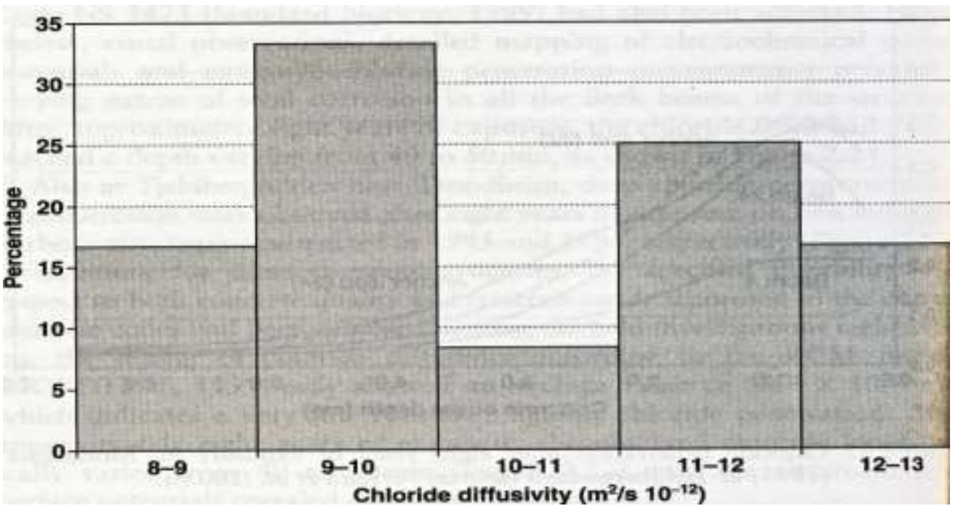

Figure-1.1 Achieved chloride diffusivity in the deck of the new concrete harbor structure at Ulsteinvik

For concrete structures in chloride containing environments, it is the regular monitoring of the real chloride penetration and evaluation of the future corrosion probability in combination with protective measures during the service period that provide the ultimate basis for achieving a more controlled durability and service life.

II. CHLORIDE DIFFUSIVITY

2.1 Mechanism of Chloride Ion Transport:

The rate of chloride penetration into concrete is affected by the chloride binding capacity of the concrete. Concrete is not inert relative to the chlorides in the pore solution. A portion of the chloride ions reacts with the concrete matrix becoming either chemically or physically bound, and this binding reduces the rate of diffusion.

2.2 Existing Test Methods:

- AASHTO T259: Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration
- Bulk Diffusion Test (NordTest NTBuild 443)
- AASHTO T277: Electrical Indication of Concrete's Ability to Resist Chloride Ion
- Penetration (Rapid Chloride Permeability Test)
- Electrical Migration Techniques
- The Rapid Migration Test (CTH Test)
- Resistivity Techniques
- Pressure Penetration Techniques

Generally the measurement of chloride diffusivity is based upon the Rapid Chloride Migration (RCM) method. Although the durations of such measurements may take only a couple of days, this is not good enough for regular quality control during concrete construction. For all porous materials, however, the Nernst-Einstein equation expresses the following general relationship between the ion diffusivity and the electrical resistivity of the material.

$$D_i = \frac{R \cdot T}{Z^2 \cdot F^2} \cdot \frac{t_i}{\gamma_i \cdot c_i \cdot \rho}$$

where:

D_i = diffusivity for ion i
R = gas constant
T = absolute temperature
Z = ionic valence
F = Faraday constant
t_i = transfer number of ion i
γ_i = activity coefficient for ion i
c_i = concentration of ion i in the pore water
ρ = electrical resistivity.

Since most of the factors in the equation are physical constant, the above relationship for a given concrete with given temperature and moisture, condition may be simplified to:

$$D = K . \frac{1}{\rho}$$

Where 'D' is the chloride diffusivity, 'k' is constant and 'ρ' is the electrical resistivity of the concrete. Since the electrical resistivity of the concrete can be measured in a more rapid and simple way than the Chloride diffusivity, it is primarily regular quality control of the electrical resistivity of the concrete which provides the basis for the indirect quality control of the chloride diffusivity during concrete construction. Therefore, as soon as the type of concrete is given, the above relationship between chloride diffusivity and the electrical resistivity must be established.

