Repairing and strengthening methods for RC structural members

A. Koçak
Yıldız Technical University, Istanbul, Turkey

M.M. Önal
Gazi University, Ankara, Turkey

K. Sönmez
Civil Engineer, Istanbul, Turkey

ABSTRACT: In this study, the repairing and strengthening methods of reinforced columns and beams which are damaged during earthquakes have been compared. Due to earthquake and/or vertical loads, damaged or insufficient structural components can be repaired and strengthened with various methods. Reinforced jacketing, repairing with steel plates and repairing with FRP components are more used methods. We often come across these three methods in practise. These three methods have advantages and disadvantages. In this study, 21 beams were investigated experimentally. The experimantal research is done on 6 reference beams and 6 cracked beams with its bottom U shaped reinforcements and by adding steel ropes to carrying points. Also 3 beams were retrofitted with steel plates on their tension zone and 6 beams were retrofitted by full jacketing. Strength degradation, energy dissipation, ductility and rigidity of the members using these methods given above are compared in the final section of this experimantal investigation.

1 INTRODUCTION

Nowadays, repairing and strengthening of damaged reinforced-concrete buildings has become an important issue. There are many different kinds of repairing and strengthening techniques in literature. Reinforced jacketing, carbon fiber and reparation with steel plates are the ones that are used the most.

When it comes to reinforced-concrete structures, certain parts or the entire building can be strengthened due to disability, damage or regulation changes. This strengthening process can be done by increasing structure rigidity through adding bearing elements and bearing system or increasing the rigidity and strength of insufficient components in the structure.

In Turkey, which is a seismic country, many structures receive major damage after an earthquake. These structures are demolished if they are highly damaged, but if they receive medium and/or minor damage, they can be repaired or strengthened. Occasionally, bearing members of the structure are repaired individually. Also components of the structure that have less strength and rigidity are retrofitted.

There are many studies in literature which examine not only the strengthening of the damaged structures or those with insufficient rigidity, but also the strengthening of columns and beams that were damaged as a result of an earthquake. There are many different repairments and strengthening methods used in these studies. Also the strengthening methods applied to the beams in this study are examined and tested in various studies. Reinforced-concrete jacketing], fixing with steel plates and carbon fiber procedures are used when beams are repaired individually.

In this study, three different procedures of repairing the damaged beams are examined experimentally [27]. First study includes full jacketing with new longitudinal and wrap reinforcement while the second one uses reinforced-concrete jacketing with tensile reinforcement and U stirrup. The last one is fixing with steel plates.

2 EXPERIMENTAL WORK

2.1 *Experimental components*

21 beams are examined to find out the efficiency of damaged beams which were repaired. All of these beams have a 2000mm clear span, and the dimensions of 100*160*2200mm. The main reinforcement is 2ϕ12, the mounting reinforcement is 2ϕ8, the stirrups are consisted of 8mm diameter grade S420 bars and spaced at 150mm. The concrete grade is C16. (Figure 1, Figure 2)

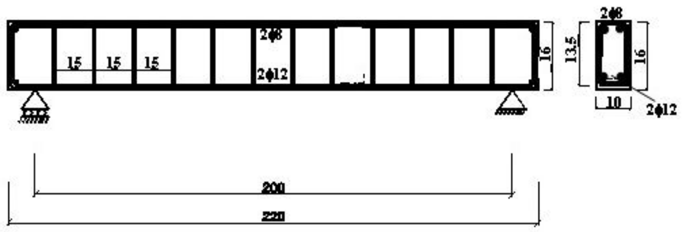

Figure 1. Specimen detail.


Figure 2. Preparing phase of beam specimens.

The beams are produced in five sets. 6 specimens (KM11, KM12, KM13, KM21, KM22, and KM23) that make up the first series are damaged and repaired by U-shaped stirrups. Additional reinforcement is 2ϕ12; Additional stirrups are ϕ8/150 (Figure 3 and Figure 4)

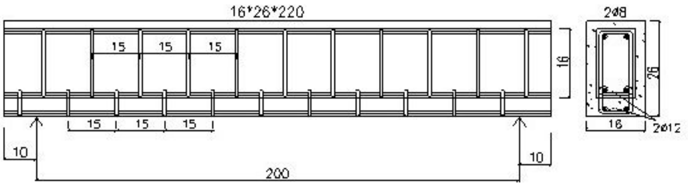

Figure 3. Reparation detail of u-shaped stirrup anchoring.


