Int. J. Electrochem. Sci., 7 **(2012)** 9825 - 9834

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Technical Report

Electrochemical Behavior of Reinforced Concrete and Its Relation With the Environment of Xalapa, Veracruz

G. Santiago-Hurtado[1], E.E. Maldonado-Bandala[1], F.J. Olguin Coca[2], F. Almeraya-Calderón[3,4], A. Torres-Acosta[5], M. A. Baltazar-Zamora[1]*

[1]Universidad Veracruzana, Facultad de Ingeniería Civil-Xalapa, Circuito Gonzalo Aguirre Beltrán S/N, Zona Universitaria 91090, Xalapa, Veracruz, México
[2]Instituto Tecnológico de Pachuca, Ciencias de la Tierra, Pachuca, Hidalgo, México
[3]Centro de Investigación en Materiales Avanzados SC (CIMAV), Chihuahua, Chihuahua, México
[4]Universidad Autónoma de Nuevo León. FIME-CIIIA. San Nicolás de los G., Nuevo León, México
[5] Instituto Mexicano del Transporte, Sanfandila, Querétaro, México
[*]E-mail: mbaltazar@uv.mx

Received: 27 July 2012 / *Accepted:* 4 September 2012 / *Published:* 1 October 2012

In this work it is evaluated the electrochemical performance of reinforced concrete exposed to the environment of the city of Xalapa, Veracruz, to portray the effect in the durability, since this depends not only from its mechanical features but also from the environment in which the structure will be build, as it has been demonstrated in some researches. 12 beams of 15 x 15 x 30 cm were made, 6 with steel to reinforce and 6 without it. Two types of concrete were designed, one with a w/c = 0.65 ratio and the other with a w/c = 0.45 ratio, with the same kind of cement, 3/8" diameter 1018 steel carbon rods, in three types of coating thickness, 15, 20 and 30 mm. The tests to evaluate the oversensitivity to corrosion of the reinforce steel, were resistance to polarization and the monitoring of potential corrosion based in the standard ASTM C-876-09.The obtained results of the first two years of monitoring indicate us noble potentials that indicate a 10% probability of corrosion, the kinetics of corrosion is negligible for 12 rods since 6 of them have a moderate level of corrosion.

Keywords: Environment, Concrete, Durability, W/C Ratio, LPR, Corrosion Rate

1. INTRODUCTION

Until a few years ago, it was thought that hydraulic concrete structures had an unlimited useful life, and that its durability depended solely from its mechanical features, so, during its designing stage, the environmental conditions in which the structures were going to be exposed were not borne in mind[1-7]. Nowadays, various researchers have demonstrated that, the durability of the aforementioned structures depend, not only from its mechanical features but also from the environment in which they will be build [8-12]. One of the most significant research works to relate the durability of concrete structures with the environment, it is the one performed by the group of the DURAR network, with the DURACON Project (Influence of the environment in the durability of concrete), this project is supported by the program of science and technology for the development (CYTED of Spain) [13]. This project is focused in studying the performance hydraulic concrete exposed to different environmental conditions in Latin America. There are 14 monitoring stations in Mexico; one of them is located in the city of Xalapa, in the state of Veracruz. The objective of this work is to hand in the results of the first two years of evaluation of the beams exposed to an environment classified as urban.

2. EXPERIMENTAL

2.1 Materials for the manufacture of concrete beams

The specimens under study were manufactured in accordance with the method of the ACI 211.1 [14] for the manufacture of concrete blends, method that takes in mind the physical characteristics of the material used in the production of hydraulic concrete which are the Portland Cement, water, the fine aggregate (sand) and the thick aggregate (gravel), up next we list the physical characteristics of the aforementioned materials.

