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Performance of Coated Steel in R.C. Beams with High Percentages of Chloride

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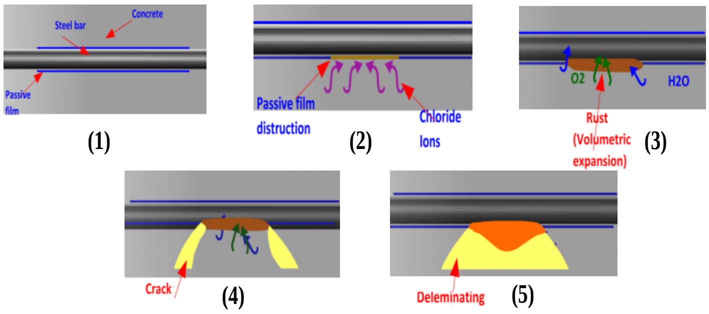
Abstract*— In this paper an experimental investigation was carried out to study the efficiency of using the epoxy coating against the corrosion of the steel reinforcement at high percentages of chloride on the structural behavior of R.C. beams. The experimental study contained twenty of R.C. beams with fixed steel reinforcement and a common concrete mix with different high percentages of salts by weight of cement (S/C=0%, 1%, 5% & 10%) in the mixing water of concrete mix. The beams were tested up to failure, and the influence of variable factors on the structural behavior such as, failure loads, strains, crack pattern and modes of failure were reported. Also, the mass loss of steel reinforcement bars was studied.

***Index Terms*— Experimental Method, Corrosion, Sodium Chloride, R.C. Structures, Epoxy Coated Protection, Internal Protective Layer.**

I. INTRODUCTION

Corrosion of reinforcing steel is one of the major worldwide deterioration problems for the reinforced concrete structures; In Egypt, an engineering consulting exposure to a three buildings in city of 6 October by the cracks many before a year. After its establishment and had been measuring the proportion of chloride ion, it was found that it reached more than 8% of the weight of cement, it means that salts% reached more than 26 times the allowable percentage by salts in reinforced concrete, which might come in concrete by salty aggregate or using salty water in mix water by ignorance or by fumes from the factories adjacent to structures or ….etc. So, the efficiency of protection by coated steel reinforcement as traditional repair methods for this problem may be very necessary and important to study. Where epoxy prohibited moisture and chlorides from reaching the surface of the steel as in Photo (1) [1] and also acted as an electric insulator to minimize the electric current needed to propagate corrosion [2]. Steel in concrete is protected naturally by the high alkalinity of the matrix and this protective quality improves with time due to continued hydration of cement. However, due to the interaction with the environment the protection capability of concrete decreases with time the chloride ions into concrete are considered to be the major cause of corrosion [1],[3],[4]. The corrosion products are expansive in nature and effectively cause a tensile pressure around the reinforcing steel. Once sufficient corrosion has occurred, splitting cracks typically develop and loss of bond is observed [5]. Moreover, the cross section of reinforcing bar is diminished, thus reducing the load-carrying capacity of the concrete member.



Photograph (1): Steps of corrosion process

The development of reliable methods for predicting chloride affect into concrete is very important to determine the service life of a reinforced concrete structure. A number of studies have been carried out to understand the effect of different percentage of chloride ions as 0.1% to 3.5% of weight of concrete mix[4],[5],[6],[7],[8],[9],[10][11],[12],[13],[14].And other research studied the behavior of reinforced concrete structure at percentage of sodium chloride up to 5% of weight of concrete mix [12],[13]. As a result of number of research, many states are switching to alternative corrosion resistant reinforcing bars by coating epoxy at normal state of salt [2],[15],[16],[17].

Reference [3] shows the behavior of R.C. beams containing different percentage of *sodium chloride (NaCl) as* (0%,1%,5% and10%) of weight of concrete mix was *studied.*

The main objective of this study is to continue this investigation. The efficiency of traditional and easy to use for workers methods of protection and repair by using epoxy coating the steel reinforcement and change the thickness of protective layer at high percentage of (NaCl) on structural behavior of R.C. beams by loading up to failure was studied.

II. EXPERIMENTAL INVESTIGATION

The test program consisted of two groups of reinforced concrete rectangular repaired beams with fixed reinforcement at different cases of epoxy coating with or without internal protective layer, and concrete constituents when exposed to four percentages of sodium chloride (NaCl) by weight of cement(S/C). In addition different corrosion time periods were considered.