Figure 4. U-shaped stirrup anchoring from underneath.

Beams making up the second set (KM41, KM42, KM43, KM51, KM52, KM53) are made up of C20 concrete and grade S420 bars with 100*160 mm dimensions and damaged. Grade S420, 2ø12 reinforcement is added up to the tensile zone of damaged beams and the beam is wrapped up by 8mm diameter stirrups spaced at 150mm. Also the undersides of the beams are opened up to the cover and additional reinforcements are connected with existing reinforcements. (Figure 5, Figure 6)

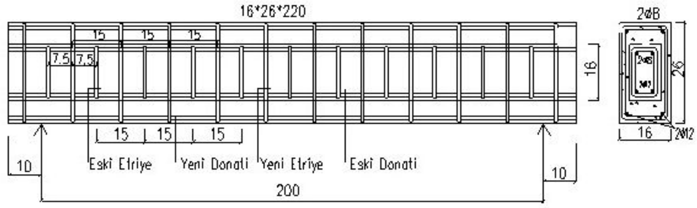

Figure 5. Detail of damaged beam strengthened by jacketing.

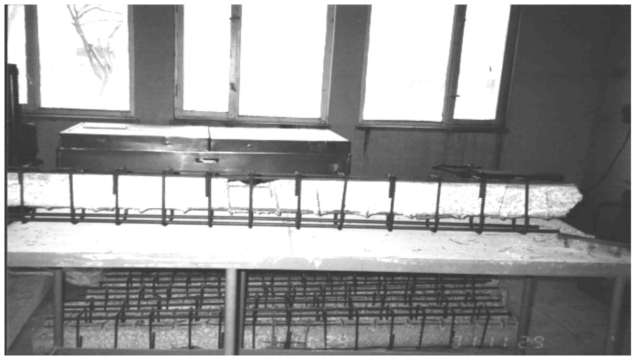
Figure 6. Jacketing Process.

Three beams are made as a the third set and repaired by epoxy resin plates. These beams (KM31, KM32, KM33) are repaired by bonding St37, 6*50*1200 mm epoxy resin plates to both sides of the beams' bending zone and tensile zone (Figure 7, 8). The epoxy mortar used to bond the steel plates has two components, namely resin and hardener. The density of epoxy mortar is 1.7 kg/ liter, compressive strength is 65 N/mm^2, bending strength is 30 N/mm^2, tensile strength is 20 N/mm^2 , concrete adhesion is 3.5 N/mm^2 and steel adhesion is 20 N/mm^2. The epoxy mortar is produced with these characteristics at a 1/3 mixture ratio.

Three specimens of steel plates are prepared for reparation which are grade St37, 400mm long and have the dimensions of 6*50*1200 mm. The yield strength of the bonding plates are f_{yk}=300 MPa with f_{su}=412 MPa breaking strength and εsu=%12.7 breaking elongation. The specimen model can be seen in Figure 9.

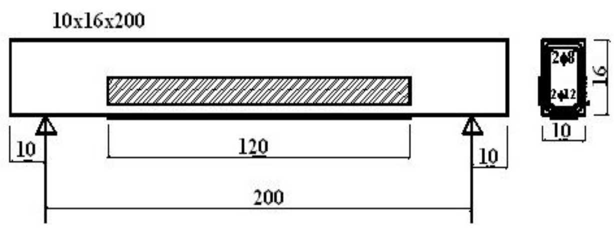

Figure 7. Details of the beam repaired and strengthened by steel plate.

Figure 8. Process of placing the epoxy plates.

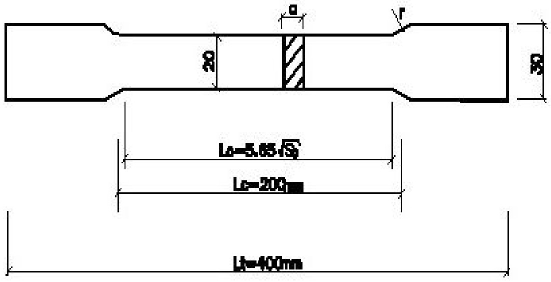

Figure 9. Steel specimen used for strengthening.

