A Comparative Study on causes of corrosion of steel reinforcement in RC structures at Bangalore, India and Kigali, Rwanda

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Abstract-Premature failure of reinforced concrete structures occurs primarily due to early corrosion of steel reinforcement. This paper intends to uplift the awareness of people about the role of structure maintenance to prevent or control corrosion in steel reinforced concrete structures. Some data collected using a designed questionnaire were distributed in Bangalore, India and Kigali, Rwanda, about corrosion of steel reinforcement which actually motivated this research. The research finds that without corrosion in steel reinforced concrete structures is just a matter of time. However corrosion map for Kigali is not available. Hence the survey has been conducted in Rwanda. Based on survey corrosion map will be prepared so that vulnerable areas for corrosion can be identified. This map will enable for protective design of structures against corrosion. The new steel RC structures corrosion monitoring systems should be incorporated for future less costly, timely maintenance for their reliable service life.

Key words: Maintenance, Corrosion, Steel reinforcement, Reinforced concrete, Structures.

I. Introduction

Premature failure of reinforced concrete structures occurs primarily due to early corrosion of steel reinforcement. Carbonation and chloride attack have been reported to be the major factors to initiate corrosion of steel in reinforced concrete structures. This depends on the environment condition (external factors), durability of concrete (internal factors) and exposure time. The propagation of Corrosion and corrosion behavior of steel in RC structures is dependent on the interaction between the influencing factors. The factors that influence corrosion are i) carbonation ii) chlorides attack iii) ingress of moisture iii) moisture content iv) relative humidity v) loss of $_{P}$H vii) temperature viii) cracking of cover concrete ix) cover concrete thickness x) porosity and pore solution composition and xi) type of steel**.** A lot of research work has been done on corrosion inhibitors and preventive measures. According to CECRI research found that some Non-coastal Cities/Towns in India found the most corrosion-prone places in the country too [1]. However, corrosion rate is the governing parameter in as far performance and service life of RC structure is concerned. Durability of any structure is determined right from design, material selection, and construction to the functional use it is put. For corrosion prevention and control, the people involved should have perfect knowledge in each area mentioned above. Reinforced concrete structures perform well as long as the alkaline environment is intactas [2]. Good quality concrete alone without minimum maintenance cannot grantee the durability of reinforced concrete structure as concretes are never free of cracks. They may deteriorate because of deterioration of the concrete itself or because of corrosion of the steel reinforcing bars inside the concrete. It is well known that the corrosion of steel reinforcements in concrete is one of the main reasons for the reduced service life of concrete structures [3].This problem has reached alarming proportions in the past three decades leading to every high repair costs, sometimes even above the initial construction cost, or the final collapse of the structure in extreme situation [4].The economic and safety concern of RC deterioration problem due to corrosion has led to enormous investments by the owners of structures in inspection, maintenance, restoration and replacement of the infrastructure as to sustain their design service life. The corrosion problem is not something new but awareness of the problem in association with civil engineering structures, particularly reinforcement or prestressed concrete highway bridges, multi-storeyed car parks and buildings is relatively new. Corrosion is insidious in nature and the corrosion of steel in concrete is only apparent when it is quite advanced and manifests itself progressively in the form of 'rust' stain, cracking, delaminating and finally spalling with exposed and corroding steel reinforcement [5].Several factors in reinforced concrete structures are known to favor corrosion: poor construction and design quality, poor materials selection, and exposure to a corrosive chemical environment. Common causes of the deterioration of concrete include alkali-aggregate reaction, chemical attack, freezing and thawing action, abrasion and fire. The effect of corrosion is not only a worldwide engineering problem but also an economic problem. Because of this economic cost, many production and manufacturing companies, state and federal highway agencies, and infrastructure developers are pursuing corrosion control methods for reinforced concrete structure. Besides the economic importance of corrosion, corrosion control has gained importance due to human safety and conservation [6]**.**There is often the misunderstanding that carbonation and chloride attack would cause deterioration of concrete. In actual fact, carbonation and chloride attack would not cause any harm to the concrete itself; they mainly cause de-passivation of the steel in concrete, which then leads to steel corrosion. To deal with corrosion and corrosion damage cases in RC structures, it is better to understand it from the grass root, right from its mechanism, initiation and propagation. Corrosion of RC cannot be completely prevented but it can be maximally controlled. For this reason therefore, the Government or policy makers, material manufacturers, contractors and building /structural owners and engineers or estate managers have to be well conversant with the problem and join hands to fight against it. The capacity to monitor and measure corrosion initiation and corrosion rate propagation respectively is a recognised step in corrosion control while timely maintenance of RC structures is considered by this research as a major mitigation measure for corrosion control to restore the designed service life of steel RC structures.

