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Comparative Study of Behaviors of Repaired and Strengthened or Strengthened R/C Plates by Using Different Techniques

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Abstract: The main purpose of this study is to comparatively study the behaviors of R/C plates under uniform loads that are repaired and strengthened with special techniques. The results that were obtained from experiments made on these repaired and strengthened R/C plates are given and by examining these results the effectiveness of the used methods were compared in terms of their relative loads/displacements, reductions in stiffness, ductility and energy absorption capacities. The obtained results show that, the plates that are repaired and/or strengthened from bottom have better behaviors of strength, stiffness and ductility as compared to those repaired and strengthened from the top.

Key words: RC plates · Repairing · Strengthening · Comparative study

INTRODUCTION

As known, repairing and strengthening of constructions are necessary for several reasons. Repairing is applied to damaged structures where as strengthening is applied to both damaged and undamaged structures [1]. Damages occur due to design (location selection, system selection, identification of loads, constructional solution, section calculations and inspection), construction (application) and usage mistakes and uncertainties [1, 2]. Defining which of these uncertainties and mistakes are more effective is a hard job even for the specialists. However, although no mistakes are made, it is priory accepted in both foreign and Turkish earthquake regulations that damages can occur after big earthquakes [1, 3]. It should be noted that dimensioning the structures in a way that they will not have any damages in these kinds of earthquakes would not be economical except for very unique engineering structures as well as not being realistic since human beings have more important necessities other than building constructions that can suffer big earthquakes.

It is known that in the active earthquake zones of the world plenty of earthquakes had happened throughout the history and they will continue to happen according to the science of earthquake engineering [3, 4, 5]. For this reason, in Turkey and countries like Turkey that are located in active earthquake zones, it is very important to repair the damages caused by earthquakes as well as other causes and to strengthen/repair the structures that are not as strong as they should be according to the earthquake regulations [2, 4, 5].

In this paper in order to contribute to the available information, the experimental behaviors of R/C plates that are repaired and/or strengthened with various techniques are compared and by discussing the obtained results some conclusions and advices are given.

Experimental Work: The series of basic plates (BP), underside-strengthened plates (UNSP), upperside-strengthened plates (UPSP), underside-repaired and strengthened plates (UNRSP), upperside-repaired and strengthened plates (UPRSP) and comparing plates (CP) are tested in experimental study.

Material Properties: Cement used in production of test plates is CEM II/A-T [6]. Physical properties of aggregates used in concrete are summarized in Table 1, mechanical properties are summarized in Table 2 and gradation of aggregate is shown in Table 3 [7-10]. A super plasticizer (Rhebuild 1000) of sulfonated, naphthalene formaldehyde dissolved in water was used in dosage

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Table 1: Physical Properties of Aggregate

Aggregate	Loose Density (kg/m^3)	Specific Weight (kg/m^3) Dry	Specific Weight (kg/m^3) Wet	Water Absorption (%)
Coarse (>4 mm)	1400	2658	2670	0,42
Fine (<4 mm)	1450	2626	2640	0,52
Equivalent Sand	95			

Table 2: Mechanical Properties of Aggregate

Average Compression Strength (MPa)	Standard Deviation (MPa)	Characteristic Compression Strength (MPa)	Elastic Modulus (MPa)	Poisson Rate
73,4	3,2	69,3	60000	0,17

Table 3: Gradation of Aggregate

Gradation Limits	Weight Rate (%)
< 1mm	25
1,00 mm -2,00 mm	15
2,00 mm -4,00 mm	25
4,00 mm -8,00 mm	35

between 1 % by weight of total cementations' material as an admixture during mixing of fresh concrete. The combined water of consistency decreased strength of the hardened cement pastes were increased at all ages of hydration [11].

Flyash is defined in Cement and Concrete Terminology (ACI Committee 116) as "the finely divided residue resulting from the combustion of ground or powdered coal, which is transported from the firebox through the boiler by flue gases." Flyash is a by-product of coal-fired electric generating plants [12].