2.3 CALIBRATION CURVE:

- This is done by producing a certain number of specimens of concrete, on which parallel testing of both chloride diffusivity and electrical resistivity at different periods of water curing are carried out.
- After the relationship between the chloride diffusivity and electrical resistivity has been established, this relationship is subsequently used as a calibration curve for an indirect control of chloride diffusivity based on the regular measurements of the electrical resistivity of the concrete construction.
- Since the testing of electrical resistivity is a non-destructive type of test, these measurements are carried out on a same concrete specimens as that being used for regular quality control of the 28 days compressive strength during concrete construction.

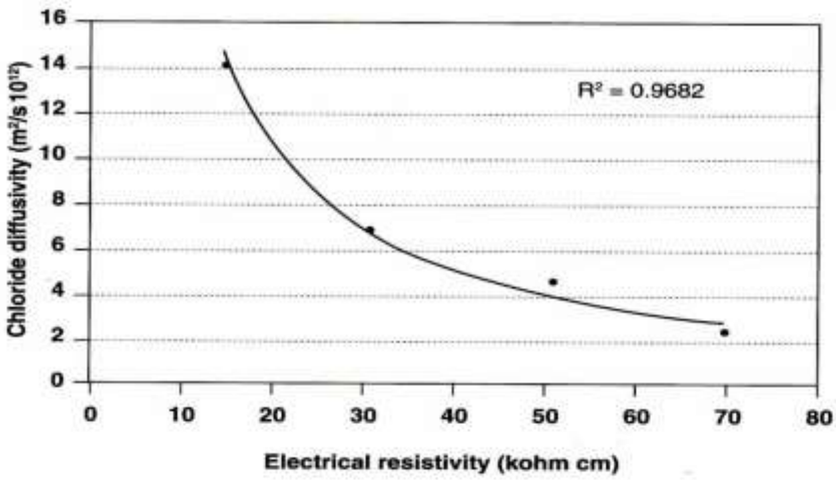

Figure-2.1 A typical calibration curve for control of chloride diffusivity based on electrical resistivity measurements.

- In order to established the calibration curve, the measurements of the chloride diffusivity are carried out on three 50 mm thick specimens cut from 100*200 mm concrete cylinders after approximately 7, 14, 28 and 60 days of water curing. These measurements are carried out on water-saturated specimen according to an established water saturation procedure. In parallel, the corresponding measurements of the electrical resistivity are carried out on three concrete specimen of the same type as that being used for the regular quality control of the compressive strength. These measurements are carried out on moist concrete specimens after the various periods of water curing.
- Based on the established calibration curve, the specified chloride diffusivity is indirectly controlled by the electrical resistivity measurements on the entire three concrete specimens used for 28 days compressive strength during concrete construction. Of all these controlled data, no individual value should exceed 30 % by that of specified chloride diffusivity.