1. Type of cement: Ordinary Portland Cement (OPC) [15].
2. Grinded silicon aggregate of 19 mm maximum size, density of 2.58 (Thick aggregate)
3. Quartz sand, density of 2.50. (Fine aggregate)
4. Water/Cement Ratio = 0.45 (f´c =350 kg/ cm2)
5. Water/Cement Ratio = 0.65 (f´c =210 kg/ cm2)
6. Plasticizer addition 0.3% by cement weight (sikament 190 CR). (Additive)
7. Accession 10 ±1.0 cm. Metal centring and cured under water for 7 days.

Table 1. Proportion of the blends used.

Materials (Kg/m^3)	Water/Cement Ratio	
	0.45	0.65
Cement	411	285
Water	185	185
Stone Aggregate	1010	1033
Fine aggregate	731	812
Additive (plasticizer)	4 cc/Kg cement	

According to the physical features of the materials and the w/c ratio design 0.45 and 0.65, the same that provide us concretes up to 350 and 210 kg/ cm^2 respectively, and that they are concretes that are placed in structures like buildings, bridges, docks, etc; the proportion calculated or material quantity used to manufacture a concrete of the fore mentioned features are summarized in the table 1.

2.2 Preparation and placing of the beams

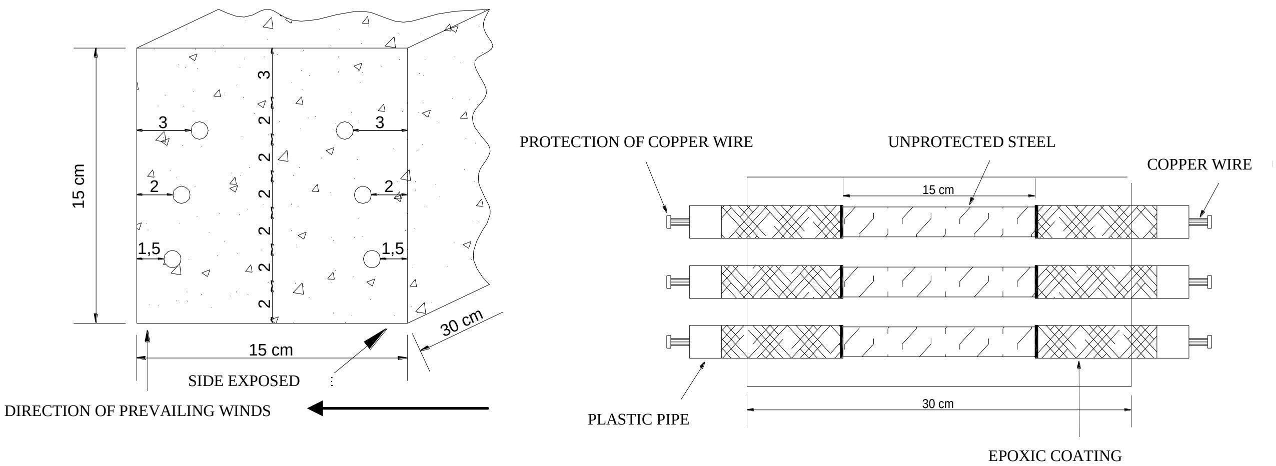

Figure 1. Sketch of the transverse and longitudinal section of the reinforced concrete beams of the DURACON project

Figure 2. Natural test station, facing the prevailing winds

For each station there were manufactured 12 concrete beams of 15 x 15 x 30 cm, from which 6 of them are made of simple concrete and the other 6 are made of reinforced concrete with 6 rods of #3 1018 steel (9.5 mm diameter). The rods were placed inside the beams in 3 different concrete coating thicknesses 15, 20 and 30 mm., figure 1 shows a sketch of the geometry of the beams in the project, figure 2 shows a photograph of the natural test station of the DURACON Project in the city of Xalapa, Veracruz.

The beams were placed on metallic bases, with a side facing the prevailing winds (exposed side) and the other side facing the non prevailing winds (protected side). The reinforced concrete beams are employed to perform the assessment of electrochemical parameters (Ecorr, icorr and ρ).

