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Effect of Reinforcement Corrosion on the Slab Capacity of Concrete Under Severe Conditions

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Abstract: **A program of thirty five samples starting at year 2002 was prepared with the same steel and the slabs dimension were 50 cm width 14 cm thickness and 240 cm span length, bottom steel included five bars with diameter 13 mm and top steel with 10 mm width, water to cement was 0.56 and the mixing water was with chloride concentration of 3% percent of the cement weight. All slabs were exposed to laboratory temperature, spread daily with water concentration 3% of chloride and the steel on slabs was connected to the electronic to accelerate corrosion process. Three levels of percentage corrosion were expected depending on the current passing in the circuit, some slabs were repaired and strengthened by removing the steel covers 10% corrosion at year 2002 and others (30% - 50%) at year 2004. The slabs group (L) 10% corrosion were tested at year 2004, both Group (M) with 30% corrosion and Group (R) with 50% corrosion were tested at year 2011. Five repairing and strengthening techniques were suggested, crushed stone mix (CSM), ready mixing (RM), crushed stone mixing with steel fibers (CSM+HF), crushed stone mixing steel (CSM+RS) and ready mixing with additional new reinforcing (RM+RS), which are usually used in structure maintenance. The obtained results show that the corrosion for steel was affected by maintenance process and all techniques didn't stop it totally. The mortars (CSM, CSM+F, RM) re-alkalized the areas where the contaminated concrete was removed and re-passivated the steel surface. Due to the reduction in the cross section area of main steel, the slabs had less ultimate strength and more ductility of the steel reinforcement, which results in wider resulted cracks than the other slabs strengthened with steel reinforcement. The outcome indicates that the slabs strengthened by Reinforcing Steel in both CSM and RM layers undergo to the higher load until cracks appear, that leads restoration of its efficiency of 70% to 95% depending on the degree of the corrosion rates.**

Keywords: **Re-Passivated, Corrosion, Potential, Maintenan ce, Cracks**

1. INTRODUCTION

J. SIM and I. BAE had tested 24 specimens of rectangular reinforced concrete beams with cross section of 15x25 cm, and total length of 240 cm and clear span is 200 cm. Reinforcing bars consisted of 2Ø10 mm in compression side, 2Ø13 mm in tension side and 10 mm stirrups in 10 cm spacing, the specimens are over designed in shear to avoid a brittle shear failure. Proper preparation of bonding surface between the existing concrete and repair materials is extremely important. Therefore, after 28 days of curing, the bonding surfaces of specimens were roughened using mechanical chipping. [5].

Mild steel is widely used material in domestic, industrial, transport and agriculture areas due to its low cost, easy availability and mechanical properties. The corrosion is the major problem associated with mild steel. The corrosion rate of mild steel varies with respect to the environment to which it is exposed, structure and design of the material and the physical, chemical and electrochemical factors associated with it. Corrosion reduces the service life of the system and increases the maintenance cost. There are many techniques like alloying, galvanizing, hot dip coating, electro and electrolesss plating, addition of corrosion inhibitors, cathodic protection, applying paints etc. are used for protecting mild steel. The selection of the method depends on design parameters, area of application, cost effectiveness etc. [2].

The weight gain of salt coated welded specimen follows a parabolic rate law during hot corrosion. Rate of oxidation was observed to be higher in the earlier cycles of the study in all the aforementioned environments, which may be attributed to the fact that during transient period of oxidation, the scales formed may be providing protection to the underneath metals, also in case of salt coated specimens, the surface scale is more porous and spelled out, thereby providing an easy diffusion path for the co rodents. The scale formed due to hot corrosion mainly contains Fe_2O_3 and Cr_2O_3, $NiCr_2O_4$ and $NiFe_2O_4$[1].

