Seismic Behavior of Low Strength RC Columns with Corroded Plain Reinforcing Bars

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ABSTRACT :

One of the major issues of construction industry is the rehabilitation of the old and deteriorating stock of structures. Corrosion of reinforcing bars and the resultant cracks of concrete members are among the most common reasons of damage that require repairing, particularly in humid environments and/or where quality of concrete is relatively low. Corrosion of reinforcement and related losses in strength and bond between concrete and reinforcing bars may increase the seismic vulnerability of existing reinforced concrete structures significantly. This paper reports the preliminary results of an experimental study on the seismic behavior of low strength reinforced concrete columns with corroded plain reinforcing bars. The specimens represent typical low strength rc columns in Turkey and many other developing countries. The specimens with plain longitudinal and transverse bars had an average concrete compressive strength less than 10 MPa, as well as insufficient amount of transverse bars in the potential plastic hinge regions. After casting, during which 4% calcium chloride was added in the mixture, the columns were subjected to accelerated corrosion process through application of electrical current. Finally, the specimens were tested under constant axial load and reversed cyclic flexure at three different levels of corrosion, as well as no corrosion case. Based on the results of the experimental study, it was understood that the corrosion of reinforcing bars effected the behavior of the low strength reinforced concrete columns significantly, particularly due to the condition of bond between concrete and steel reinforcement. It should be noted that the bond strength was already low in no corrosion case due to low quality of concrete and plain surfaces of reinforcing bars.

KEYWORDS: bond, column, corrosion, cyclic, seismic, reinforced concrete

1. INTRODUCTION

The corrosion of materials, especially reinforcing steel in concrete has received increasing attention in recent years because of its widespread occurrence in certain types of structures and the high cost of repairing. Concrete normally provides reinforcing steel a film that passivates the steel and protects it from corrosion by creating highly alkaline environment. Exposure of rc to chloride ions is the major cause of corrosion. As the solid products of corrosion occupy a greater volume than the original steel and exert substantial expansive stresses on the surrounding concrete, deterioriation of concrete due to corrosion of the reinforcement occurs. Concurrently the cross-sectional area of the reinforcement is reduced and the loss of bond between steel and concrete is observed (ACI-222R-01, 2001). Limited number of studies on the behavior and retrofitting of corrosion damaged rc columns exist in the literature. Pantazopoulou et al. (2001) examined the performance and efficiency of jacketing of corrosion damaged reinforced concrete columns with FRP wraps as an alternative to conventional repair methods. A parametric study was conducted on several small scale columns which were subjected to accelerated corrosion with different reinforcement configurations. The performance and efficiency of jacketing with FRP wraps was markedly improved when increasing number of FRP layers were used in the jacket. Bousias et al. (2002) studied the contribution of the FRP jacketing for enhancing the deformation capacity of RC columns with corroded reinforcement. According to their findings, FRP wrapping of columns without earthquake resistant detailing and with corroded reinforcement did not improve strength but increased deformation capacity.

This study focuses on the effects of corrosion level on the performance of rc columns under constant axial load and reversed cyclic bending effects. The compressive strength of concrete used in the construction of the columns was less than 10 MPa. The lap splice length of longitudinal reinforcement at the column-foundation interface was 40 times the diameter of longitudinal bars. The columns were subjected to constant axial load corresponding to 50% of column axial load capacity. The tests were carried out on non-corroded specimens as well as specimens with two varying level of reinforcement corrosion. The test results are evaluated in terms of damage pattern, load-displacement hysteresis curves, energy dissipation capacities, as well as bond between reinforcing bars and concrete.

2. EXPERIMENTAL STUDY

2.1. Test Specimens

Three rectangular columns were cast with cross-section dimensions of 200×300 mm. The height of all columns were 1400 mm and the columns were supported by a foundation of size 700×700×500 mm.