The beams were tested to failure and the influence of variable factors on the structural deformation, strains of steel and concrete (compression), mass-loss of steel reinforcement and mode of failure were reported

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A. Materials

The cement used in this study is Ordinary Portland cement (OPC), the fine aggregate was dry natural sand and the coarse aggregate consisted of a mixture of rounded and crushed gravel with 20 mm maximum nominal size to give concrete mix with compressive strength equal to 300kg/cm^2 for tested beams (without any salt) as shown in Table (1).

Table (1): Concrete Mix

Composition	kg/m3 of concrete
Coarse aggregate (20 mm)	1250
Washed and dried fine aggregate	625
Cement	350
Water	162.5

Sodium chloride was used as a source of chloride ions. In order to avoid the effects of different chloride ions diffusion rates due to different captions, the salts were added to concrete by dissolving the different quantities (0%, 1%, 5%, and 10%) by weight of cement in mixing water before casting. Details of the tested beams were given in Table 2.

Table (2): Details of the test program

Group No.	Specimen No.				% NaCl of Cement Weight (s/c)	Corrosion time period
	Control model (without salts)	Models with (2Φ) internal protective layer with epoxy	Models with (4Φ) internal protective layer with epoxy	Salty model with full epoxy coated		
A	C. B. 3	-	-	-	0	12 months
	-	E. B. 2	E. B. 11	P. B. 1	1	
	-	E. B. 5	E. B. 14	P. B.3	5	
	-	E. B. 8	E. B. 17	P. B.5	10	
B	C. B. 4	-	-	-	0	18 months
	-	E. B. 3	E. B. 12	P. B. 2	1	
	-	E. B. 6	E. B. 15	P. B. 4	5	
	-	E. B. 9	E. B. 18	P. B. 6	10	

Deformed high tensile steel with 12 mm diameter was used as the main reinforcement and high tensile steel with 10 mm diameter as hangers and normal mild steel 6 mm diameters was used in shear stirrups. Full or partially Epoxy coated material was used to protect steel reinforcement with different depth of protective layer of concrete.

B. Specimens

Each rectangular beam was 100 mm * 250 mm in cross section and 1600 mm long. The internal longitudinal high strength steel reinforcement consisted of 2 ϕ 12 mm at the bottom and 2 ϕ 10 mm bars at the top of the beam as shown in Figure 1. Four different batches of concrete mixtures with different percentage of sodium chloride (NaCl) by weight of cement (S/C) of 0%, 1%, 5% and 10% were used for the construction of the two groups of beams as shown in Table 1.the epoxy protection painted with different depths (2 ϕ, 4 ϕ, full) where ϕ is the diameter of main steel reinforcement as shown in Figure (2) and photo 2. After 28 wet and dry days, the specimens were left in natural weather outside the laboratory without any curing. Groups (A& B) of concrete beams were tested after two time periods of 12 months & 18 months respectively.

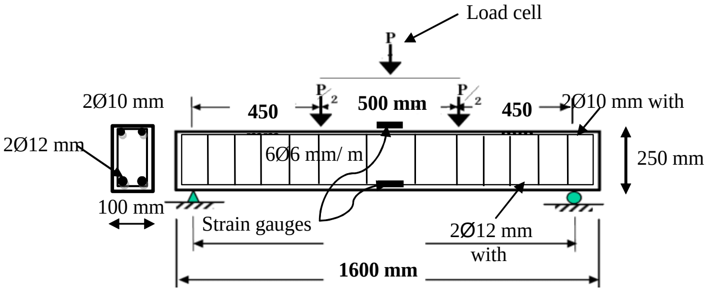


Fig (1): Set up details

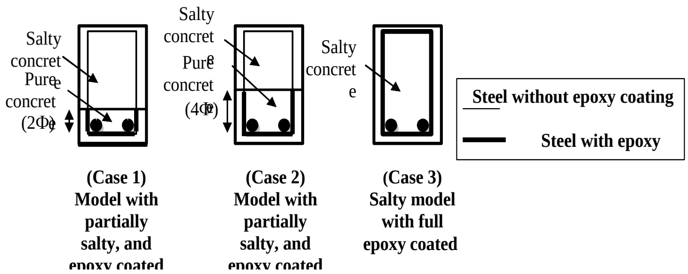
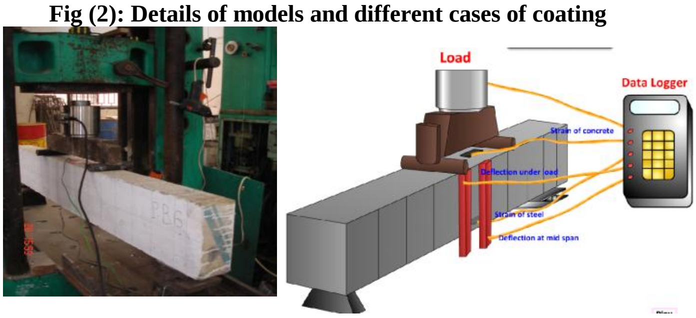