According to tensile experiments done on steel samples used in test plates as reinforcement, tensile strength of steel is 366 MPa [13].

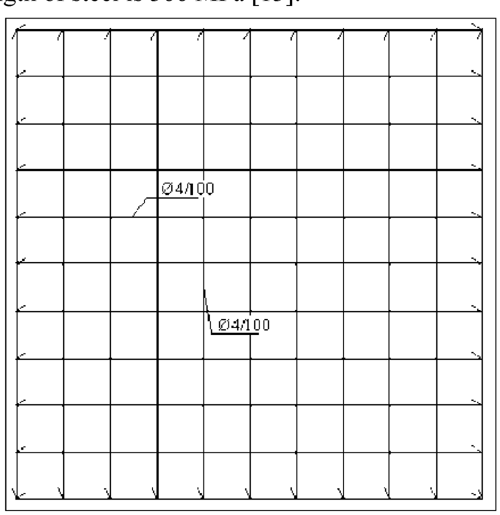


Fig. 1: Reinforcement Plan of Test Plates

Test Plates (BP, UNSP, UPSP, UNRSP, UPRSP, CP): Test plates are produced with 1050x1050 mm dimensions to use existing tools and equipments in Karadeniz Technical University Construction and Material Laboratory Test Plate series, their symbols and reinforcements are summarized in Table 4, cross-section details are shown in Table 5, Reinforcement plan is shown Figure 1, composition of concrete is shown in Table 6 and mechanical and physical properties of concrete is shown in Table 7.

Formworks assembled to vibratory table have been used in production of plates and concrete cover was 1 cm. A day later from the concrete casting, formworks were removed and plates were kept at 21°C ± 2°C and %70 ± %5 relative humidity.

Repairing and Strengthening Methods of Test Plates

Production of UNSRP and UNSP: For the production of UNSRP, Basic Plates (BP) were damaged by loading at midpoint and one day after that, deflection of plates was recovered by loading reverse side. After that, concrete cover on the underside of basic plates was removed up to the tension steel. The concrete surface was cleaned by washing with a brush and water. For the purpose of repairing, cracks were filled with grout. And also reinforcements were placed and concrete was poured at 40 mm height (thickness) with the goal of strengthening the plates. It is note that epoxy resin was used to obtain the maximum adherence at old and new concrete interface. However for the production of UNSP, concrete cover on the underside of undamaged basic plates was removed up to the tension steel. In a similar way concrete surface was cleaned by washing with a brush and water, reinforcements were placed concrete was poured at 40 mm height and epoxy resin was used to obtain the maximum adherence at old and new concrete interface (Table 5).

Table 4: Test Plate Series and Their Reinforcements

Test Plate Series	Symbol	Reinforcement
Basic Plate	BP	Φ4/100
Underside-Strengthened Plates	UNSP	2 X Φ4/100
Upperside-Strengthened Plates	UPSP	2 X Φ4/100
Underside-Repaired and Strengthened Plates	UNRSP	2 X Φ4/100
Upperside-Repaired and Strengthened Plates	UPRSP	2 X Φ4/100
Comparing Plate	CP	2 X Φ4/100

Table 5: Cross-sections of Test Plates

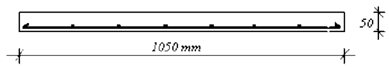
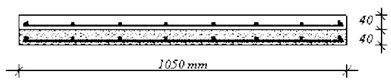
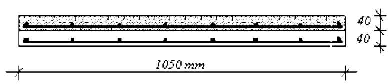
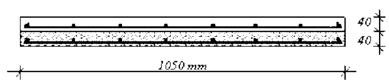
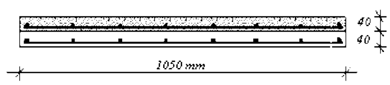
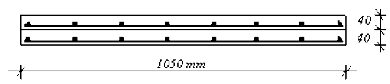
Test Plate Series	Cross-Section Details	Reinforcements
BP		Φ4/100
UNSP		2 X Φ4/100
UPSP		2 X Φ4/100
UNSRP		2 X Φ4/100
UPSRP		2 X Φ4/100
CP		2 X Φ4/100