2.3 RCM METHOD FOR MEASUREMENT OF CHLORIDE DIFFUSIVITY:

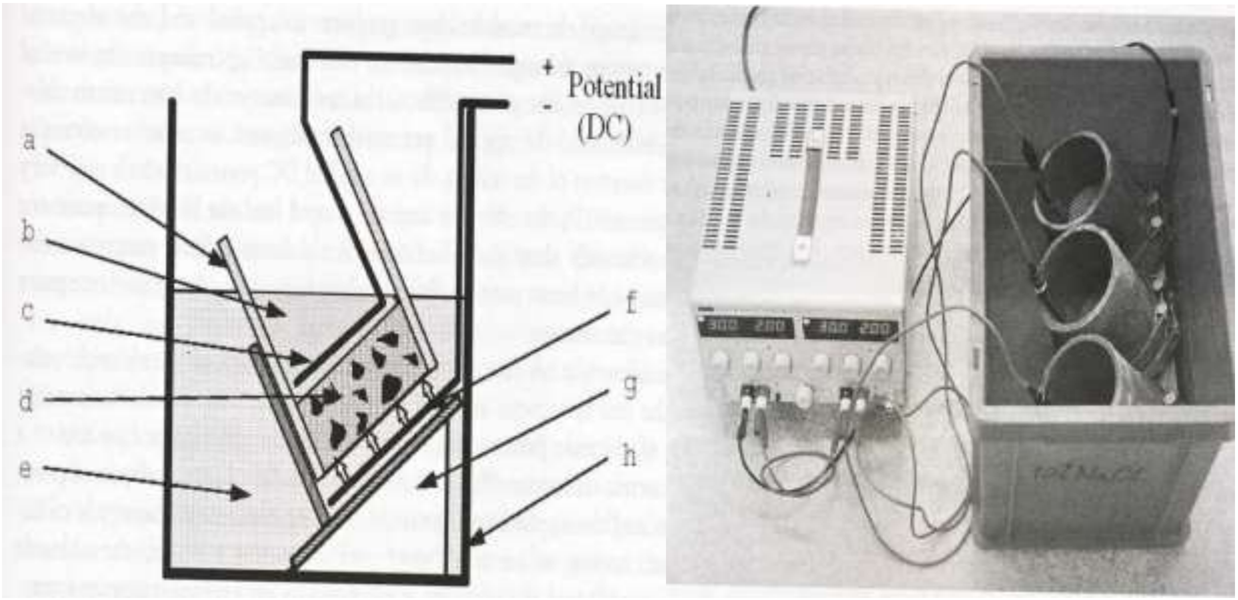

Figure-2.2 Experimental set up for the RCM method, where, (a): rubber sleeve, (b): anolyte, (c): anode, (d): concrete specimen, (e): catholyte, (f): cathode, (g): plastic support and (h): plastic box.

2.3.1 Test specimen:

The testing is normally based on 3*50 mm cut slices of a concrete cylinder with dia 100 mm. these slices either be cut from a concrete core with the same diameter.

2.3.2 Testing procedure:

- Immediately before testing the test specimen are preconditioned according to a standard water saturation procedure.
- The specimens are then mounted into rubber sleeves and placed in a container with a 10 % NaCl solution, while the insides of the sleeves are filled with a 0.3 N NaOH solution.
- A set of concrete specimen under testing using the RCM method is shown in fig.2.2
- Through the use of the separate electrodes placed on each side of the specimens, an electrical voltage gradient is applied and the electrical current passing through the specimen is observed. Depending upon the level of the observed current which reflects the resistance of concrete to chloride penetration, the applied potential is adjusted in order to obtain a proper duration of the testing.
- By an applied DC potential which may vary from 10 to 60 volts, the chloride ions are forced into the concrete specimens over a relatively short period of time. For a normal dense concrete attest duration of 24 hours may be typical, while for a more dense concrete more time may be needed.
- Immediately after the above accelerated exposure to the chloride solution, the test specimens are split into two halves, from which the average depth of chloride penetration is observed on the split surface by use of the colorimetric technique. Based on the observed depth of penetration and the applied testing conditions, the concrete diffusivity is calculated according to an established procedure. As a result, the chloride diffusivity of the concrete is obtained as an average value and standard deviation from the testing of the three specimens.

2.3.3 Evaluation of the obtained result:

When the resistance of the concrete to the chloride penetration is characterized by the RCM method as described above, it should be very clear that the result obtained on the basis of such a accelerated chloride penetration are very different than what is taking place under more realistic and normal condition in the field. Therefore this type of testing primarily distinguishes the difference in chloride mobility in the concrete from one type of concrete to another, and does not properly reflects the difference in the ability of the different types of binder systems to bind the penetrating chlorides. Hence, all result obtained by the above accelerated test method should only be considered as a simplified way of comparing the resistances to chloride penetration of various types **of concrete.**

3. Electrical Resistivity:

The electrical resistance of concrete plays an important role in determining the quality of concrete from the point of view 'corrosion susceptibility potential' at any specific location. This parameter is expressed in terms of "Resistivity" in ohm-cm.

Table-3.1 Corrosion risk from resistivity

Resistivity ohm-cm	Corrosion Probability
Greater than 20,000	Negligible
10,000 – 20,000	Low
5,000 – 10000	High
Less than 5,000	Very high

Several experimental techniques and test methods exist for the electrical resistivity measurement of concrete and, when applied to the same type of concrete, all these test methods gives different test results. However, there are two different types of test methods, which appear suitable for regular quality control during concrete construction:

1) Two-electrode method
2) Wenner method (Four Electrode Method)

3.1 Two-Electrode Method:

The resistivity of concrete (ρ) is calculated using the following equation:

$\rho = R*(A/t)$ Where, R = Resistance, A = Surface Area of Specimen, t = Height of the Specimen

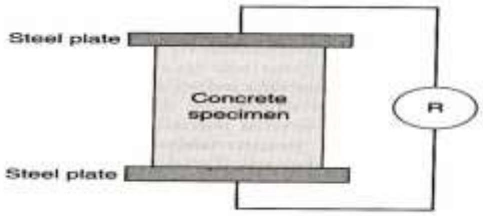

Figure-3.1 The two-electrode method for electrical resistivity measurement of concrete.