Fig (2): Details of models and different cases of coating



Photograph (2): Test setup and beam before loading

C. Items of investigation

Once repaired beams reached the target ageing (12 months & 18 months), they tested to failure. Repaired beams were test with load applied symmetrically at two points at mid-span through a spreader beam load application points near the center of the specimen were spaced 500 mm apart load was measured with load cell placed between the spreader beam and hydraulic cylinder. Displacement was measured at mid-span of the beam and underlying load section as shown in Photo 3. Concrete strain was measured using strain-gages located at the compressive face at mid-span between the load points. Strain gages were placed at mid-span on the longitudinal main steel on one side of the beam face. The test setup and its strumentation placement are shown in Figure 1 & Photo 3. After verification of data collection, the load was increased monotonically until failure, loading was suspended at 2 KN intervals to mark and measure cracks.

After testing of repaired beams, steel reinforcement (main, secondary and stirrups) was pushed out of the concrete, cleaned well to remove the rust, and then the weight of the bars was measured and compared with the steel reinforcement of the control one to calculate the percentage of mass-loss.

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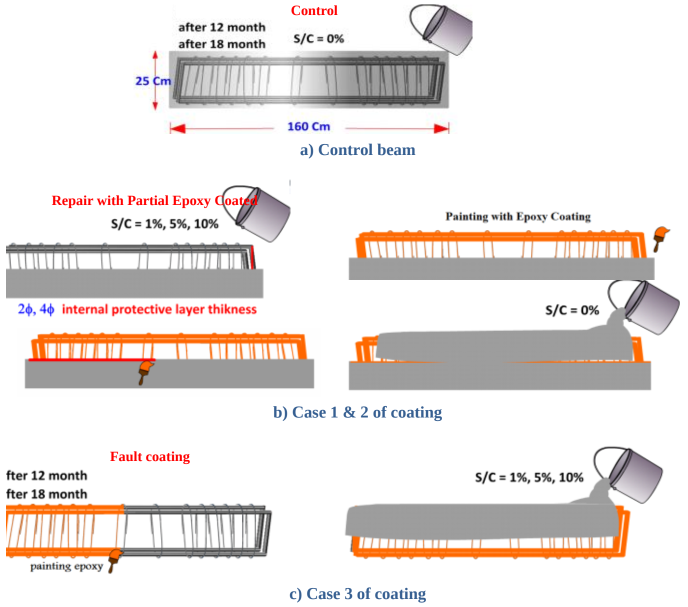
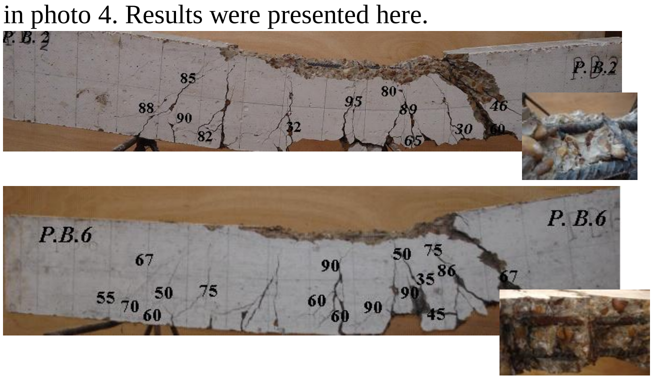


Photograph (3): Steps of repaired beams casting

III. RESULTS AND DISCUSSION

The main objective of this series of testes was to establish the effect of different protection and repair cases at different (S/C %) and ageing time periods on the structural behavior of R.C. beams. From the data obtained during the experimental program, mode of failure of models and crack pattern shown in photo 4. Results were presented here.