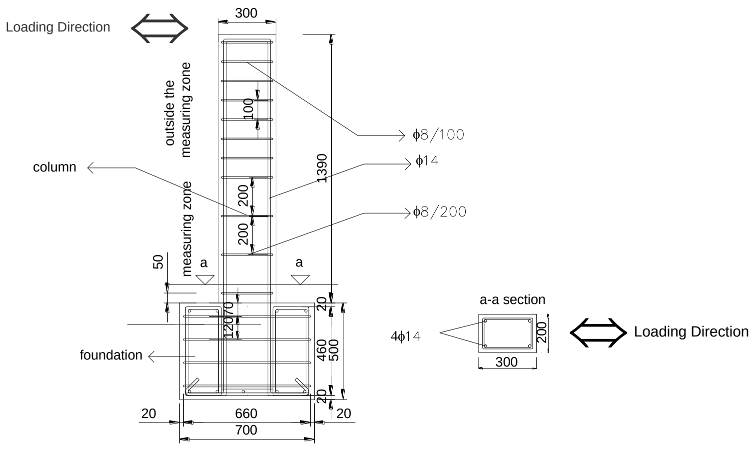

Figure 1 The reinforcing cage of the specimens

Specimens were named with the first and second letters symbolizing low strength concrete (LS), the third and fourth characters denote the level of corrosion (C0, C1, C2). LS-C0 was the specimen with no corrosion. LS-C1 was subjected to accelerated corrosion for two weeks while LS-C2 was for fifteen weeks.

The reinforcing cage is shown in Figure 1. The geometric longitudinal steel reinforcement ratio was 1 % with four 14 mm bars. Clear cover was 20 mm from the transverse bar. To prevent damage of the concrete, transverse reinforcement spacing was reduced at the top of the columns where the axial and lateral loads were applied. The spacing of the transverse reinforcement in measuring zone was 200 mm to represent existing columns with insufficient transverse reinforcement at the potential plastic hinging zone.

2.2. Material Properties

2.2.1. Concrete

In order to determine the mechanical characteristics of the concrete, standard cylinders were prepared and cured under similar conditions like columns. These standard cylinders of 150×300 mm were tested under compression at various ages. At each test age, at least 3 specimens were tested. The 28 day compressive strength of concrete was around 5 MPa. The composition of materials used in concrete mix is shown in Table 1. This type of mix was used to represent typical low strength structural components in Turkey.

Table 1 Composition of materials used in concrete mix (kg/m^3)

Material	Proportions
Cement (CEM2 42.5R)	200
Water	200
$CaCl_2$	8
Crushed sand (0–3 mm)	674
Crushed sand (0–5 mm)	578
No.1 Aggregate (5 – 12 mm)	674

The average compresive strength and elasticity modulus versus time relationships are shown in Figure 2. The 28 day compressive strength of the concrete used in the foundations of columns was 28 MPa. The foundation was designed according to current design codes to prevent damage in foundations.

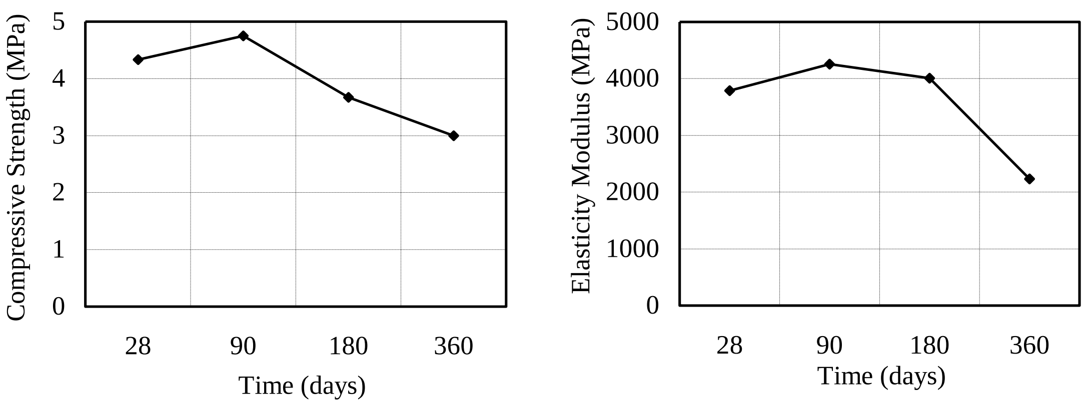

Figure 2 The compresive strength and elasticity modulus of the concrete cylinders versus time