3.2 Wenner Method:

Two outer electrode- measures the low-frequency alternating current passing through specimen. Two inner electrodes- measure the voltage drop.

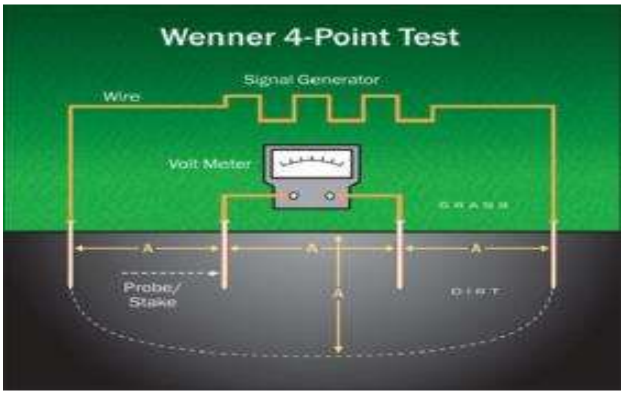

Figure 3.2 Wenner method

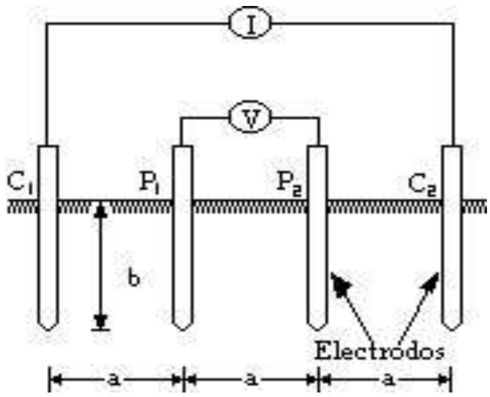

Figure-3.3 Four electrode method

P = 2πaV/I

Where,

A = electrode spacing

V = voltage drop

I = current

3.2.1 Testing procedure:

- If the regular quality of the compressive strength during concrete construction is based on the testing of concrete cubes, the electrical resistivity is observed from two diagonal readings on two opposite sides of each cubes, but top surface of cube should be avoided.
- In case of cylinder, the resistivity is observed from three longitudinal readings along each cylinder.

3.2.2 Evaluation of the obtained result:

Both test methods are only used for indirect testing of chloride diffusivity based on the established calibration curve. (see fig-2.2)

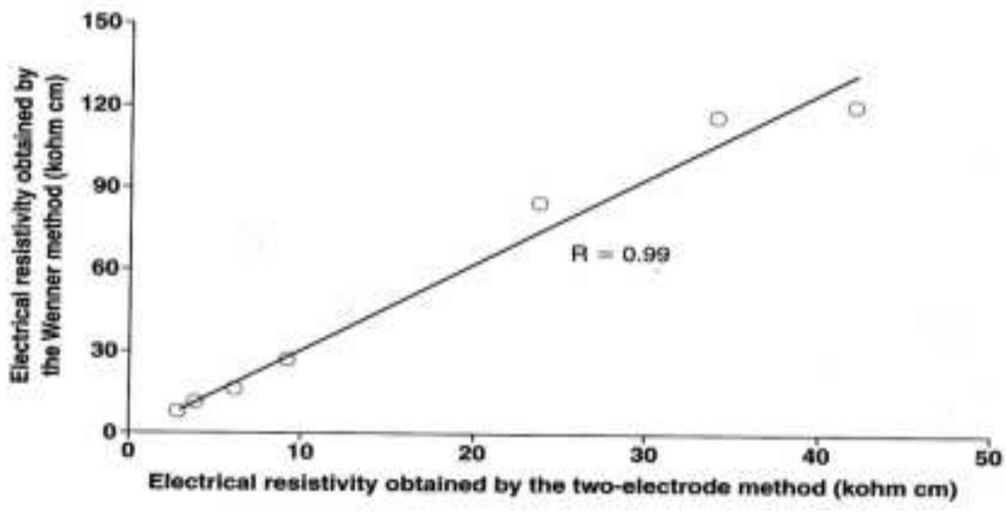

Figure-3.4 Relation between resistivity obtained by the Wenner method and Two-electrode method.