3. RESULTS

3.1 Physical properties of the concretes

On table 2 are presented the physical properties obtained from the reinforced concretes used, like: Effective porosity (ρ), coefficient of capillary absorption (ka), resistance to water penetration (m) and resistance to compression (f'c). The resistance to compression obtained was, like in most cases, higher than expected.

Table 2. Physical properties of the concretes employed

Parameter	Water/Cement Ratio	
	0.45	0.65
f'c, N/mm^2	51.5	40.0
m, s/m^2	3.48×10^7	3.60×10^7
ka, $Kg/m^2\ s^{1/2}$	1.47×10^{-2}	1.99×10^{-2}
ρ, %	8.5	11.9

3.2 Record of environmental parameters

Figures 3 to 5 show the behavior of the environmental parameters (relative humidity, temperature, precipitation) during the first two years of exposure.

The bar chart in figure 3 shows that average relative humidity oscillates between 75 and 85% during this stage of the study. That is an ideal percentage to have the phenomenon of corrosion in the steel to reinforce.

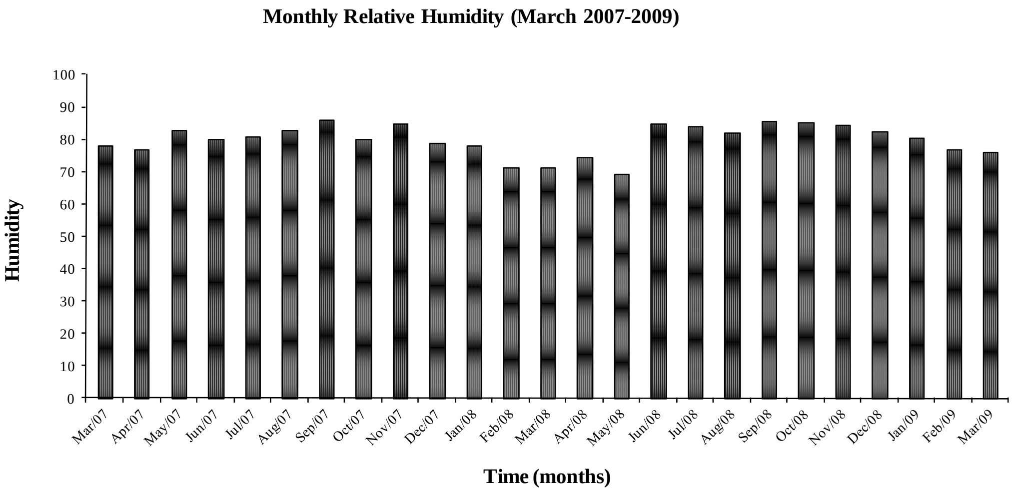

Figure 3. Monthly relation of relative humidity (average).