2.2.2. Reinforcement

Three different types of reinforcing bars were used: S220 plain bars with a diameter of 14 mm which had a yield strength of 352 MPa used as longitudinal bars, S220 plain bars with a diameter of 8 mm which had a yield strength of 378 MPa used as transverse bars, S420 deformed bars with a diameter of 16 mm used in the foundation. The stress-strain behavior of the reinforcement is shown in Figure 3.

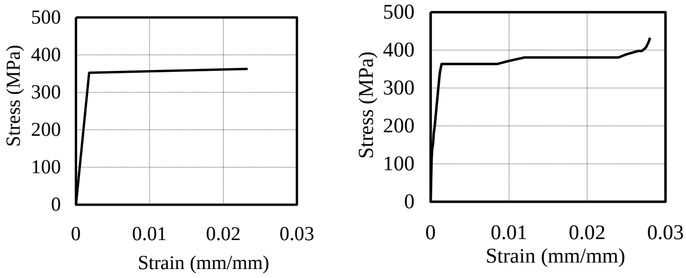

Figure 3 The stress-strain relationships of the S220(ϕ14) and S220(ϕ8) bars

2.3. Accelerated Corrosion

For accelerated corrosion, calcium chloride was added in the mixing water during concrete casting. The weight of calcium chloride was 4% of cement weight. After casting, to increase the corrosion rate even more, calcium chloride solution was sprayed from the outer sides of the specimens and a fixed potential of 6 Volts was applied. During accelerated corrosion, the longitudinal reinforcement was connected to a power supply so as to behave as the anode of the electrochemical corrosion cell. The cathode is provided by the steel mesh wrapped around the column. The corrosion potential and rate values were measured with certain time intervals by Gecor8 corrosionmeter using linear polarization and half-cell potential methods. According to ASTM-C876 (1999), the corrosion potentials higher than -500 mV is considered as severe corrosion risk, between -500 mV and -350 mV as high corrosion risk, between -350 mV and -200 mV as medium corrosion risk and lower than -200 mV as low corrosion risk. The corrosion potential values of LS-C0, LS-C1 and LS-C2 are -75 mV, -460 mV and -475 mV, respectively. It should be noted that LS-C0 was the specimen with no corrosion. LS-C1 was subjected to accelerated corrosion for two weeks while LS-C2 was for fifteen weeks.

2.4. Instrumentation, Test Setup and Testing Procedure

The experimental test setup is shown in Figure 4. The transverse load was applied at the tip of the specimen, approximately at 1200 mm height from the base of the column with a MTS hydraulic actuator of 250 kN capacity. An axial load of 124 kN was applied through a jack from the top of the column. The specimens were tested under constant axial load and reversed cyclic flexure at three different levels of corrosion, as well as no corrosion case. The loading history was composed of excursions at certain drift ratios for pulling and pushing cycles.