From the above literature survey, it was evident that control of corrosion is an unavoidable one. Therefore this paper emphasises understanding the concept of comparing corrosion inhibitors and preventive measures in Kigali, Rwanda and Bangalore, India

II. Methodology

A questionnaire was formulated as a tool to collect data and distributed to the targeted groups of people such as the building owners, constructing and consulting firms, engineers and government agencies relevant to construction, evaluation and maintenance of structures in cities, Kigali in Rwanda and Bangalore in India.

Data collected from questionnaire were compared with the data of project reports from Civil-Aid Techno Clinic Pvt. Ltd. These projects were the work inferred to Civil-Aid Techno Clinic Pvt. Ltd. and A. B. V Company to investigate the structure soundness or to assess the cause of distress available in some structures in different localities in Bangalore city. The data in the reports were obtained using systematic procedure of physical observations and detailed investigative study with both Non- destructive testing (NDT) and Destructive testing techniques.

III. Experimental Investigation Methods

Physical Experimental investigation was done in two methods, viz, Non Destructive Tests (NDT) and Destructive Methods. Rebound Hammer test as per the guidelines in Indian standard IS: 1311- (Part11)-1992-(Reaffirmed in 2004), Ultra Pulse Velocity Test (UPV) as per Indian standard, Half-cell Potential Measurements Test was carried out on R.C members using Copper-Copper Sulphate Half-cell to estimate the stage of corrosion in reinforcing bars as per the guidelines furnished by ASTMTC-876-91 - (Reaffirmed in 1999), the cover meter studies were carried out on various RC members, in order to assess the thickness of cover concrete and to map the disposition of peripheral embedded rebars in the R.C. members and Core test to assess the quality/strength of in-situ concrete in reinforced concrete members as per the guidelines in IS: 516-1959 ((Reaffirmed in 2013).

Chemical experimental investigation on collected concrete samples were also done. Carbonation test was carried out on R.C. members using phenolphthalein indicator in 0.1N methyl alcohol to assess the extent of carbonation in cover of RC members. Chloride determination was test was carried out on concrete to estimate the level of chloride in concrete and expressed in terms of chloride by weight of concrete as mentioned in I S 456 of 2000 limits the chloride content. Sulphate determination test on concrete is carried out is carried out to estimate the level of sulphate in the concrete expressed in terms of percentage of sulphate by weight of concrete. The level of PH in fresh concrete is generally in the range of 12 to 14. Due to carbonation, the PH value of concrete will be reduced considerably. When PH of concrete falls below 10, the alkalinity of the concrete will not be adequate to protect the rebars against corrosion.

IV. Result

As per the survey results, the majority of structural owners in both cities tell that there is no corrosion of in RC Structure the few who admit the presence of corrosion in RC structure have seen or experienced it in their own structures. In Bangalore RC structures are generally exposed to moderate corrosion condition as indicated by corrosion map of India. In Kigali, Rwanda has not done any investigation hence structure corrosion condition exposure is not known. However the researcher has used a questionnaire as a tool to collect data. Director's of Infrastructure of Nyarugenge District, Gasabo District and One Stop Center of Kigali City were not aware of corrosion in concretes. Constructing firms and other civil engineers pin point's poor construction and poor design to be reason for premature RC structure's failure. Others including engineers have mentioned that limited knowledge about corrosion of steel reinforcement more especially for the case of Rwanda.

For the case of consultancy agencies, Civil-AID TECHNOCLINIC PVT.LTD has reports to support their response that in most old buildings over 35 years in service, is having corrosion of steel in reinforced concrete is commonly found. Carbonation in concrete is found to have reached or gone beyond the level of reinforcement. High probability of corrosion is commonly found in Half-Cell potential results.

Table 1 shows the summary of test results of chemical analysis and physical test on 14 buildings with the age from 10 years to 60 years in Bangalore, India.

Table 1 Summary of Data collected from 14 RC structures in Bangalore, India for the purpose of corrosion assessment.