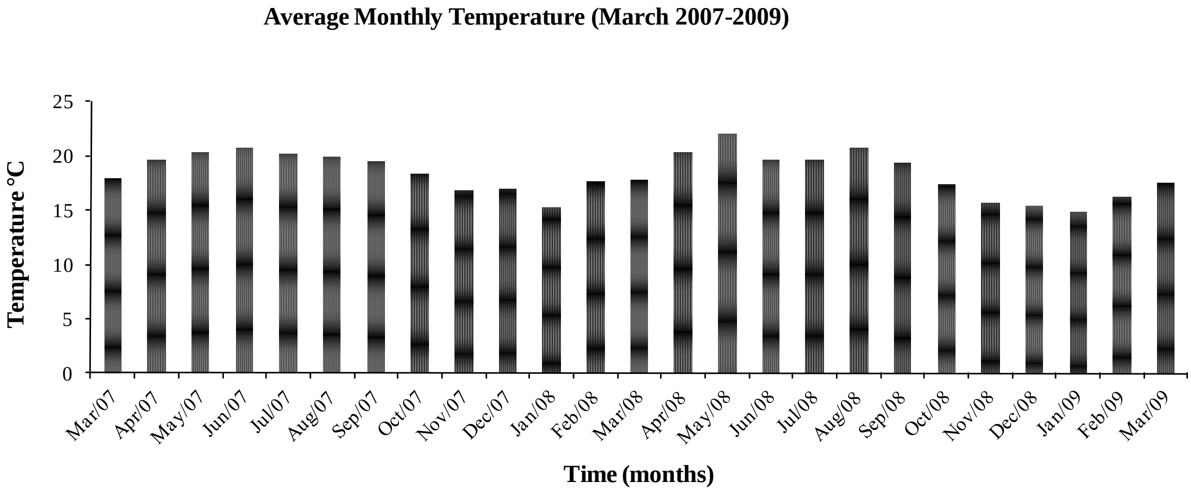

Figure 4. Monthly Variation of the temperature.

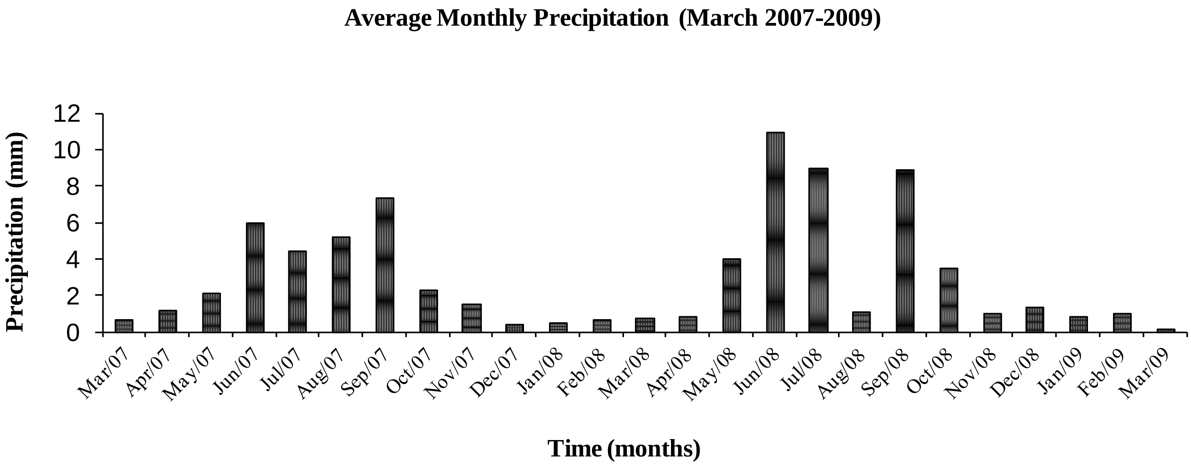

Figure 5. Monthly Variation of the precipitation.

The average temperature recorded it is between 15 and 21°C (figure 4); and the bigger average of precipitation were recorded in September 2007 and June 2008 coinciding with the two most negative potential of corrosion values reported on this two first years of research (figure 5).

3.3. Corrosion potentials

The corrosion potential monitoring of the test specimens was performed according to ASTM C876-09 [16] standard, and evaluations were carried out according to what shown in table 3 [17-19].

Table 3. Corrosion Potentials (E_{corr})

Ecorr (mV vs $Cu/CuSO_4$)	Probability of Corrosion
< - 500	Severe Corrosion
-500 to -350	90% Probability of Corrosion
-350 to -200	Uncertainty of Corrosion
> -200	10% Probability of Corrosion

The results of the measurement of corrosion potentials can be observed in figures 6 to 8, that corresponds to the 6 beams studied three with a ratio of w/c = 0.45 and three with a ratio of w/c = 0.65, the results of the side exposed to the predominant winds are presented.