Table 6: Composition of concrete used in production of test plates

Water/Cement	Cement (kg/m^3)	Flay ash (kg/m^3)	Water (kg/m^3)	Total Aggregate (kg)	Saturation Water (kg/m^3)	Super plasticizer (kg/m^3)
0,60	350	35	210	1757,74	3,60	3,5

Table 7: Mechanical and physical properties of concrete used in production of test plates

Mechanical and Physical Properties	
Average Compressive Strength (MPa)	29,75
Standard Deviation (MPa)	1,11
Characteristic Compressive Strength (MPa)	28,33
Initial Elasticity Modulus	34000
Poisson's Ratio	0,24
Saturated Unit Weight (kg/m^3)	2364
Dry Unit Weight (kg/m^3)	2347

Production of UPSRP and UPSP: UPSRP and UPSP were produced by applying the same methods, as mentioned above, at the upper side of basic plates.

The Test Set-Up: The test set-up used for loading the plates is shown in Figure 2. In this test set-up, the test plates are loaded by controlling load magnitude and loading applied until the load carrying capacity of the test plates.

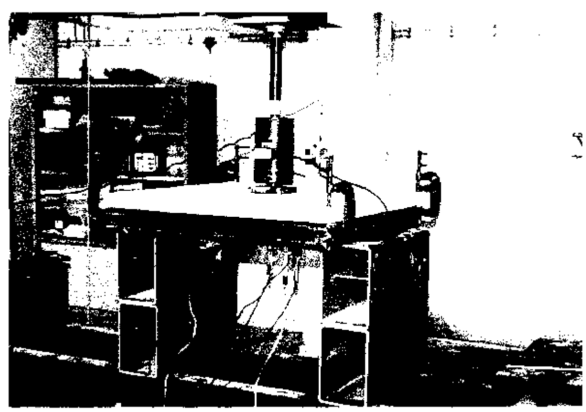


Fig. 2: A View of Test Setup

The load was applied monotonically by a 300 kN capacity load cell through a steel plate of 150mm x 150mm x 30mm dimensions and the loading speed was constant. In this test set-up, the displacement at the centre of test plates was recorded by a computer system (Autonomous

Data Acquisition Unit) every 1 kN. The displacement change is measured by using linear variable differential transducers (LVDT) and two strain gauges were installed on each plate along the centre lines of them (Figure 2).

RESULTS

The results obtained from the test plates are given in the following subheadings in tables and graphs to compare the results of strengthened-repaired and strengthened plates shown in Table 4 and Table 5 with each other. Comparisons are made in terms of the load carrying capacity, displacement, rigidity variation, ductility and energy dissipation capacity. Load-displacement and load-strain relations are shown in Figure 3 and Figure 4.

Load-Displacements: For test plates, average loading and displacements at failure are given in Table 8 and load-midpoint displacement curves are given in Figure 5.

As seen from Table 8, Average loadings at failure for UNSRP and UNSP plate series are 42 kN and 43 kN and average loadings at failure for UPSRP and UPSP plate series are 38 kN and 39 kN respectively. Moreover average midpoint displacement of test plates except basic plates is 33,98mm. This situation shows that repairing and strengthening at underside is more effective than repairing and strengthening at upper side in respect of bearing capacity. And also this attributed to placement of new concrete and neutral axis.