S.No	Year of	Age of Structures (yrs)	YEAR OF EVALUATION &	1ST EVALUATION STUDY	UPV Test IN RC (N/mm^2)	HALF-CELL POTETIAL RESULTS	COVER CONCRETE DEPTH	CARBONATION	CHLORIDE Max-min	SULPHATE maxi-min (%)	PH	GRADE OF CONCRETE In (N/mm^2)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	1975	30-still occupied	07-09/2005	29/07/2005 Corrosion was observed even with bare eyes.	Doubtful	Moderate to advanced stage of corrosion	In efficient Cracking and spalling and exposed corroded rebar was there.	Up to the level of reinforcement	-	-	-	in-situ 8-10
2	-	60	26/08/2008	21july-01/08 2008	-	Moderate stage of corrosion	Was in order	-	-	-	-	15 - 18
3	1985	26	1/July / 2011	10119-26/April-18/June 2011	Medium-Good concrete 16-22	Uncertainty of corrosion to high probability of concrete	Was in order	Reached reinforcement level	-	-	-	-
4		40	12/01/2013	7-21/10/2012	Doubtful	High probability Of corrosion	In adequate in a Few tested RC Members	Up to the level of reinforcement	0.41-0.44	3.6-3.74	8.66-9.85	In-situ strength 18-20
5	1990	21	24/11/2011	2/11/2011	Medium	High probability Of corrosion	20-35	Up to the level of reinforcement	0.40 – 0.58	3.01-3.10	10.05 - 11.05	In-situ strength 3.2-3.4
6	2007	6	15/July/2013	25-27 June/2013	Medium-Good concre	High probability Of corrosion	Column 40-70 Beam	Beyond the level of reinfor	0.16-0.84	2.889 - 3.38kg/m^3	9.9 - 11.66	In-situ strength

					te		25-45 Slabs 12-30	cement				26-36
7	19 64	45	18/02/ 2009	23/01/2 009	Doubtf ul CONC RETE Comp. Strengt h less than 15N/m m2	High probability Of corrosion/ Extensive corrosion	In adequ ate in a Few tested RC Mem bers	Beyon d reinfor cement level	0.34- 0.54	3.10- 3.23	11. 34- 11. 80	In- situ streng th 12- 16.
8	19 82	30	12/04/ 2012	5&6/ja n/2012	Doubtf ul- Mediu m	High probability Of corrosion	In adequ ate in a Few tested RC Mem bers	Beyon d reinfor cement level	0.72- 0.79	3.09- 3.14	8.8 2- 8.8 9	Less than 15
9	19 75	23	08/02/ 2008	30/11- 03/12 /2007	Mediu m- Doubtf ul15- 20N Low pulse velocit y were found in few colum n and beams	High probability Of corrosion	Adeq uate	Beyon d the level of reinfor cement	Chlo ride cont ent In a few mem ber is high er than the stipu lated limit	The level of sulph ate in concr ete is highe r than the permi ssible in some memb ers	Le ss tha n 10	The streng th 22- 28
1 0	19 78 - 19 80	Aro und 30yr s old	25/07/ 2009	17- 19/Jun e 2009	15-18	UNCERTAI NITY/High probability Of corrosion	In the range of 15-30	Reache d the level of reinfor cement in the most RC Membe rs tested	0.4- 0.5	3.14- 3.32	9.8 6- 10. 48	15- 18, the test on brick morta r show ed 3.5-4 absor ption was 9.4- 10.1 % Again st the maxi mum

												permi ssible of 20% & the mixin g propo rtion of cent and sand range 1:8:6 to 1:9:7 far from desire d 1:6
1 1	19 82	25	31/03/ 2011	03/07/J an /2011	22-25	High probability Of corrosion	25-35	Reache d the level of reinfor cement in the most RC Membe rs tested	0.54	3.49	9.8 9	15-18
1 2	19 78	34	21/Jan /2012	03- 04/01/2 012	15.0- 18 Mediu m concre te	High probability	25-50	Cover concret e has lost alkalini ty	0.25- 0.52	3.4- 3.62	8.9 8- 8.6 0	Rebo und test 16.1- 16.7
1 3	19 95 - 19 96	9	06/07/ 2009	18/06/2 009	12-15 Doubtf ul- mediu m	High probability Of corrosion	Is in order	Beyon d the level of reinfor cement	1.90- 2.49	3.60- 3.67	8.3 4- 9.4 4	12-15
1 4	19 82	29	25/ma y/2011	18/Apr il/2011	Doubtf ul- mediu m 15-19	High probability Of corrosion	Was satisf actory excep t in the certai n locati ons in first flow.	Cover concret e has lost alkalini ty	0.27- 0.55	2.69- 2.98	9.0 2- 9.9 2	16-20