Lim Kar Sing has conducted field study on corrosion for a period of 12-months. All buried steel coupons were successfully retrieved and examined for weight loss. The measurement of soil resistivity has been successfully carried out throughout the study. The results show that a negative relationship exists between soil resistivity and corrosion rate. The findings were further confirmed by regression analysis which illustrates a negative logarithmic relationship as the best model to express the relationship between soil resistivity and soil corrosiveness. The results signify that the longer the exposure time, the more stable the relationship between soil resistivity and soil corrosiveness. To conclude, soil resistivity alone can serve as a general indicator to determine soil corrosivity based on potential metal loss. This may simplify the procedure of assessment during site investigation whereby speedy results can be obtained during site investigation [4].

Corrosion phenomena, including stirrup corrosion, were studied in an experimental investigation presented in this paper. High levels of corrosion reached up to 20% of the main bars and 34% of the stirrups legs. The occurrence of crack initiation, propagation, and cover delamination was examined. The specimens had the shape of a beam end and were corroded with an accelerated method; an imposed current was used, taking care to keep the current density as low as practically possible for the duration of the laboratory testing. The effects of this process were compared with those of natural corrosion using models from the literature. The location of the bar, middle and corner placement, the amount of transverse reinforcement, and the corrosion level of longitudinal reinforcement and of transverse reinforcement were studied. The results concerning the concrete cracking in the experimental campaign are presented. The crack patterns and widths were analyzed, showing differences between specimens with or without stirrups and whether stirrups were corroding the conclusions addressed the importance of taking into consideration both high corrosion levels and corrosion of stirrups for the assessment of deteriorating structures [3].

2. Experimental Work

Thirty five slabs were tested, the slabs were divided into stages with respect to the percentage of corrosion. The reduction in the cross sectional area of main steel was taken as a main factor. The slabs were divided into three groups Group (L) with the calculated rate of corrosion of 10%, Group (M) with 30% and Group (R) with 50%. The corrosion potentials were measured. Trying to limit the corrosion process in each rate of it, five repairing and strengthening techniques were suggested, crushed stone mix (CSM), ready mixing (RM), crushed stone mixing with steel fibers (CSM+HF), crushed stone mixing steel (CSM+RS) and ready mixing with additional new reinforcing (RM+RS), which are usually used in structure maintenance.

The two main used materials were crushed stone basalt size 2 and Cetorex Grout ready-mix, the other used materials were Harex Steel Fibers, Epoxies (Kemapoxy 131, Kemapoxy 104), Addibond (Add Bond 65), and Superplasticizer (Add Crete DM2) purchased from C.M.B. Corporation. The slabs were placed vertically and sheltered. Then each six slabs were connected together in parallel to an adapter turnout 12volts/150mA to an AC Power supply. The main program details and methods of repair and strengthening are shown in table 1

After the application of dynamic corrosion process, all slabs had developed cracks along the line of the bars and some hairline cracks perpendicular to them with some corrosion stained in evidence on the surface. The slabs then were opened carefully by using the hammer and nail to remove the concrete cover to a depth at the center of the reinforcement. The corrosion degree was estimated by area reduction percentage for the entire reinforcement net of each slab, Then the average value was calculated for each slab, Hence the slabs were divided into three groups low 10% corrosion was repaired year 2003, medium corrosion 30% was repaired year 2004 and high corrosion 50% 2007 General visual results of corrosion and opening of different types of slabs are shown in the figures.

Table 1.Repair and Test Program for Slabs p (L&M&H).