Photograph (4): Mode of failure of full protection models after 18 Months

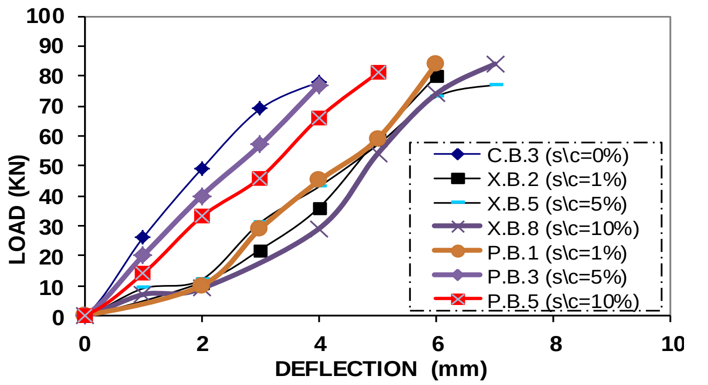


Fig (3): Effect of full protection on deflection of S/C% after 12 months

Figure (3) studies the relation between load and deflection at experimental beams (X.B.) (beams with salt as in references [1] and[3] any details show that references, and the protection beams at different S/C% after testing time equals 12 months. It shows that the full protection (Case 3) increased the stiffness and moment resistance of beam to reach about 20% more than salty one at S/C=10%, due to the effect of epoxy in decreasing the corrosion.

Figure (4) studies the relation between load and compression strain of concrete at experimental beam (X.B.5) and the protection one (P.B.3) at S/C= 5% with testing time equal 12 months; it shows that the protection decreased the maximum strain of concrete about 30% than in case of (X.B.5).

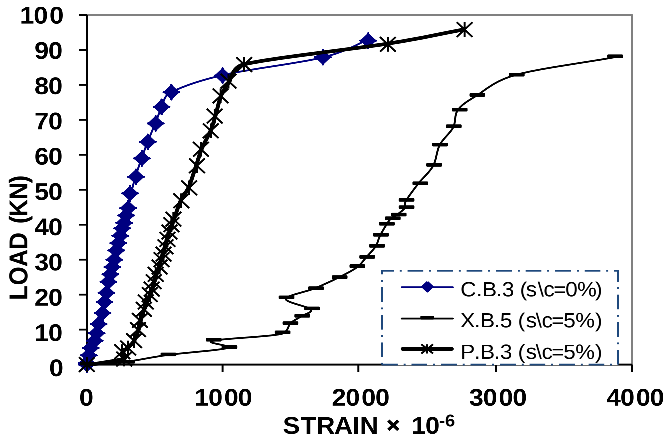


Fig (4): Effect of full protection on compression strain of concrete at S/C=5% after 12 months

Figure (5) studies the relation between percentages of salt (S/C %) and the percentages of mass-loss of steel due to corrosion at protection, and experimental beams, at S/C= 1, 5, and 10% at testing time equal 12, and 18 months. It shows that after 12 months as testing time, the increasing of salts increased mass-loss % to about 19%, however it decreased it about 37% less than experimental group at S/C=10%, and after 18 months as testing time, it is observed that the increasing of salts increased mass-loss % to be about 20%, however it decreases it about 40% less than experimental group at S/C=10% because the protection increased the resistance of steel against corrosion.

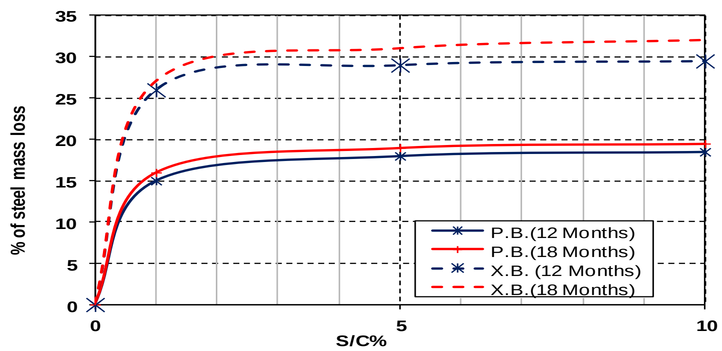


Fig (5): Effect of full protection on mass-loss at different of S/C% after 12, 18 months

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Figure (6) shows the relation between load and S/C% at control, experimental beams, and protection beams which tested after 12, and 18 months of casting. It's observed that, the protection improved the behavior of beams because the full painting of epoxy material protected reinforcement against corrosion, so it increased the capacity of failure load around 9% over than salty group in 18 months, and S/C= 10%.