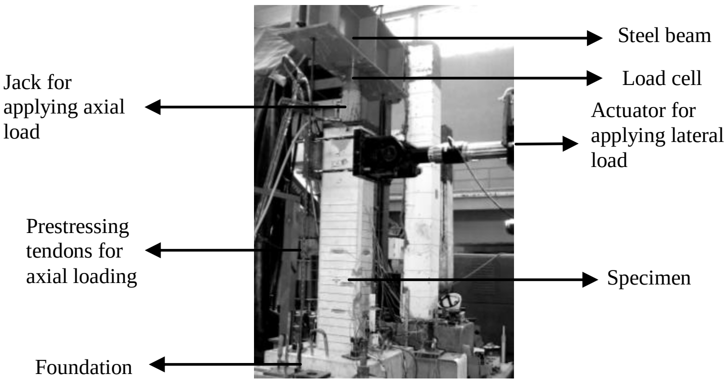

Figure 4 Experimental setup

The instrumentation details of the specimens are shown in Figure 5. Six linear variable differential transducers (LVDTs) were placed between the top of the footing and three levels of the column above the base. Ten electrical straingages were bonded on the longitudinal and transverse bars and four of them were placed on the surface of the concrete, which were on the same alignment as the transverse bars.

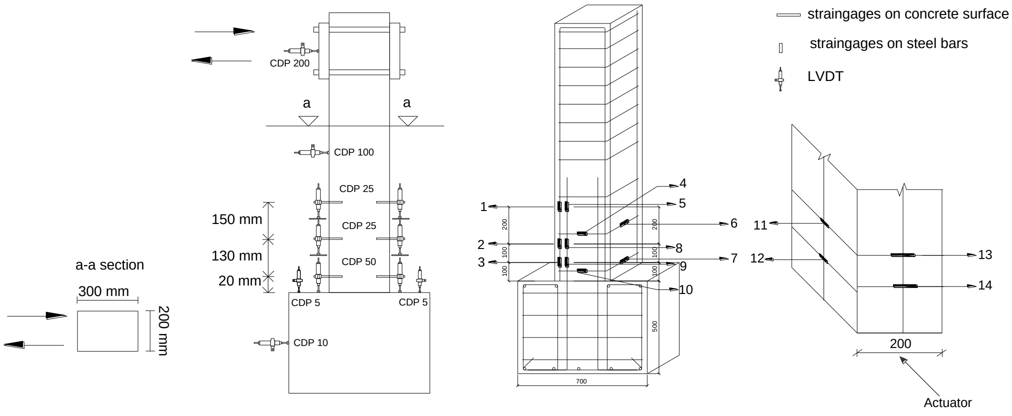

Figure 5 Instrumentation details of the specimens

3. TEST RESULTS

Force-displacement curves for specimens LS-C0, LS-C1 and LS-C2 are shown in Figures 6, 7 and 8, respectively. Reference specimen, LS-C0, reached maximum load capacity at 42 mm (0.035 drift ratio), LS-C1 at 7.2 mm (0.006 drift ratio) and LS-C2 at 18 mm (0.015 drift ratio). As seen in Figures 6, 7 and 8 at -48 mm (-0.04 drift ratio), LS-C0 had 15%, LS-C1 had 25% and LS-C2 had 67% strength loss with respect to maximum load. The cyclic behavior of the columns was dominated by flexure. It should be noted that none of the specimens could reach their theoretical flexural strengths (≈31 kN) and experienced strength degradation due to loss of bond at the lap splices of longitudinal bars. Although the main cause of strength degradation was loss of bond, the higher amount of corrosion caused a reduction in strength as well as ductility. While the gradual decrease of strength with increasing corrosion may be attributed to the loss of effective cross-sectional area of longitudinal bars, the increase in rate of loss of strength with increasing corrosion level may be due to the higher damaging effect of rusted reinforcement on low strength concrete due to displacement reversals. The envelopes of load-displacement curves and the variation of ratios of residual plastic displacements (δ_{res}) to the displacement at which unloading began (δ_{un}) with respect to drift ratios are presented in Figure 9.