Expression	Description
CSM	Crushed stone mix.
CSM+RS	Crushed stone mix + Reinforcement steel; (2 # 10 mm) in group L and (3 # 10 mm) in group M&H
CSM+HF	Crushed stone mix + Hrex Fiber.
RM	Ready mix. (Cetorex Grout)
RM+RS	Ready mix. + Reinforcement steel; (2 # 10 mm) in group L and (3 # 10 mm) in group M&H

L:Low corrosion 10% M:Med. corrosion 30%
H:High corrosion 50%

3. Results

1-Results Of Groups (L, M And H)

All Slabs, which were repaired and strengthened with Crushed Stone Basalt Mix 2.5cm, Ready Mix 2.5cm and Crushed Stone Basalt Mix +Fibers 2.5cm didn't show any scaling, nor rust stain; they had a good appearance after repair. The results show some differences in the two main performances of the anodic potentials of the repairing systems of group M; the slabs in each repairing and strengthening system had the same behavior with a small difference of not more than 40 mv, and all of them had low anodic potentials than the slabs without repair. The following figures describe the variation of the potentials with the time for the average values of all measurements and comparison deflections under static loading for each strengthening and repairing system (CSM, RM, CSM + F) and slab without repairing as shown in fig. 1 and fig.2 for group (L) 10% corrosion.

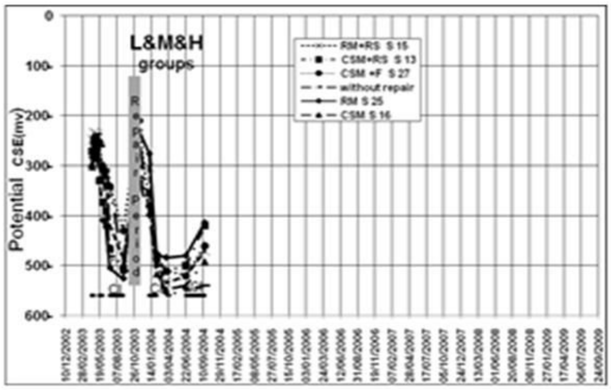

Fig.1.Variation potential values of steel with time for slabs group (L)

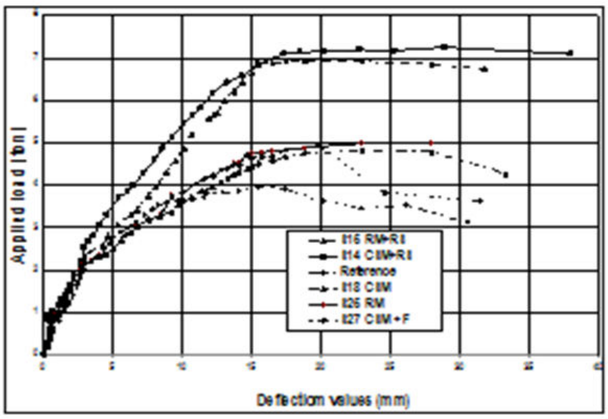

Fig.2. Comparison Deflections under static loading group (L)

Figures, describe the variation of the potentials with the time for the average values of all measurements and comparison deflections under static loading for each strengthening and repairing system (CSM, RM, CSM + F) and slab without repairing as shown in fig. 3 and fig.4 for group (M) 30% corrosion.

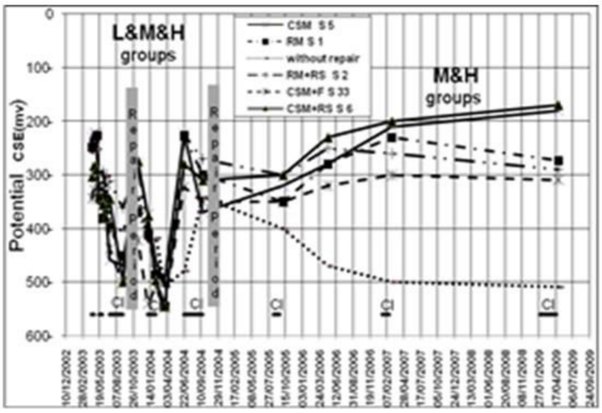

Fig.3. Variation potential values of steel with time for slabs group(M)