4. Concrete Cover:

For concrete structures in severe environments, the specified concrete cover is normally very thick and the reinforced system may also be very congested. Cover meter based on the pulse induction technique may also be used for the control of the concrete cover of steel reinforcement. Straight manual readings of concrete cover on protruding bars in casting joints during concrete construction may also provide the proper basis for the regular quality control. The necessity to provide adequate cover thickness to control corrosion needs no emphasis. A cover thickness survey is useful to determine existing cover thickness in a specified location, where damage has been identified and elsewhere, for comparison on the same structure.

Figure-4.1 (a) A closer view of the Dia observations (b) Close view of the previous Rebars dia measurement

The cover thickness can be measured non-destructively using commercially known cover meters. The cover meters are also used to identify the location and diameter of rebar: COVERMASTER and PROFOMETER are commercially available instruments, which are used to measure the cover thickness and rebar size. Table 4.1 shows how the cover readings are to be interpreted for corrosion assessment.

5. Case Study of Reinforcement bars location traced: -

Rebars were traced with following details:
Structure- Recent one, Cast in situ
On vertical wall it was measured, with the help of Bosch instrument, as 200 mm c/c in horizontal direction and 100 mm c/c in vertical direction.
Structure- New one, Cast in situ
On vertical wall it was measured, with the help of Bosch instrument, as 170 mm c/c in horizontal direction and 200 mm c/c and 150 mm c/c in vertical direction.
The cover to Rebars was found to be more than 85 mm thus it was difficult to measure dia of the rebars at that location, since the instrument has its own limitation.
At the junction of horizontal and vertical rebars were with chiseling of the cover concrete exposed to the cover depth to see that a cover of 85 to 90 mm existed with dia of the bar seen as 16 mm of vertical bar.
On Left hand side cover was within limits i.e. 40mm (Lesser than 50 mm) hence it resulted in some observation of Rebars dia at various locations.
Different observations showed various readings of the rebars as 23.7 mm, 41.0 mm, 39.8 mm, 36.2 mm, 41 mm, 21.3 mm, 35.9 mm, 23.7 mm, 39.7 mm, 23.9 mm, 39.8 mm and 26.8 mm. This showed different combinations of diameter of bars having crossing at the location.

Table 5.1 Observation for quality of Concrete by Rebound hammer and UPV

Recent RCC Box Section at Near End by Rebound Hammer							
S.N.	Minm.	Maxm.	Std Dev.	Ave X	F_{ck} MPa	Direction	Remarks
1.	41	45	1.8	43.7	49.4	Horizontal	Ref R=44
2.	42	57	5.5	49.2	60.4	Horizontal	

Recent RCC Box Section at Near End by Ultra Sonic Pulse Velocity Tester						
S.N.	Path Length mm	Travel Time µ Sec	Velocity m/Sec	σ MPa	Rebound No ref.	Remarks
1.	200	83.9	2380	-	44	Recent Right side
2.	200	142.6	1400	-	36	New Right side
3.	200	108.8	1840	-	36	New Right side
4.	200	83.5	2400	-	36	New Left side, across joint

Table -5.2 Interpretation of Cover Thickness Survey.

Sl. No	**Test Results**	**Interpretation**
1	Required cover thickness and good quality concrete	Relatively not corrosion prone
2	Required cover thickness and bad quality concrete cover	Corrosion prone
3	Very less cover thickness yet good quality cover concrete	Corrosion prone

Figure-4.2 Field Structure Exposed to Aggressive Exposure Condition

5. Electrical Continuity:

In principle, electrical continuity is controlled by measurements of the ohmic resistance between various parts of the reinforcement system.
Over the last ten years, Cathodic Protection (CP) has increasingly been used to provide long-term corrosion control for reinforced concrete structures in marine environments. CP is an electro-chemical method, which can effectively stop further corrosion of the reinforcing steel regardless of the salt content in the concrete. Systems using both sacrificial (galvanic) and impressed current anodes have been success fully applied to the splash, tidal and atmospheric zones of marine structures.