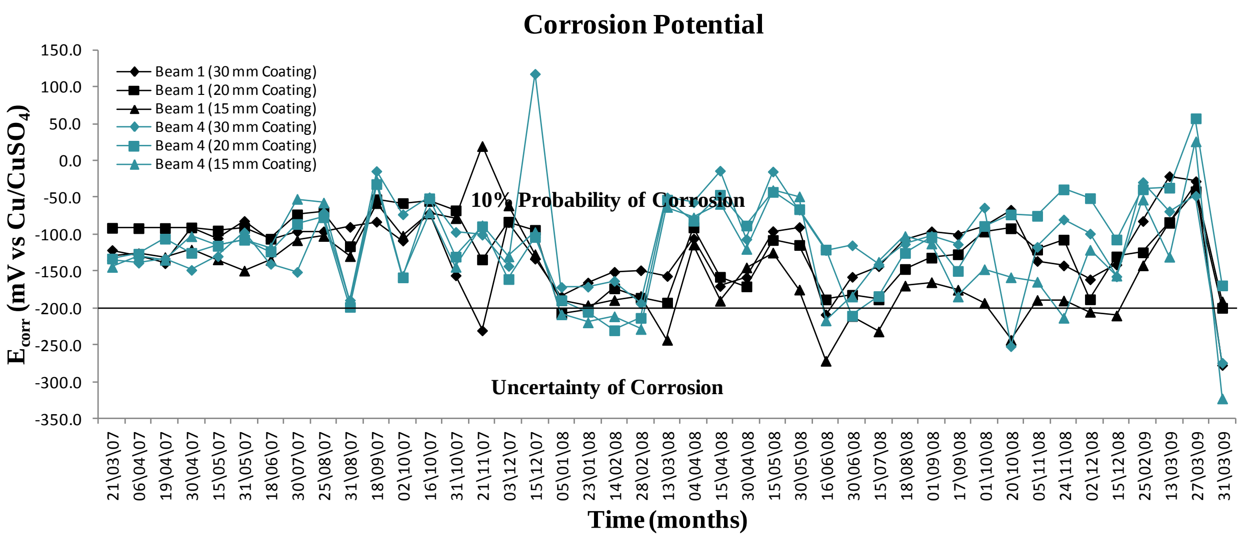

Figure 6. Behavior of potentials of corrosion Beam 1 ratio w/c= 0.45 and Beam 4 ratio w/c= 0.65

In figure 6 in general it is observed according to the standard ASTM C-876-09 a tendency of potentials that indicate us a 10% of probability of corrosion in the rods with its different coating up to the first 5 months, after which the 15 and 20 mm coatings of the beam 4 (w/c= 0.65), show values of

50% that are developing the process of corrosion, observing the influence of the coating. In the beam 1 it is observed how the coating rod of 15 mm shows the most negative values through the months of study, also to the end of the second year it is presented the values of potential on the beam 4 with a coating of 15 mm and 20 mm which indicate a 90% of probability of corrosion.