The reference beams of the fourth set include three beams (RKMk1, RKMk2, RKMk3) are made up of C16 concrete and grade S420 steel. Using the same reinforcement ratio and dimensions (100*160 mm), the fifth set of reference beams (RKMb1, RKMb2, RKMb3) are produced with dimensions that fit after strengthening process (160*260 mm) by using C30 concrete and grade S420 steel (Table 1, Table 2, Table 3). Beams belonging to the first series were loaded to the bearing capacity as calculated in advance; the test was then stopped when a 8mm displacement was reached at midspan.

Table 1. Experiment Components.

Serial Number	Specimen Serial Number	Beam Serial Number	Component Section (mm)	Description
1 2 3 4 5 6	1	KM 11 KM 12 KM 13 KM 21 KM 22 KM 23	Before, 100*160 after repairing 160*260	Jacketing: U-shaped stirrups to the undersides and 2Φ12 reinforcement are added to beam.
7 8 9 10 11 12	2	KM 41 KM 42 KM 43 KM 51 KM 52 KM 53	Before retrofitting, 100*160 After retrofitting 160*260	Jacketing, 2ø12 extra reinforcement and ϕ8/15 stirrups added to the undersides of the damaged beams
13 14 15	3	KM 31 KM 32 KM 33	100*160	Two epoxy plates are placed to the under and each side of the beams
16 17 18	4	RKMk 1 RKMk 2 RKMk 3	100*160	Reference beam with sections 100x160 mm
19 20 21	5	RKMb 1 RKMb 2 RKMb 3	160*260	Reference beam with sections 160x260 mm

The specifications of beams are given below in Table 2. The efficiency of known methods, behaviors of the beams, load-bending relationship after strengthening, rigidity, ductility, load bearing capacity and energy dissipation capacity are examined. The success of the strengthening procedure, efficiency of the method, the values before and after the process and the load against displacement curves are compared.

Table 2. Material and geometrical specifications of the beams.

Serial Number	Specimen Number	Dimensions (mm)	Reinforcement	Reinforcement area (mm^2)	Reinforcement ratio	Measured d (mm)	f_{ck} (MPa)	f_{yk} (MPa)	f_{su} (MPa)
1	KM11	100x160x2200	2ø12	226	0.014	130	22.204	529.74	804.42
2	KM12	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
3	KM13	100x160x2200	2ø12	226	0.014	137	22.204	529.74	804.42
4	KM21	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
5	KM22	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
6	KM23	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
7	KM 41	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
8	KM 42	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
9	KM 43	100x160x2200	2ø12	226	0.014	136	22.204	529.74	804.42
10	KM51	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
11	KM52	100x160x2200	2ø12	226	0.014	130	22.204	529.74	804.42
12	KM53	100x160x2200	2ø12	226	0.014	130	22.204	529.74	804.42
13	KM31	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
14	KM32	100x160x2200	2ø12	226	0.014	130	22.204	529.74	804.42
15	KM33	100x160x2200	2ø12	226	0.014	130	22.204	529.74	804.42
7	RKMk1	100x160x2200	2ø12	226	0.014	130	22.204	529.74	804.42
8	RKMk2	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
9	RKMk3	100x160x2200	2ø12	226	0.014	135	22.204	529.74	804.42
10	RKMb1	160x260x2200	4ø12	452	0.01	240	33.27	529.74	804.42
11	RKMb2	160x260x2200	4ø12	452	0.01	245	33.27	529.74	804.42
12	RKMb3	160x260x2200	4ø12	452	0.01	245	33.27	529.74	804.42

2.2 *Damaging and strengthening of beam specimens*

The beams that were produced as a test specimen had a span length of 2000mm and were loaded until they broke up with a medium degree of damage. Loads were increased 1962 N every phase. In every load phase, the displacement values of beams having ½ and ¼ points of span length were recorded digitally and by researchers (Figure 10)

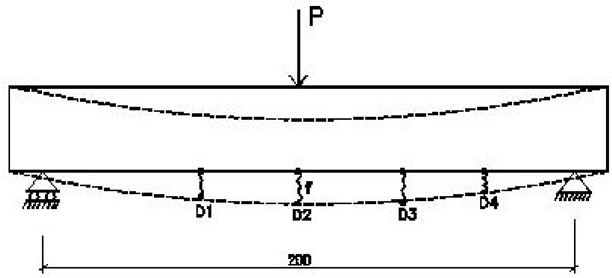

Figure 10. Displacement measurement points and testing system.