As seen from Figure 5, transition from elastic region to plastic region for UPSRP and UPSP plate series is softer than for UNSRP and UNSP plate series. This finding can

Table 8: Average Loading at Failure for Test Plates and Corresponding Average Displacements

Plate Series	Symbol	Average Loading at Failure (kN)	Midpoint Displacement (mm)
Basic Plate	BP	14,42	16,95
Underside-Strengthened Plates	UNSP	43,00	34,95
Upperside-Strengthened Plates	UPSP	39,00	33,18
Underside-Repaired and Strengthened Plates	UNSRP	42,00	33,02
Upperside-Repaired and Strengthened Plates	UPSRP	38,00	34,68
Comparing Plate	CP	45,50	34,71

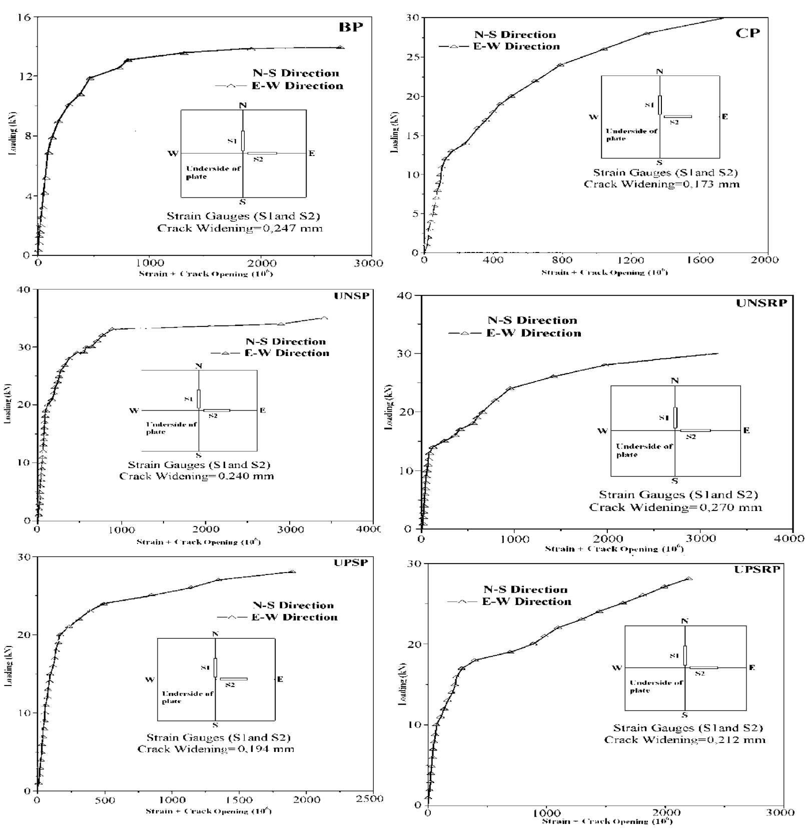


Fig. 3: Load-(strain+crack widening) graphs of test plates

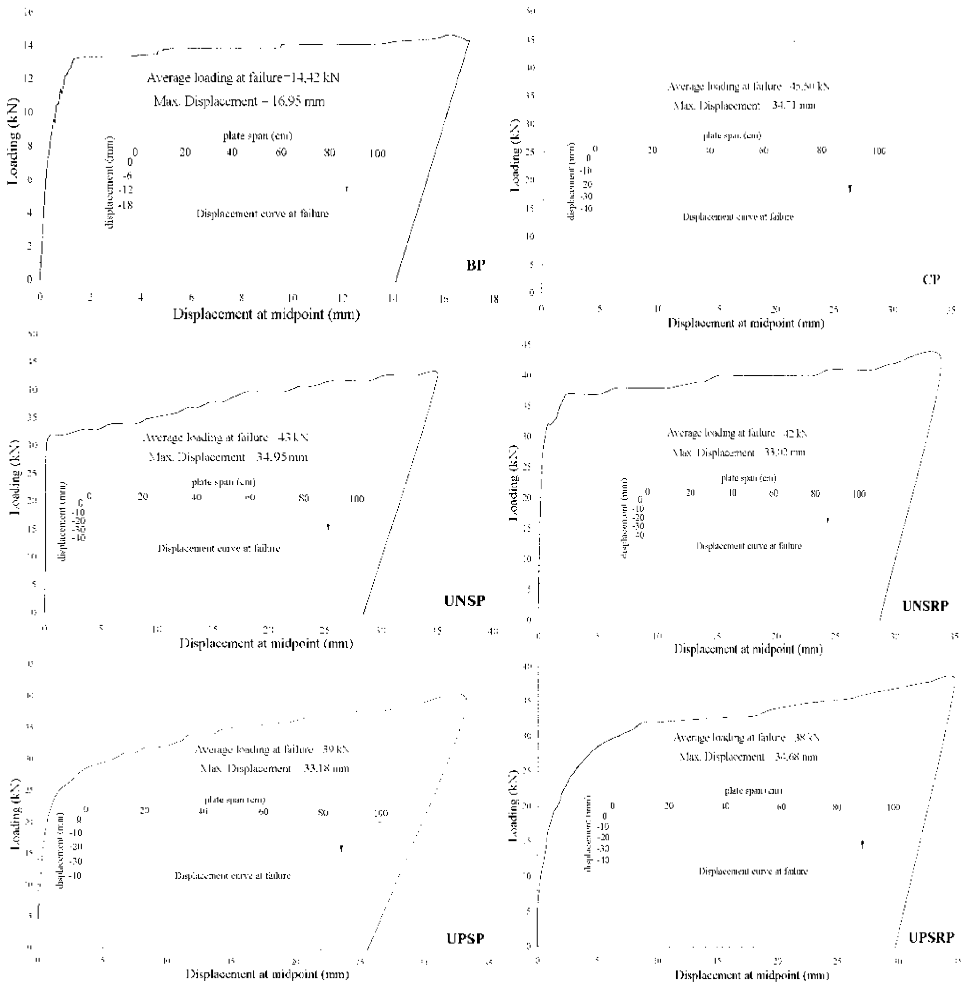


Fig. 4: Load-displacement graphs of test plates

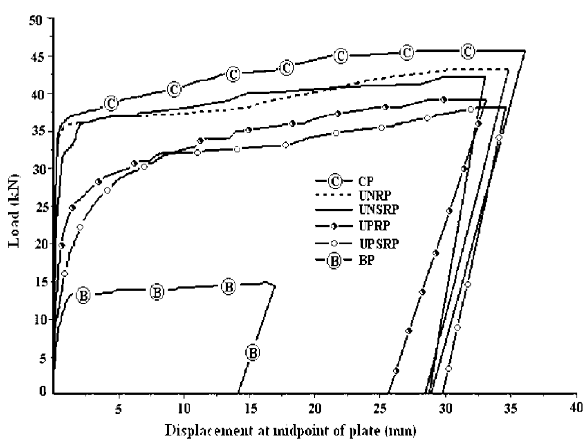


Fig. 5: Load-midpoint displacement graphs

be explained by the location of new added steel rebar. Because new concrete is in tension zone at UNSP and UNSRP but it is in compression zone at UPSP and UPSRP. That the resistance of old concrete is higher than the resistance of new concrete supports the accuracy of this finding.

Rigidity Variation: Rigidity at failure is defined and obtained as the slope of the line drawn from the origin of the load-displacement curve to the intersection of the horizontal line drawn from failure load chosen from load displacement curve. Rigidity at origin is defined and obtained as the slope of the line drawn tangent to the origin of the load-displacement curve. Nevertheless decrease in rigidity up to failure is determined with the assistance of rigidity at failure and rigidity at origin. Rigidities of the test plates at the origin and at failure and decrease in rigidity up to failure are given in Table 9.

As seen from this table average decrease in rigidity is %95 at the middle of plates and this situation shows that behaviors of plates are observed until the failure.