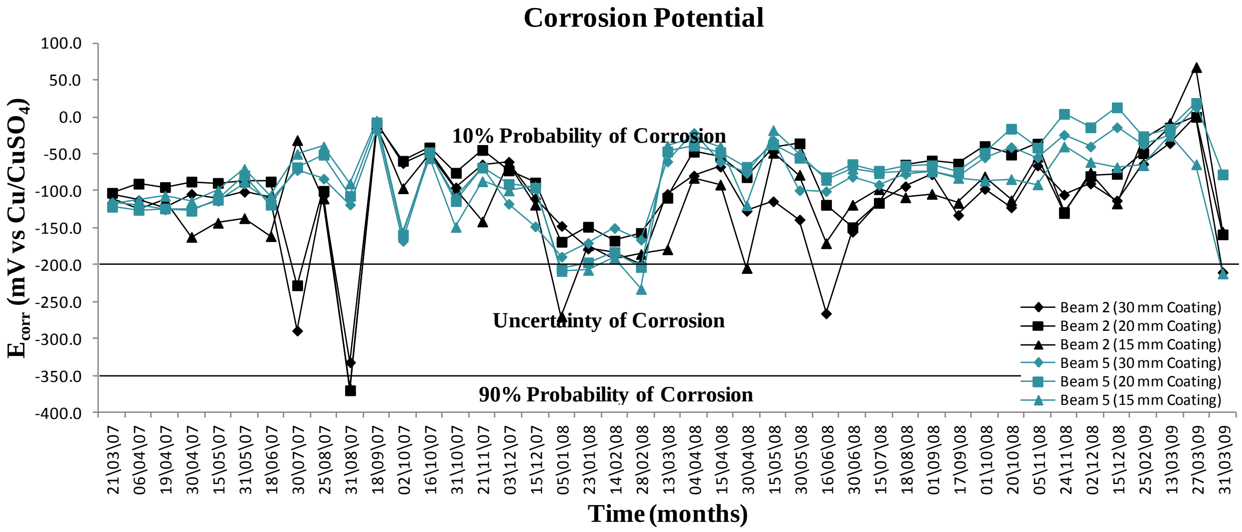

Figure 7. Behavior of potentials of corrosion Beam 2 ratio w/c= 0.45 and beam 5 ratio w/c= 0.65

Figure 7 has the record of data obtained and with that it is observed that in the first 3 months it was presented a homogeneous behavior of potentials in all the coatings, as well as some are observed in two readings (June and August) of the beam 2 coating of 20 mm and 30 mm, this can be attributed to a mistake in the reading since after that the six rods with its different coatings reported homogenous values more positive than -200 mV indicating according to the standard a probability of 10% of corrosion in the system, even that also it can show that this same coatings suffered alterations in the months where it showed a high content of humidity.

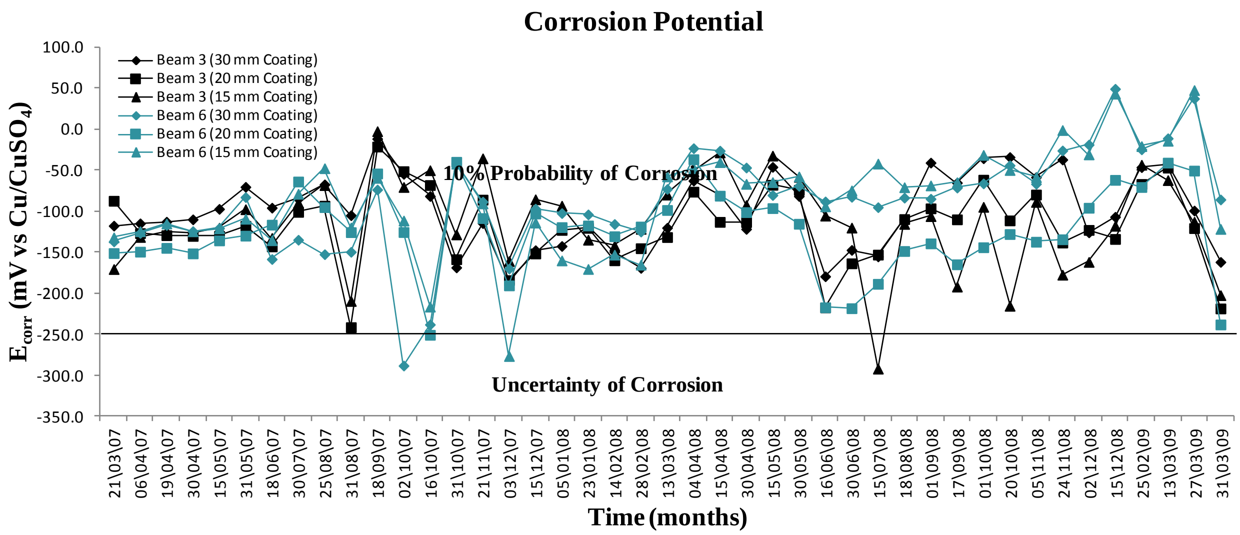

Figure 8. Behavior of potentials of corrosion Beam 3 ratio w/c= 0.45 and Beam 6 ratio w/c= 0.65

At the end of the reading, the rod with 15 mm coating of both beams, 0.45 and 0.65 reported a more negative value of -200 mV which indicate a 50% probability and identifying the influence of the coating and of the quality of the concrete, coinciding with both beams 1 and 4.