The beams that belong to the first series were loaded to a bearing capacity which calculated before, the test was stopped when 8mm displacement examined at the middle of beam span. Neither a major displacement at the tensile reinforcement nor crushing at the pressure zone was allowed. Theoretic and experimental values of beams that belong to the first series were given in Table 3.

The beams that were made of C20 concrete, grade S420 steel with dimensions of 100*160 mm were damaged and then strengthened. A 2ø12 grade S420 reinforcement was applied to tensile zone and the beam was wrapped up with 8mm diameter stirrups which were spaced at 150mm. Also the bottoms of the beams were opened up to the cover and additional reinforcements were connected with existing reinforcements. The third group of beams that were damaged was repaired by bonding the steel plates, both under and on each side of the beams. The repaired beams were tested and the displacement values were determined every time the load was increased.

3 EXPERIMENTAL WORK

The load-displacement curves of test components repaired by jacketing and steel plates are compared with the load-displacement curves of the reference beams (Figure 11, 12, 13, 14) The strength values, rigidity, ductility, load bearing and energy dissipation capacities are examined and the results can be seen at Tables 5, 6 and 7. Also the cracks that emerged during the test process are examined both before and after the strengthening of repaired beams.

3.1 *Load-displacement relationship*

The five sets of specimens are exposed to loading and their test values are evaluated and recorded Twelve beams that make up the first two groups are repaired by jacketing; the remaining three specimens are repaired by steel plates and exposed to reloading afterwards. The load-displacement curves that are estimated by the values determined through the loading and breaking of the specimens according to the program, are drawn by both reading from the comparator at points D1, D2 and D3 according to the loading and reading points shown at Table 10 and upon being saved to computer records at point D2 (Figure 11-14). The values used to make up the curves are taken from LVDT that is placed in the middle of the beam span and from comparator. In general, the numbers and widths of cracks at bending zone of the components are similar to each other. The reference beams that make up the second and third group are exposed to loading as well and the displacement values due to loading are recorded. As far as the strengthening through reinforced concrete jacketing goes, the load-displacement curves of the beams that are repaired by damaging ended up similar to the load-displacement curves of the reference beams that are identical to the dimensions after jacketing (Figure 11, 12). The load-displacement curves drawn by repairing the steel plates are similar to the load-displacement curves belonging to the simple beam. However, the results cannot come close to those estimated by reinforced concrete jacketing (Figure 13).

3.2 *Load bearing of the specimens*

During this experimental study, the moment load bearing and horizontal load bearing capacities of the specimens are examined both before and after the strengthening. According to the results, when it comes to the beams whose sections, reinforcements and material strengths were the same (Table 2), the cracking load and the yield load values are almost identical (Table 4). In most of the experiments, as far as the specimens go, experimental failure loads are lower than the theoretical failure loads. The breaking loads acquired through jacketing the entire section are close to the load bearing results that are achieved at the reference beams and are higher than the strengthening applied to the U-shaped stirrups. Moreover, the breaking load achieved by strengthening is higher as compared to the initial section and reference beams fitting the initial section. The breaking load increase of the specimens subject to experiment by being jacketed on 4 sides as compared to the reference beams corresponding to the initial section (100x160 mm) is 200%. When compared to the reference beams corresponding to the section after strengthening, this increase is around 122%. The increase of the breaking load belonging to the stirrups u-shaped from underneath and one-sided jacketing applied by extra reinforcement is 156% when compared with the initial section and 68% when compared with the reference beams that have repaired beam section. The ratio is 19% when it comes to the repair made by plates.

Table 3. Theoretical and experimental load-bearing capacities of damaged beams.