Table 9: Decrease in Rigidity at Failure of Test Plates

Plate Series	Measured Stiffness (kN/mm)		
	At Origin	At Failure	Stiffness Reduction (%)
BP	19.1	0.80	95
UNSP	28.6	1.00	96
UPSP	19.1	0.96	95
UNSRP	14.3	1.03	93
UPSRP	19.1	0.90	95
CP	28.6	1.03	96

Table 10: Displacements and Ductility Coefficients of Test Plates

Plate Series	Average Displacement		
	At Yielding δ_y	At Failure δ_{max}	Average Ductility Coefficient (δ_{max}/δ_y)
BP	1,58	16,95	10,7
UNSP	2,15	34,95	16,2
UPSP	2,32	33,18	14,3
UNSRP	2,08	33,02	15,8
UPSRP	2,47	34,68	14,1
CP	2,08	34,71	16,7

Table 11: Energy Dissipation Capacities and Ratios of Test Plates

Plate Series	Energy Dissipation Capacity (kN.m)	Energy Dissipation Capacity According to Comparing Plate (%)
UNSP	1,24	91
UPSP	1,01	74
UNSRP	1,20	88
UPSRP	1,04	76
CP	1,37	100

Ductility: It is well known that ductility is defined as the deformation capacity without an important decrease in load carrying capacity and can be expressed by the ductility coefficient. In this paper, ductility coefficient is determined by the ratio of maximum displacement and displacement at yield point of plates at midpoint (Table 10).

As seen in this table ductility of Comparing Plates (CP) is greater than the others. And also UNSP and UNSRP plate series following them.

Energy Dissipation Capacity: In this paper and also technical literature energy dissipation capacity of test plates is defined as capability of carrying external loads with elastoplastic strains and can be calculated with the area under the load-displacement curve for each plate [16]. Determined capacities and their ratios with respect to comparing plate are shown in Table 11.

As seen in this table strengthened plates at underside have best performance in respect of energy dissipation according to comparing plates. Repaired and strengthened plates at underside and the other plate follow it. As mentioned before, this finding also attributed to the location of new concrete and neutral axis.

The study is supports that the results of researchers who are defend the opinion that biaxial tension and rebar aren't change the maximum unit strain of concrete [17-20]. And it is stated that developed yield lines in test plates are compatible with yield line theory in technical literature [21, 22].

CONCLUSION

Some of conclusions obtained from this study are summarized below:

- The ratios of the average failure loads of UNSRP and UNSP to the average failure load of the comparing plate are 92% and 95% respectively, the ratio of UNSRP to UNSP is more than 97%.
- For UNSRP and UNSP, the permanent displacements after unloading is 85% of the total displacements of these plates.
- The ratios of the average failure loads of UPSRP and UPSP to the average failure load of the comparing plate are 84% and 86% respectively, the ratio of UPSRP to UPSP is more than 97%.

- For UPSRP and UPSP, the permanent displacements after unloading are 76 % and 85% of the total displacements of these plates respectively.
- The load carrying capacity of the UPSRP is 90% of the load carrying capacity of the UNSRP; the load carrying capacity of the UPSP is 91% of the load carrying capacity of the UNSP.
- The rebar in the test plates change the maximum unit displacements that create the first cracks. This indicates that the first crack is due to maximum unit displacement (strain) rather than maximum tensile strength and explains the collapse of reinforced concrete structures with ductility.
- The average ductility coefficients of the UNSRP, UPSRP and CP are 16, 14.2 and 16.7 respectively.
- The behaviors of the UNSRP are more ductile than those UPSRP.

In summary, this study shows that repair and strengthening form underside is more effective than repair and strengthening from upper side for load carrying capacity, rigidity variation, ductility and energy dissipation capacity. However the authors are aware of the fact that these results are valid for the plates used in this study and in the conditions that this study was carried out. Therefore it is believed that more experimental and theoretical studies should be done with different plates, loads and support conditions before generalizing these.

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