Figure 8 shows potentials with values that indicates us a 10% of probability of corrosion during the two years, except some peaks where certain rods report values of potential that indicates uncertainty. Just like the previous pairs of beams analyzed in figures 6 and 7, at the end of the two years the chart seems to indicate a tendency of more negative values, placing them in the zone of uncertainty.

4. DISCUSSION

4.1 Corrosion rate

To assess the results of kinetics of corrosion that the test specimens presented and obtained with electrochemical technique of Lineal Polarization Resistance (LPR) according to the linear region of the Stern–Geary plot [20], the interpretation of the values of the i_{corr}, are given according to what it is indicated in the manual of the DURAR network [21], which indicates us the level of corrosion in agreement to said value, as you can see on table 4.

Table 4. Of interpretation of the i_{corr}.

Velocity of Corrosion (i_{corr}) $\mu A/cm^2$	Level of Corrosion
< 0.1	Negligible
0.1 – 0.5	Moderate
0.5 - 1	High
> 1	Very high

Table 5 presents the kinetics of corrosion of the steel to reinforce in µA/cm2 of the side exposed to the predominant winds, of the six beams and the three coverings, said values point us out the level of corrosion is negligible according to table 4, except two rods of the beam 5, coating 15 and 20 mm that show 0.205 and 0.11 µA/cm2, presenting the steel to reinforced in an active state with a moderate level of corrosion just like in beam 1, coating 15 and 20 mm that show 0.121 and 0.113 µA/cm2, and the beam 2, coating 15 and 30 mm, both with a current density of 0.104 µA/cm2.

Table 5. i_{corr} values of the first 2 years of exposition, exposed side.

BEAMS	COATING (CM)	21-mar-07 i *corr* $(\mu A/cm^2)$	18-jun-07 i *corr* $(\mu A/cm^2)$	21-nov-07 i *corr* $(\mu A/cm^2)$	30-apr-08 i *corr* $(\mu A/cm^2)$	31-mar-09 i *corr* $(\mu A/cm^2)$
BEAM 1	3	0.01	0.035	0.033	0.066	0.093
Rat. w/c = 0.45	2	0.01	0.087	0.051	0.111	0.113
	1.5	0.017	0.058	0.03	0.073	0.121
BEAM 2	3	0.019	0.043	0.033	0.82	0.104
Rat. w/c = 0.45	2	0.025	0.039	0.051	0.13	0.089
	1.5	0.016	0.073	0.041	0.181	0.104
BEAM 3	3	0.016	0.013	0.026	0.57	0.067
Rat. w/c = 0.45	2	0.024	0.027	0.034	0.071	0.072
	1.5	0.02	0.053	0.029	0.05	0.054
BEAM 4	3	0.008	0.025	0.016	0.046	0.041
Rat. w/c =0.65	2	0.015	0.032	0.03	0.069	0.045
	1.5	0.02	0.016	0.022	0.32	0.065
BEAM 5	3	0.037	0.065	0.047	0.054	0.046
Rat. w/c = 0.65	2	0.219	0.24	0.121	0.023	0.11
	1.5	0.025	0.098	0.028	0.132	0.205
BEAM 6	3	0.019	0.063	0.023	0.049	0.04
Rat. w/c =0.65	2	0.014	0.028	0.02	0.062	0.039
	1.5	0.017	0.025	0.02	0.037	0.029