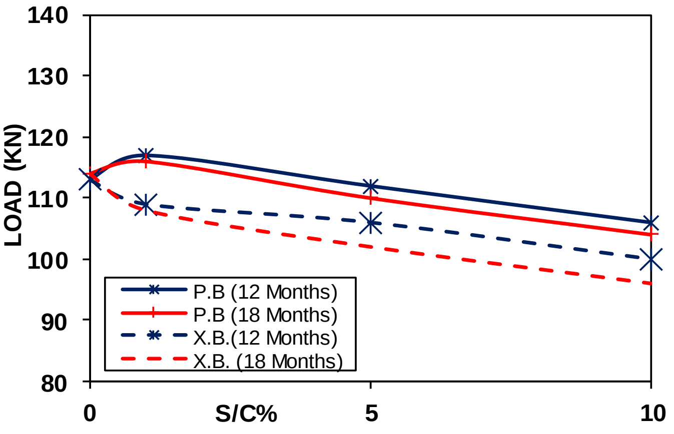

Fig (6): Effect of full protection on load capacity at different of S/C% after 12, 18 months

Figure (7) studies the relation between load and deflection at control, experimental beam (X.B.8), and epoxy repaired beam (E. B.8) at S/C= 10% with testing time equal 12 months It shows that, epoxy repair increased the moment resistance o beam about 15% over than experimental beams.

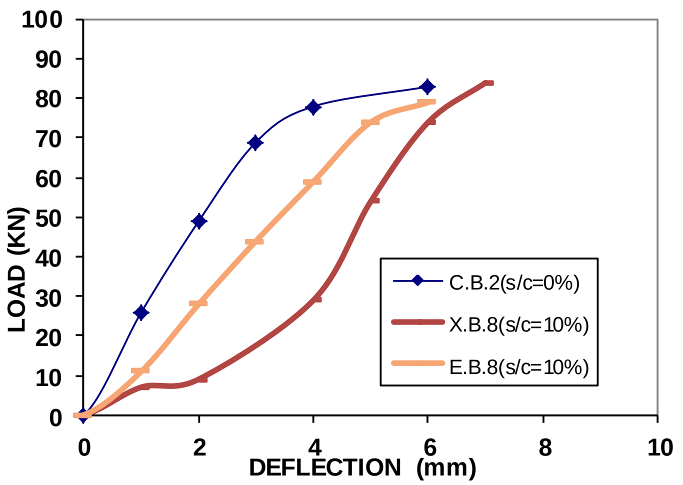

Fig (7): Effect of partially epoxy repair on deflection at height \ at S/C=10% after 12 months

Figure (8) studies the relation between load and deflection at control , experimental beam (X.B.3) and repair epoxy repair beam with 4Ø as internal protective layer (E. B.3), epoxy repair beam with 4Ø as internal protective layer (E. B.12) at S/C= 1% with testing time equal 18 months. It's observed that the increasing of epoxy depth to be 4Ø increased stiffness and moment resistance of beam about 25% over than experimental one then it became very close with E.B.3 at elastic range. However at plastic range, the increasing of epoxy depth to be 4Ø decreased the elongation by 7% less than (E.B.3).

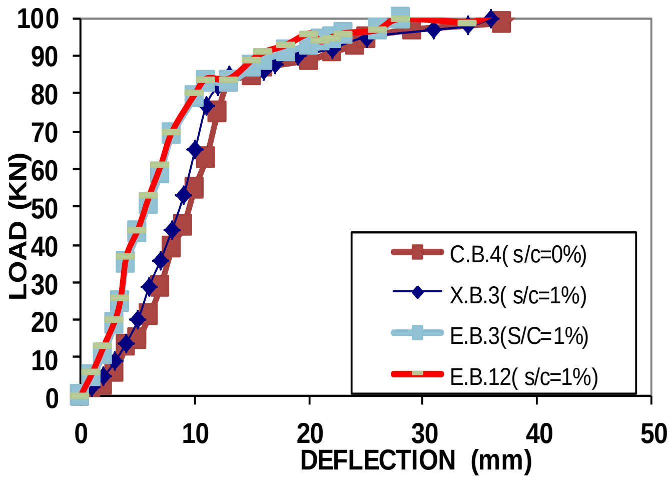

Fig (8): Effect of full and partially epoxy on deflection at different height at S/C=1% after 18 months