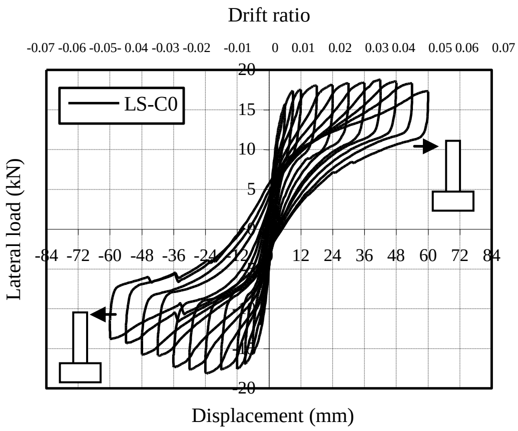

Figure 6 Force-displacement curves for specimen LS-C0

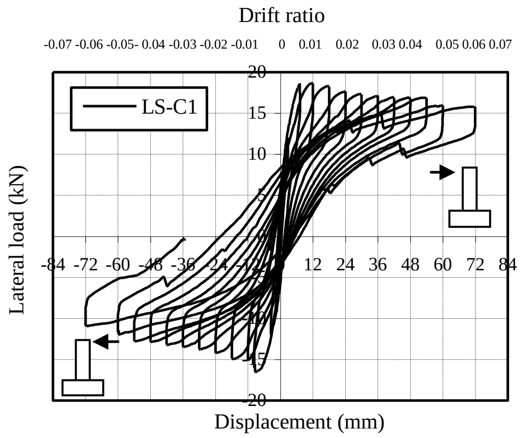

Figure 7 Force-displacement curves for specimen LS-C1

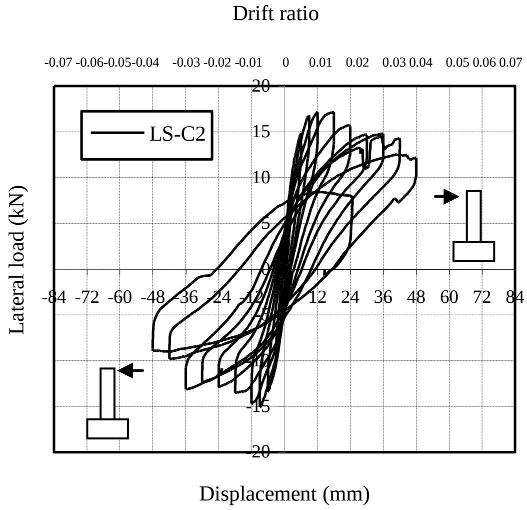

Figure 8 Force-displacement curves for specimen LS-C2

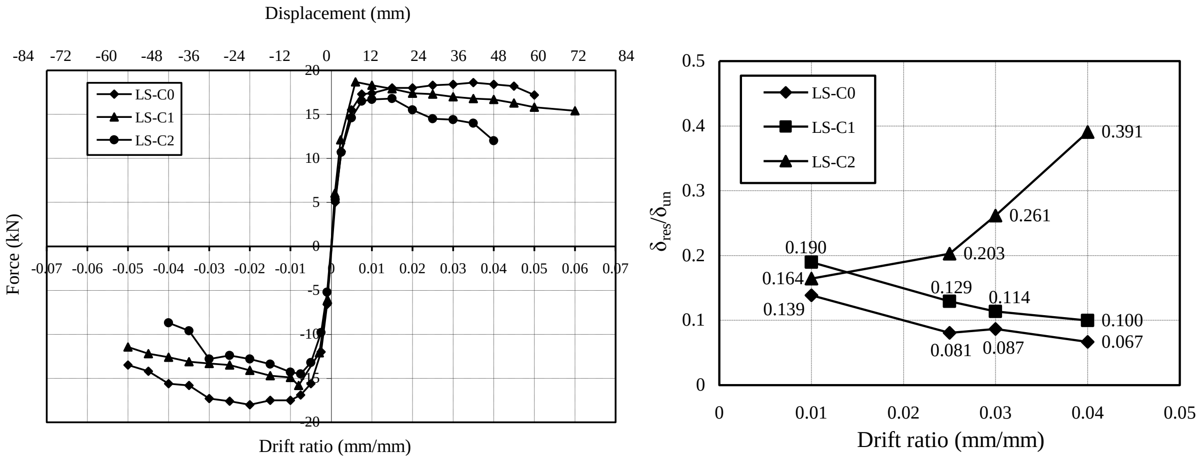

Figure 9 Force versus drift ratio and the variation of residual displacement for all specimens