Table 2 shows the summary of main corrosion inhibitors in concrete structures, viz, Chloride and pH value

S/no (as for chloride range)	Range of age (Years)	Chloride content range	pH range (alkalinity)
13,6	10-20	0.16-2.49	8.34-11.66
14,12,11,10,9,8,1,3,4,5	21-40	0.40-0.79	8.82-11.05
2,7	41-60	0.34-0.54	11.34-11.80

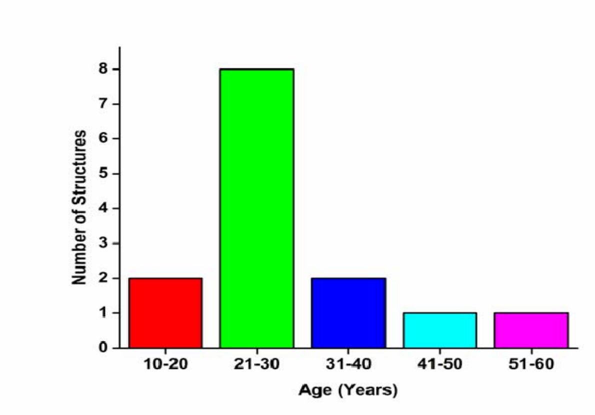

Figure 1a. Range of age in assessed structures

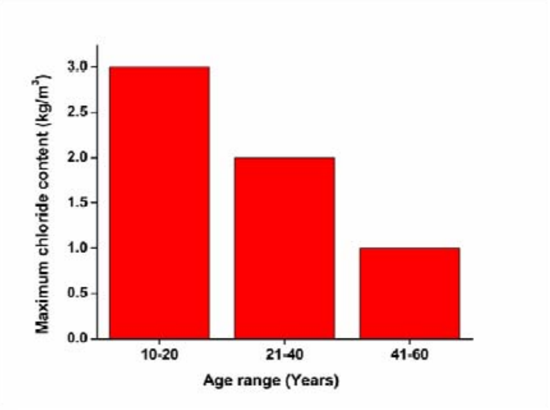

Figure 1b. Structural service life Vs chloride

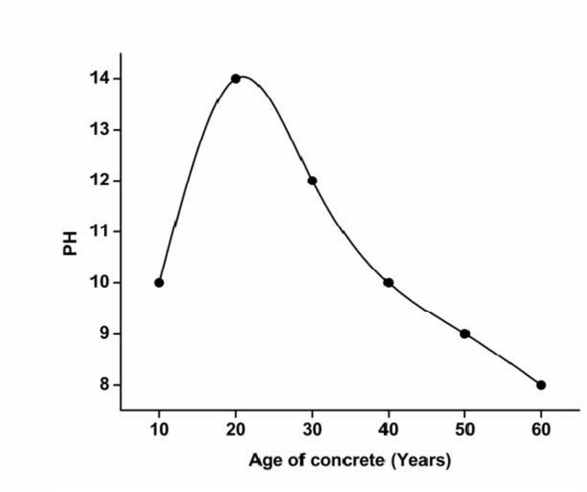

Figure 1c. Effect of age on pH in reinforced concrete

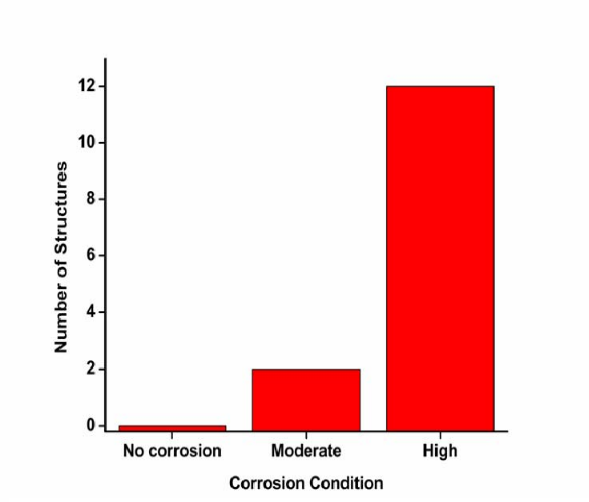

Figure 1d. Corrosion condition in all 14 structures

Figure 1. a, b, c and d show the relationship between steel reinforced concrete service life and age, chloride content, pH and corrosion condition respectively.