No	Specimen Name	Theoretical Mmax. (Nmm)	Exp Mmax (Nmm)	Theo Pu (kN)	Exp Pu (kN)	Displacement of middle point (mm)
1	KM 11	$10630*10^3$	$11000*10^3$	21,26	22,00	19,00
2	KM 12	$10630*10^3$	$12000*10^3$	21,26	24,00	18,75
3	KM 13	$10630*10^3$	$11000*10^3$	21,26	22,00	22,00
4	KM 21	$10630*10^3$	$10000*10^3$	21,26	20,00	14,00
5	KM 22	$10630*10^3$	$10500*10^3$	21,26	21,00	13,90
6	KM 23	$10630*10^3$	$11000*10^3$	21,26	22,00	10,70
7	KM 41	$10630*10^3$	$12000*10^3$	21.26	24.00	19.40
8	KM 42	$10630*10^3$	$11500*10^3$	21.26	23.00	15.55
9	KM 43	$10630*10^3$	$11000*10^3$	21.26	22.00	14.80
10	KM 51	$10630*10^3$	$11500*10^3$	21.26	23.00	11.20
11	KM 52	$10630*10^3$	$11500*10^3$	21.26	23.00	22.00
12	KM 53	$10630*10^3$	$9000*10^3$	21.26	18.00	15.00
13	KM 31	$10630*10^3$	$12000*10^3$	21.26	24.00	16.00
14	KM 32	$10630*10^3$	$10500*10^3$	21.26	21.00	17.80
15	KM 33	$10630*10^3$	$12500*10^3$	21.26	25.00	19.50
16	RKMk1	$10630*10^3$	$9500*10^3$	21.26	19.00	32.10
17	RKMk2	$10630*10^3$	$10500*10^3$	21.26	21.00	27.60
18	RKMk3	$10630*10^3$	$10000*10^3$	21.26	24.00	31.25

3.3 *The ductility of specimen*

For the beams to have a ductile behavior the reinforcement percentage should be within the range specified by the regulations and thus, all the beams are furnished to have the ductility requirement. When exposed to the experiment, all 6 beams provided enough ductility. However there is a decrease in the ductility of some beams because the total ductility ratio of the repaired beams is higher than necessary. In this study, it is estimated that there could be some possible loss of material strength and loss due to loading and bearing conditions, so these elements are taken into consideration. By using the load-displacement curve derived from the loading of the specimens, the shape change of each element due to breaking is divided by the shape change due to creeping, hence, the ductility of each element is calculated (Table 5).

3.4 *Bending rigidity of the specimens*

The comparisons and comments about the rigidity of the specimens made through the load-displacement curves. The bending rigidities that are calculated are shown in Table 6. There is no big difference when it comes to the rigidity of the reference beams and the beams repaired by jacketing and steel plates. As far as load-displacement relations go, the rigidity is calculated by determining the inclination up to the first crack load. The rigidity loss is calculated by the inclination determined by using failure load on the load-displacement curve and compared with the rigidity during the first crack.

Table 4. Theoretical and experimental values of the repaired beams.

Beam serial number	Displacement of yielding moment Δ_y (mm)	Displacement of breaking moment Δ_U (mm)	Ductility $\mu_\Delta = \frac{\Delta_U}{\Delta_Y}$
KM11	6,2	31,5	5,1
KM12	6,2	27,8	4,5
KM13	5,6	29,1	5,2
KM21	6,6	26,1	4,0
KM22	6,4	28,5	4,5
KM23	6,4	26,5	4,1
KM41	6.2	35.0	5.6
KM42	6.1	28.4	4.7
KM43	6.0	31.2	5.2
KM51	5.1	35.3	6.9
KM52	5.0	23.8	4.8
KM53	4.6	30.7	6.7
KM31	7.1	30.1	4.2
KM32	7.2	26.4	3.7
KM33	7.0	26.4	3.8
RKM1b	6.9	43.1	6.2
RKM2b	8.0	49.8	6.2
RKM3b	7.0	48.2	6.9
RKM1k	9.1	28.3	3.1
RKM2k	8.1	32.8	4.0
RKM3k	9.0	27.9	3.1

Table 5. Ductility ratio of beams.