As seen in Figure 9, δ_{res}/δ_{un} ratios for specimens LS-C0 and LS-C1 decreased with increasing drift ratios, while δ_{res}/δ_{un} ratios for specimens LS-C2 increased. The increase in residual plastic displacements are also related to the higher damaging effect of corroded reinforcing bars on low strength concrete with displacement reversals, which also is believed to play an important role on relatively steeper post peak branch of load-displacement envelope. The variation of axial strains of longitudinal bars at different locations is presented in Figure 10. These strain values are measured at the drift ratios of ±0.02. As seen in this figure, due to effect of slip, the reinforcing bars are not stressed remarkably in the case of specimen LS-C0 without corrosion and LS-C1 with minimal corrosion. However, the strains were higher in case of specimen LS-C2 with more corroded reinforcing bars. It is interesting to note that inspite higher axial strains measured on the longitudinal bars of specimen LS-C2, its strength was not higher than LS-C0 and LS-C1. This may be due to variation of axial strain and stresses of longitudinal bars throughout the height and section due to non-uniform level of corrosion.

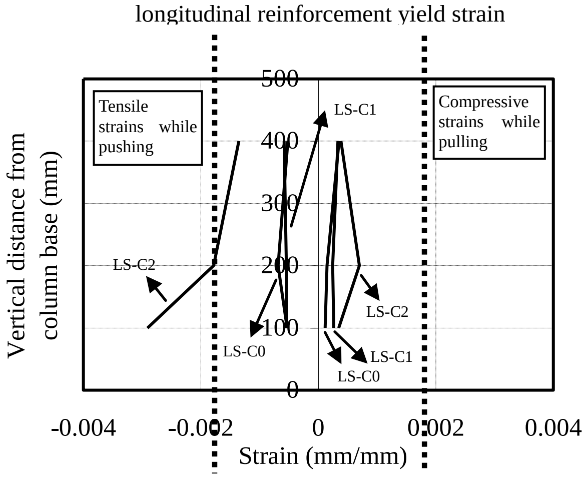

Figure 10 Strain distribution of longitudinal reinforcement

The curvature values of the column measured in 300 mm gage length above the foundation are in the order of 10^{-5} (1/mm), while the curvatures measured in 20 mm gage length are in the order of 10^{-3} (1/mm). According to Figure 11, it is of great interest to note that the damage is accumulated especially in 20 mm high zone of the column from top of the base according to the moment-curvature relationships of all specimens. Damage was not distributed over a certain plastic hinge length but accumulated at the interface of the column and foundation. The damage mechanisms of each specimen are shown in Figure 12. As it can be seen from this figure, supporting the measurements in Figure 11, the bending cracks mainly occurred in the column-foundation interface. In all specimens it is possible to observe vertical cracks initiated at the tips of the lap spliced bars. It should be noted that the concrete cover spalling was also observed for all specimens (at drift ratios of 0.035, 0.03 and 0.025 for specimens LS-C0, LS-C1 and LS-C2, respectively).