6. **Conclusion**

The lack of proper durability and long-term performance of many important concrete infrastructures not only represents technical and economic problems, but also has a great impact on available resources, environment and human safety. In recent years, therefore, extensive research has been carried out in many countries to obtain better control of the various deterioration processes of concrete structures in marine environments, and never before has so much knowledge and experience regarding durability and service life been available. It is a great challenge for the professional community, therefore, to utilize and transform more of all this knowledge and information into good engineering practice for achieving a more controlled durability and service life. For concrete structures in severe marine environments, recent experience has shown that the specification of a high strength or high performance concrete does not necessarily ensure a proper durability. However, the combination of a performance-based concrete quality control appears to provide a better basis and strategy for ensuring a more controlled durability and service life for concrete structures.

References:

1. Gjørv, O.E., Durability and Service Life of Concrete Structures, Proceedings of First fib Congress 2002, Session 8, Vol. 6, Japan Prestressed Concrete Engineering Association, Tokyo, 2002, pp. 1-16.
2. Gjørv, O.E., Durability of Reinforced Concrete Wharves in Norwegian Harbours, Ingeniørforlaget, Oslo, 1968.
3. "Standard Test Method for Electrical Indication of Chloride's Ability to Resist Chloride" (ASTM C1202-94) 1994 Annual Book of ASTM Standards V 04.02, ASTM, Philadelphia, pg. 620-5
4. McGrath. P. Development of Test Methods for Predicting Chloride Penetration into High Performance Concrete, Ph.D. Thesis, Department of Civil Engineering, University of Toronto, 1996
5. McGrath., P. and Hooton, R.D., "Influence of Voltage on Chloride Diffusion Coefficients From Chloride Migration Tests", Cement and Concrete Research, Vol. 26, No. 8, pp. 1239-1244, 1996
6. ACI 224R-01, Control of cracking in concrete structures, American Concrete Institute 2001.
7. American Concrete Institute, ACI 365 "Service-Life Prediction," ACI, Detroit, MI, USA.