No	Specimen Name	Theoretical M max. (Nmm)	Exp M max (Nmm)	Theo Pu (kN)	Exp Pu (kN)	Displacement of middle point (mm)
1	KM 11	$26000*10^3$	$27300*10^3$	52,00	34	31
2	KM 12	$26000*10^3$	$27850*10^3$	52,00	33,5	28
3	KM 13	$26000*10^3$	$26540*10^3$	52,00	32,5	29
4	KM 21	$26000*10^3$	$25370*10^3$	52,00	35	26,5
5	KM 22	$26000*10^3$	$25500*10^3$	52,00	34,5	28,4
6	KM 23	$26000*10^3$	$25000*10^3$	52,00	34	27
7	KM 41	$22300*10^3$	$23680*10^3$	44.60	40.0	35.0
8	KM 42	$22300*10^3$	$23550*10^3$	44.60	39.5	28.0
9	KM 43	$22300*10^3$	$22700*10^3$	44.60	38.0	32.0
10	KM 51	$22300*10^3$	$22500*10^3$	44.60	41.0	35.5
11	KM 52	$22300*10^3$	$21000*10^3$	44.60	38.5	24.0
12	KM 53	$22300*10^3$	$22800*10^3$	44.60	42.0	31.3
13	KM 31	$11372*10^3$	$12350*10^3$	22.74	17	30
14	KM 32	$11372*10^3$	$12700*10^3$	22.74	14.5	26.5
15	KM 33	$11372*10^3$	$11500*10^3$	22.74	16.5	26.5
16	RKMk 1	$10630*10^3$	$9500*10^3$	21,26	13,5	28
17	RKMk 2	$10630*10^3$	$10500*10^3$	21,26	13,6	32,5
18	RKMk 3	$10630*10^3$	$10000*10^3$	21,26	13,6	28
19	RKMb 1	$26700*10^3$	$27140*10^3$	53,40	42	43
20	RKMb 2	$26700*10^3$	$26970*10^3$	53,40	46,5	50
21	RKMb 3	$26700*10^3$	$27018*10^3$	53,40	46	43

Table 6. Bending rigidity of specimens.

Beam Serial number	Pu,test (kN)	Displacement of middle point (mm)	Energy dissipation capacity (kNmm)
KM11	34	31	114747,74
KM12	33,5	28	109873,69
KM13	32,5	29	113207,57
KM21	35	26,5	101135,62
KM22	34,5	28,4	111074,81
KM23	34	27	101839,96
KM41	40	35	168119.79
KM42	39.5	28.0	133091.99
KM43	38.0	32.0	145486.86
KM51	41	35.5	174353.92
KM52	38.5	24	111402.98
KM53	42	31.3	154353.48
KM31	17	30	97923.54
KM32	14.5	26.5	80696.64
KM33	16.5	26.5	84870.07
RKM1b	42	43	160430.42
RKM2b	46.5	50	195658.12
RKM3b	46	43	164760.39
RKM1k	13.5	28	87021.1
RKM2k	13.6	32.5	102482.6
RKM3k	13.6	28	87251.5

3.5 *Energy dissipation capacities of the specimens*

By using the load-displacement curve, the energy dissipating capacity is estimated via calculating the area that was under the curve and is shown in Table 7. When we compared the energy dissipation capacity of reference beams, steel plate repairs and beams repaired by jacketing from underside, the best results are achieved by the beam model that is repaired by jacketing with winding the beam up with stirrups. The best energy dissipating increase is achieved by jacketing.

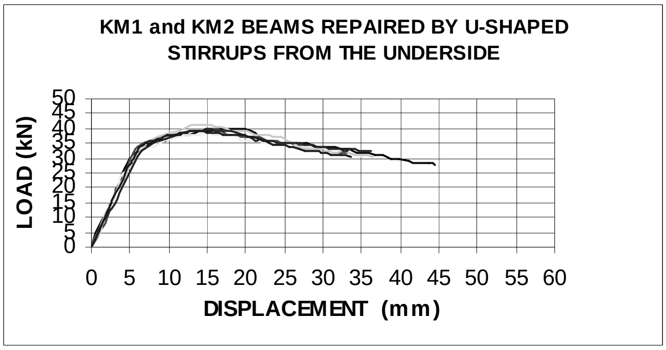

Figure 11. Load-displacement graph of beams which were repaired by jacketing from below.