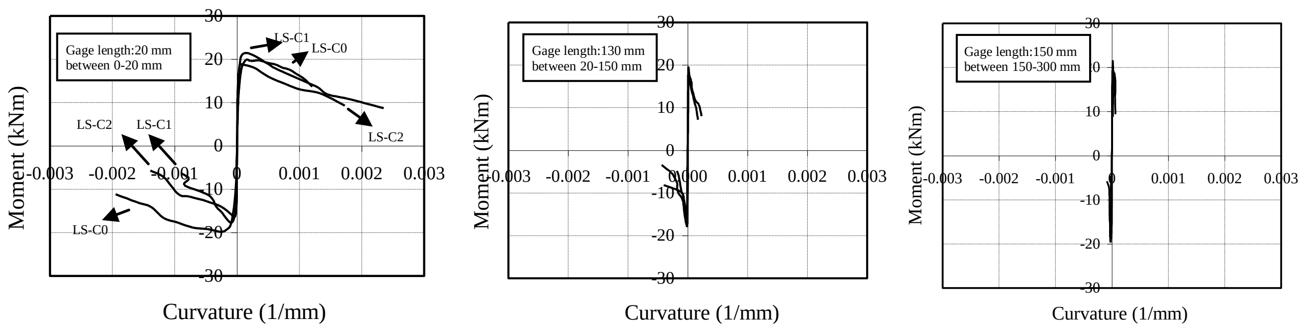

Figure 11 Moment-curvature relationships obtained in different gage lengths

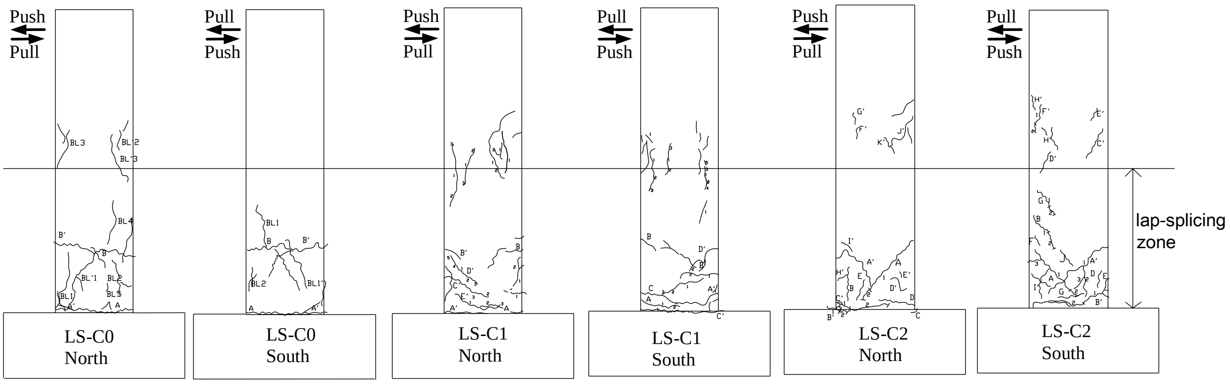

Figure 12 Damage mechanisms of specimens

4. CONCLUSIONS

Three cantilever columns were tested under constant axial load and reversed cyclic lateral loads. All specimens were constructed using low strength concrete and plain reinforcing bars and with insufficient lap splices at column-foundation connection. One of the specimens was reference specimen while two of them were subjected to different levels of accelerated corrosion. They were tested to failure and the performances of these columns were studied through their strength, deformation capacity, strain distribution and failure mode characteristics. While all specimens failed prematurely due to loss of bond, the strength and ductility of reference specimen without corrosion was slightly higher than the specimens with corroded reinforcement. The reference specimen reached maximum load capacity at higher drift ratios with respect to specimens with corroded reinforcement and survived without a strength loss until relatively larger drift ratios. It was observed that the curvatures and the damages were accumulated in the column-base connection for all corrosion levels due to loss of bond between plain reinforcing bars and low strength concrete. These findings are deemed as valuable information while deciding retrofit strategies for such weak existing structural members.

ACKNOWLEDGEMENTS

Financial contributions of the Scientific and Technological Research Council of Turkey and Telateks Textile Company are acknowledged. The authors appreciate the assistance of staff of Structural and Earthquake Engineering Laboratory and Material Laboratory of Istanbul Technical University.

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