8. Arya, C., "Influence of cathode-to-anode area ratio and separation distance on galvanic corrosion currents of steel in concrete containing chlorides," Cement Concrete Research, V 25, 989-998, 1995.
9. Bilicik J. "Permeability of concrete as a method for calculating the life expectancy of reinforced concrete components", Proceedings of the International Conference on the Protection of Concrete, Dundee, 1990, 681 pp. Pihlajavaara S. E., "Some results of the effect of carbonation on the porosity and pore size distribution of cement paste", Materials and Construction, 1968, pp. 521 - 526.
10. Bishara SW, Rapid Accurate Method for determining water-soluble chloride in concrete, cement, mortar and aggregate, 1991, ACI Materials Journal, 88:265-270.
11. Bungey JH, Millard SG. Testing of Concrete in Structures, Chapman and Hall, Third edition, 1996.
12. Cabrera J.G., Claisse P.A. and Hunt D.N., A statistical analysis of the factors which contribute to the corrosion of steel in Portland cement and silica fume concrete, Construction and Building Materials, 1995, Vol.9, No.2.
13. Chand Y. Repair priority decision and estimation of residual service life of reinforced concrete elements from in-situ investigation data. IIT DELHI; M. Tech. thesis, 2013
14. Chaudhary GR, Jain KK, Jha KN, Bhattacharjee B, Condition assessment of RC structures- reliability of some in-situ techniques, International Journal of 3R's. 2011, 2:241-245
15. Christensen, B.J., Coverdale, R.T., Olson, R.A., Ford, S.J., Garboczi, E.J., Jennings, H.M., Mason, T.O., 1994. Impedance spectroscopy of hydrating cement-based materials: Measurement, interpretation, and application. J. Am. Ceram. Soc. 77 (11): 2789-2804
16. Concrete Society, "Guide to the Maintenance and Repair of Reinforced Concrete Structures in the Arabian Peninsula", presented at the Bahrain 6th International Conference, November 2000.
17. Dewaele P.J. Reardon E.J. and Dayal R., "Permeability and porosity changes associated with cement grout carbonation" Cement and Concrete Research, 1991, pp. 441 - 454.
18. Dhir R.K., Hewlett P.C, Byars E.A. and Shaaban I.G., "A new technique for measuring the air permeability of near surface concrete", Magazine of Concrete Research, 1995, pp. 167- 176.
19. Dhir R.K., Hewlett P.C. and Chan Y.N., "Near - surface characteristics of concrete: prediction of carbonation resistance", Magazine of Concrete Research, 1989, pp 137 - 143.
20. Diaz, B., Nóvoa, X.R., Pérez, M.C., 2006. Study of the chloride diffusion in mortar: A new method of determining diffusion coefficients based on impedance measurements, Cem. Concr. Comp 28:237-245.
21. Feldman, R.F., Chan, G.W., Brousseau, R.J., Tumidajski, P.J., 1994. Investigation of the rapid chloride permeability test, ACI Mat J 91:246-255
22. Figg J. W., "Methods of measuring the air and water permeability of concrete", Magazine of Concrete Researched 1973, pp 213 - 219.
23. Glass, G.K., Buenfeld, N.R., 2000. Chloride-induced corrosion of steel in concrete Prog. Struct. Engng. Mater. 2:448-458.
24. Hollaway LC, Leeming MB. eds. Strengthening of Reinforced Concrete Structures, Wood head Publishing Limited
25. Illston J.M., Construction Materials, E&FN Spon, 2nd. Ed. 1994.
26. Jaffer, S.J., Hansson, C. M. ,"The influence of cracks on chloride induced corrosion of steel in ordinary Portland cement and high performance concretes subjected to different loading conditions," Corrosion Science, V 50, 3343-3355, 2008
27. Jain KK, Bhattacharjee B. Application of fuzzy concepts to the visual assessment of deteriorating reinforced concrete structures. Journal of Construction Engineering and Management, ASCE 2012; 138: 399-408
28. Jain KK, Bhattacharjee B. Visual inspection and condition assessment of structures [vikas]: an innovative tool for structural condition assessment. International Journal of 3R's 2012; 3:349-357.
29. Jain, J.A., Neithalath, N., 2010. Chloride transport in fly ash and glass powder modified concretes-Influence of test methods on microstructure. Cem. Concr. Compos 32 (2): 148-156
30. Kasai Y., Matsui I., Fukushima Y. and Kamohara H. "Air permeability and carbonation of blended cement mortars", ACI SP - 79,1983, pp.435 - 451.
31. Kay T. Assessment and renovation of concrete structures, Longman Scientific and Technical, 1992.
32. Li, Z, Leung C, Xi Y, Structural Renovation of Concrete, Spon Press. 2009.
33. Loche, J.M., Ammar, A., Dumargue, P., 2005. Influence of the migration of chloride ions on the electrochemical impedance spectroscopy of concrete paste, Cem. Concr. Res 35:1797-1803.
34. Lydon F. and Odaalah M., "On surface relative permeability test for concrete", Construction and Building Materials, 1988, pp .102 - 105.
35. Mallik SK, Gupta AP, Reinforced Concrete, Oxford & IBH Publishing Co.1983.
36. Manchiryal, R.K., 2009. Dielectric response based characterization and strength prediction of cementations materials. PhD. Dissertation, Clarkson University, Potsdam, New York
37. Marsh B.K., Day R.L., Bonner D.G. and Illston J.M., "The effect of solvent replacement upon the pore structure characterization of Portland cement paste", Proceedings RILEM / CNR Symposium on principles and application of pore structural characterization, Milan, 1983, Paper 003.
38. McCarter, W.J., Starrs, G., Chrisp, T.M., Blewett, J., 2003. Characterization and monitoring of cement-based systems using intrinsic electrical property measurements Cement and Concrete Research, 30: 197-206

39. Neithalath, N., Weiss, J., Olek, J., 2006. Characterizing enhanced porosity concrete using electrical impedance to predict acoustic and hydraulic performance. Cement and Concrete Research, 36: 2074-2085
40. Neville A.M. and Brooks J.J. "Concrete Technology", Longman Group Ltd.,1990, 438 pp.
41. Otsuki, N., Miyazato, S., Diola, N.B. and Suzuki, H."Influences of bending crack and water-cement ratio on chloride-induced corrosion of main reinforcing bars and stirrups," ACI Materia's Journal, V 97, n4, pp. 454-464, 2000.
42. Papadakis V.G., Vayenas C G and Fardis MN. Fundamental modelling and experimental investigation of concrete carbonation, ACI Materials Journal, 1991, pp 363 - 373.
43. Park R, Paulay T. Reinforced Concrete Structures, John Wiley &Son, 1975.