Figure (9) studies the relation between percentages of salt (S/C %) and the percentages of loss- mass of steel due to corrosion at repair (4Φ), and experimental beams, at S/C= 1, 5, 10% at testing time equal 12, and 18 months. It is observed that, the increasing of salts increased mass-loss % to be about 18%, however it decreases it about 44% less than experimental group at S/C=10% after 18 months

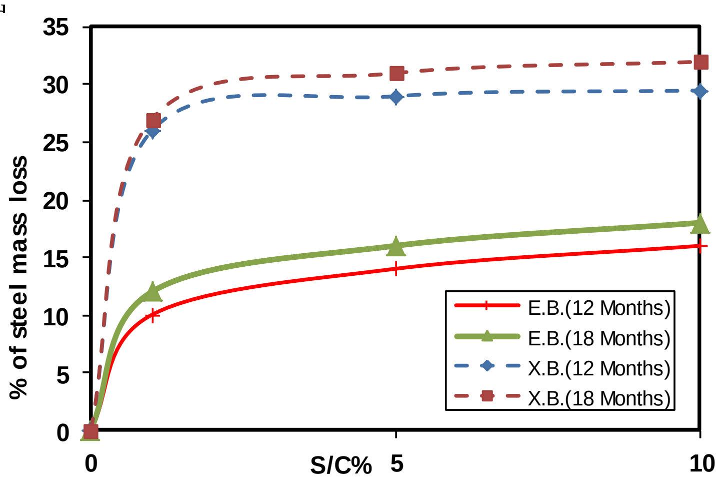

Fig (9): Effect of partially protection on mass-loss at different of S/C% after 12, 18 months

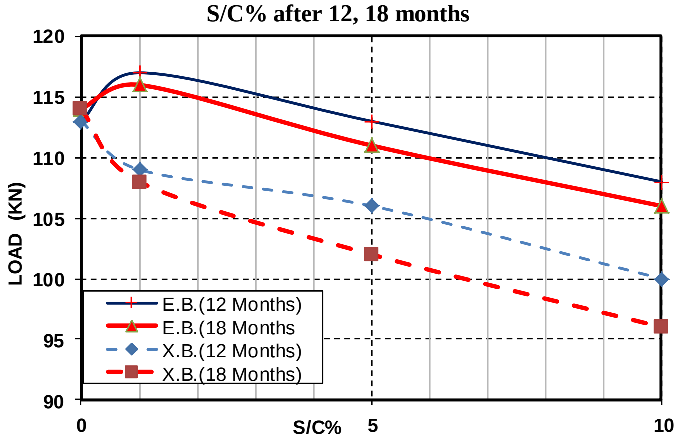

Fig (10): Effect of 4 Φ partially protection on load capacity at different of S/C% after 12, 18 months

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Figure (10) shows that, the 4Ø internal protective layer with painting epoxy increased the capacity of failure load of beams with marked values reached to about 11% over than salty beams in 18 months, S/C=10% because the internal protective layer with thick thickness increased the alkaline of concrete around bar of steel, and partial painting epoxy of steel increased the protection of main steel.

IV. CONCLUSION

1. The steel protection increased the moment resistance and stiffness of beam up to 20% more than non-protected one at S/C=10% after 12 months.
2. The steel protection had a significant effect on the strain of concrete as the time increases at S/C=5% where the both strains decreased about 30% less than non-protected beams.
3. The steel protection decreased mass-loss of steel about 40 % less than in case of non-protected beams because of increasing the steel resistance against corrosion so, it increased the capacity of failure load around 9% over than salty group at age 18 months, and S/C= 10%.
4. Increasing of epoxy depth to be 4Ø increased stiffness and moment resistance of beam about 25% over than experimental one as in refrences[1]&[3] at elastic range. However at plastic range, the increasing of epoxy depth to be 4Ø decreased the elongation by 7% less than (E.B.3).
5. The case (1) (2Ø) decreased the mass-loss of steel about 31% less than salty beams at S/C=10% after 18 months, however, it increased the capacity of failure load of beams about 7% over than salty beams. The decrease of mass-loss of steel reached 44% as the thickness of internal proactive layer increases to (4Ø), so, the failure capacity load of beams increased about 11% over than salty beams after 18 months, and S/C=10%.
6. From above conclusions, it is observed that the epoxy method of repair with internal protective layer thickness (4Ø) was the best method of repair as increase of time age.

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