5. CONCLUSIONS

The E_{corr} values that are presented through this two years in the steel to reinforce with its different coatings in general are more positive than -200 mV, which based in the standard ASTM C 876-09 indicate us a risk of corrosion of 10%. The values of the of corrosion rate corroborate the active passive state of the reinforce of 12 of the 18 rods of the exposed side, given that in 6 of them, two of the beam 5 of ratio w/c= 0.65, two of the beam 1 and two of the beam 2 both with ratio w/c= 0.45 are presented at the end of this two years with a moderate level of corrosion, generated by the exposure to the environment of the city of Xalapa, differently from other stations in the project that given to the limited humidity and precipitation the system is placed in a passive state for both rations w/c.

ACKNOWLEDGEMENTS
The authors externalize their gratitude to PROMEP for the financial support granted for the development of this research Project through of Body Academic Strengthening Convocation 2012, ID 9997, key UV-CA-300, office No. PROMEP/103.5/12/4615. Thanks to A. Borunda-Terrazas and J.M. Lugo-Cuevas for their technical assistance.

References

1. A. Legat, *Electrochimica Acta,* 52 (27) (2007) 7590.
2. M.A. Baltazar-Zamora, G. Santiago H and et al., *Int. J. of Electrochem. Sci*., 7 (2012) 588.
3. M. Maslehuddin and et al., *Construction and Building Materials*, 21 (8) (2007) 1825.
4. M. Bitaraf and S. Mohammadi, *Construction and Building Materials,* 22 (4) (2008) 546.
5. C.P. Barrios, M. Baltazar-Zamora and et al., *Int. J. of Electrochem. Sci.*, 7 (2012) 3178.
6. S.A. Civjan, J.M. LaFave and et al., *Cement & Concrete Composites,* 27 (6) (2005) 688.
7. W. Chale, M. Teekavanit, K. Kiattikomol, A. Siripanichgorn, C. Jaturapitakkul, *Construction and Building Materials,* 21 (5) (2007) 965.
8. Pin Gu and et al, *Cement and Concrete Research*, 26 (8) (1996) 1151.
9. M.A. Baltazar-Zamora, E. Maldonado-Bandala, G. Santiago-Hurtado and et al., *Int. J. of Electrochem. Sci.*, 7 (2012) 2997.
10. T. Belleze, M. Malavolta and et. al., *Cemente & Concrete Composites,* 28 (3) (2006) 246.
11. R. Aveldaño and N. Ortega, *Construction and Building Materials*., 25 (2) (2011) 630.
12. L. Dhouibi, E. Triki, A. Raharinaivo, *Cement & Concrete Composites,* 24 (2002) 35.
13. O. Troconis and et al., *Corrosion Science*, 49 (7) (2007) 2832.
14. Proporcionamiento de Mezclas, Concreto normal, pesado y masivo ACI 211.1, Ed. IMCYC, México (2004). 29.
15. NMX-C-414-ONNCCE-2004, ONNCCE S. C. México (2004).
16. ASTM C 876-09 Standard, Test method for half-cell potentials of uncoated reinforcing steel in concrete. West Conshohocken, PA, American Society for Testing and Materials, (2009).
17. H. Won-Song and V. Saraswathy, *Int. J. Electrochem. Sci.*, 2 (2007) 1.
18. Ping Gu and J.J. Beaudoin, *Construction Technology Up date*, 18 (1998) 1.
19. S. Ramachandran and James J, Beaudoin. *Handbook of analytical techniques in concrete science and technology*. Noyes Publications/William Andrew Publishing, LLC. Norwich, New York, U.S.A. (2001) 468.
20. M. Stern and A.L. Geary, *J. Electrochem. Soc.* 104 (1) (1957) 56.
21. Red DURAR, *Manual de Inspección, Evaluación y Diagnóstico de Corrosión en Estructuras de Concreto Armado,* CYTED Program, Rio de Janeiro, (1997).