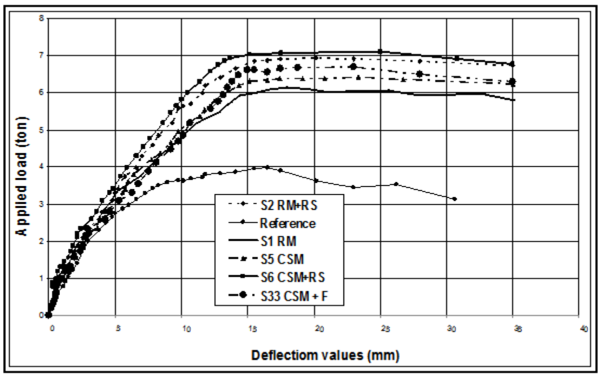

Fig.4. Comparison Deflections under static loading group (M)

Figures, describe the variation of the potentials with the time for the average values of all measurements and comparison deflections under static loading for each strengthening and repairing system (CSM, RM, CSM + F) and slab without repairing as shown in fig. 5 and fig.6 for group (H) 50% corrosion.

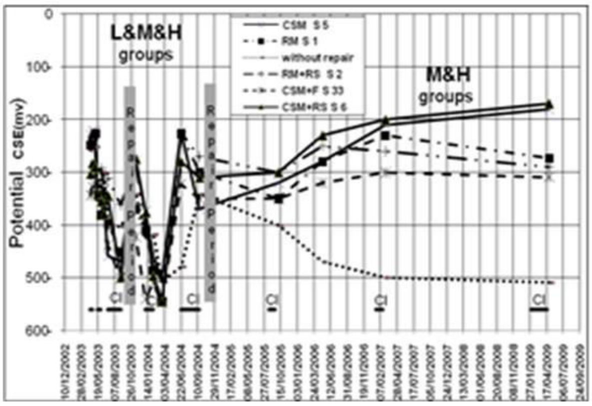

Fig.5. Variation potential values of steel with time for slabs group(H)

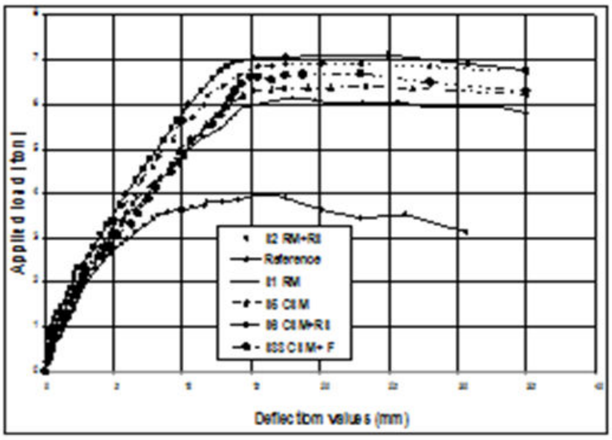

Fig.6. Comparison Deflections under static loading group (H).

The efficiency of the different repairing and strengthening systems can be evaluated directly by comparing the repaired and strengthened slabs with respect to the original slab S0. The maximum measured values of deflection corresponding to the point of maximum deflection along the slab span at cracking load (δcr.) and at 0.85 of ultimate load (δu) and the values of ratios of cracking and ultimate deflections of tested slabs (δcr / δu) are given in table 2 for all the tested slabs.

Table (2) shows in tabled data the comparison at different load stages.