Fig 1a shows the number reinforced concrete structures selected at random for evaluation and their range of age in service. It was found that more than 57% of the structures selected randomly were ranging between (21-30) years of age. 14.3%, 14.3%, 7.14% and 7.14% were ranging in (10-20),(31-40),(41-50) and (51-60) respectively.

Fig 1b shows the chloride content with respect to age for the reinforced structures considered. It shows that more chloride was found in structures of the range (10-20) years and (21-40) years as compared to the range (41-60) years of age.

Fig 1c compares alkalinity (pH) of concrete with steel reinforced concrete structure life.

Fig 1d shows corrosion condition in all investigated steel RC structures. Where12 structures showed high corrosion potential and only 2 had moderate corrosion potential among the 14 steel reinforced concrete structures evaluated.

V. Discussion of Results

The data from Kigali, Rwanda shows that there is little awareness and knowledge about corrosion of steel in reinforced structure. Again data is lacking for the corrosion situation in Kigali and Rwanda in general. It was found that a big number of Reinforced concrete structures that inferred to civil –aid techno clinic pvt ltd for assessment of structural soundness have (21-30) years old. After assessing their structural soundness it was found that they require maintenance to restore their performance in service life as shown in Table 1.

Also from Table 2, it was observed that carbonation is the major cause of distress in all 14 structural members' evaluated being at steel level or beyond steel. This is more confirmed by the lower pH lagging below 9 in almost all fourteen structures. This means that steel reinforcement was no longer passivated hence prone to corrosion. A great surprise was found, during the assessment of structural soundness of existing residential buildings in Bangalore with the same exposure of moderate corrosion. Reinforced concrete structures here referred to as (S/no.2) and (to S/no13) constructed to serve the same function exhibited a very big difference in service life. It is reported that with S/no.2 with two floors, the ground floor was constructed about 60 years before where as the first floor was constructed about 40 years before and since then it has been in service with good performance though it was calling for maintenance at this stage. As compared to S/no.2, Structure referred to s/no.13 was built in 1995 and only 9 years of age in service it was highly distressed with carbonation beyond steel level, severe corrosion of rebars in Reinforced concrete members and very high chlorides range of (1.90 - 2.49) kg/m^3 and calling for maintenance. The big difference in durability was attributed to poor design and poor construction practice. After assessment and analysis of the results for Structure (S/no.6) ,the early loss of durability as it was found with cracks, spalling and delamination, high carbonation and corrosion of reinforcement was attributed to poor design.

VI. Conclusion

Corrosion map of Rwanda is necessary**.** This map will enable for protective design of structures against corrosion. Compared to other parameters evaluated carbonation was found to be the more cause of the distress and un soundness of structures. Corrosion of steel reinforcement was found to be high in most RC members tested has led to delamination and spalling of concrete. Rehabilitation was highly needed to restore the normal functionality of these structures. Due to high corrosion of steel found, corrosion inhabitant products inclusion are recommended to control the rate of corrosion and it should particular for each structure and it is advised to be done by experienced expert personnel in the area of corrosion of steel RC structures. Maintenance is not avoidable in steel RC structures for better performance during their service life. Poor design and poor construction practices characterizes most of the old buildings (35-above).This has a big role in shortening the service life of RC structures due to less durability. For new reinforced concrete structures corrosion monitoring systems should be incorporated especially in big structures with high designed service life. However corrosion map for Kigali is not available. Hence the survey has been conducted in Rwanda (questionnaire for survey are given in annex -1).Based on survey corrosion map will be prepared so that vulnerable areas for corrosion can be identified. This map will enable for protective design of structures against corrosion. More work is planned to collect the preliminary data for corrosion of situation in Rwanda**.**

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Civil-Aid Technoclinic Pvt.Ltd " reports" table -2 summarizes the data collected from 14 RC structures in India for the purpose of corrosion assessment.

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