Slab No.	S15 - L	S2 - M	S25 - L	S24 - H	S1 - M	S33 - M	S27 - L	S20 - H	S17 - H	S14 - L	S6 - M	S19 - H	S18 - L	S5 - M	S0 Ref	S23 - H
Repair system	RM RS	RM+RS	RM	RM	RM	CSM+F	CSM+F	CSM+F	CSM+RS	CSM+RS	CSM+RS	CSM	CSM	CSM	-	RM+RS
P_{cr} (ton)	3.0	2.4	2.1	3.0	2.0	2.6	2.2	2.5	2.5	3.7	2.5	2.5	2.3	2.3	1.3	2.5
P_u (ton)	6.9	6.95	5.0	6.8	6.2	6.5	5.0	7.5	7.9	7.2	7.2	7.5	4.9	6.3	4.0	7.6
δ_{cr} (mm)	4.8	2.4	2.5	2.8	2.1	2.7	2.5	2.7	2.5	5.1	2.5	2.8	2.7	2.2	2.0	2.9
δ_u (mm)	24.0	20.0	23.0	20.0	18.0	27.0	23.0	20.0	33.0	28.0	25.0	18.0	25.0	27.0	17.0	18.0
$\delta_{Failure}$ (mm)	33.54	35.00	28.60	35.00	35.00	35.00	32.00	35.00	35.00	38.54	35.00	35.00	32.52	35.00	32.22	35.00
δ_u/δ_{cr}	5.0	8.33	9.2	7.14	8.6	10.0	9.2	7.4	13.2	5.49	10.0	6.42	9.25	12.2	8.5	6.2
P_{cr}/P_u	0.438	0.345	0.42	0.4410	0.523	0.400	0.440	0.333	0.316	0.514	0.347	0.333	0.469	0.365	0.325	0.329

4. Conclusion

From the previous comparisons and analysis we can conclude the following:

A. Repair efficiency of group L under corrosion process

1. The mortars (CSM, CSM+F, RM) re-alkalized the areas where the contaminated concrete was removed and protected the steel against further corrosion for the small period.
2. The RM repair system showed the least amount of corrosion and a moderate effectiveness to prevent further corrosion than the other systems with more than 90 percent efficiency.
3. The CSM repair system showed sensible effectiveness to prevent further corrosion with efficiency of about 40 percent.
4. The repair system CSM+F is less in growth of cracks with efficiency of 40 percent.

B. Repair efficiency of group M&H under corrosion process

1. The mortars (CSM, CSM+F, RM) re-alkalized the areas where the contaminated concrete was removed and re-passivated the steel surface.
2. The results obtained within the first few months of exposure after repair indicated more than 95 percent efficiency of no corrosion activity for all specimens of group M.
3. With the high chloride content in old concrete, all repair systems decreased the rate of corrosion, however the best one was the RM.
4. The CSM+F could reach a reasonable degree of preservation with increasing the thickness of its repairing layer.
5. These results change significantly as the exposure time increases. A highly permeable concrete mix, numerous flexural cracks, low cover, and cast-in chlorides increase the rate of oxidation.Also, the crushed Stone Mix past showed less reaction with only slight effectiveness to prevent futher chloride penetration through the Crushed Stone Mix layers to the old concrete, while the repair system Crushed Stone Mix with Steel Fibers is less in growth of cracks.

C. The general comparison for systems (L, M&H) under static load

1. System slabs repaired with RM, CSM and CSM+FDue to the big contact between the old concrete and both the RM, CSM and CSM+F and decrease of the included shear stress in the contact layer between old concrete and RM, CSM and CSM+F, there are no more significant differences in the behavior under static load test, except a slight decrease in ultimate strength which is due to the small thickness of this layer and the reduction in the cross section area of main steel due to static load test, except a slight decrease in ultimate strength due to the corrosion rate, that leads to both the two systems CSM and RM restoring its strength by range 50% to 60% depending on reduction in the cross section area of main steel and also the main distinct differences that can be observed here with the higher value of (Pcr/Pu) for the CSM+F layer with low corrosion rate as shown in table 2 and its narrower crack widths than the other slabs, which were repaired with RM or CSM.
2. System Slabs Strengthened with Reinforcing Steel Due to the reduction in the cross section area of main steel, the slabs wider have less ultimate strength and more ductility of the steel reinforcement which results in wide cracks than the other slabs strengthened with steel reinforcement. The results show that the slabs strengthened by Reinforcing Steel in both CSM and RM layers undergo to the higher load until cracks appear, that leads to the restoration of its efficiency of 70% to 95% depending on the degree of the corrosion rates.

5. References

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