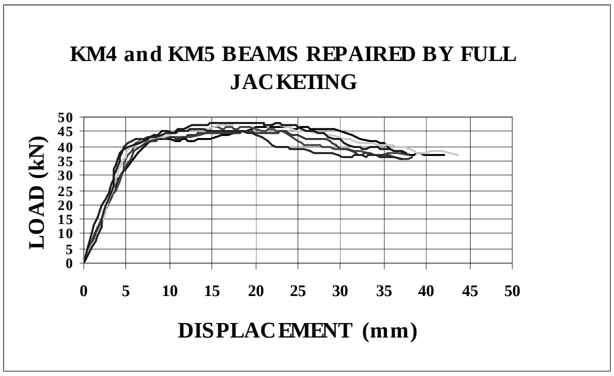

Figure 12. Load-displacement graph of beams which were repaired by reinforced concrete jacketing.

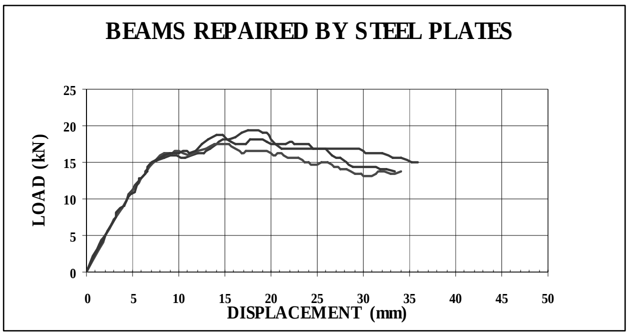

Figure 13. Load-displacement graph of beams which were repaired by steel plates.

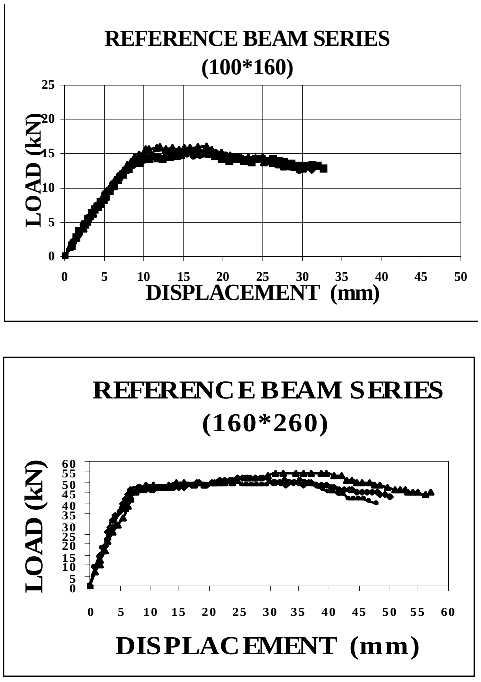

Figure 14. Load-displacement graph of reference beams (RKM1, RKM2, RKM3 (100*160) and (160*260)).

Table 7. Energy dissipation capacities of beams.

Beam Serial number	Displacement Of mid-point (mm)	Yield rigidity (kN/mm)	Breaking rigidity (kN/mm)	Rigidity decrease (%)
KM11	31	3,27	0,62	81,04
KM12	28	3,27	0,70	78,6
KM13	29	3,07	0,64	79,16
KM21	26,5	2,75	0,75	72,73
KM22	28,4	2,90	0,70	75,86
KM23	27	3,07	0,72	76,55
KM41	35	3.73	0.67	82.01
KM42	28	3.73	0.80	78.56
KM43	32	3.73	0.70	81.24
KM51	35.5	4.33	0.67	84.53
KM52	28	4.70	0.93	80.22
KM53	31.3	4.70	0.75	84.05
KM31	30	2.35	0.64	72.77
KM32	26.5	2.35	0.64	72.77
KM33	26.5	2.35	0.70	70.22
RKM1b	43	3.48	0.57	83.63
RKM2b	50	3.27	0.55	83.18
RKM3b	43	3.73	0.60	83.92
RKM1k	28	1.73	0.53	69.37
RKM2k	32.5	1.80	0.44	75.56
RKM3k	28	1.88	0.55	70.75

4 CONCLUSION AND SUGGESTIONS

In this experimental study, 21 beams with reference beams are damaged, 6 beams of the first set repaired by half jacketing from underneath, the other 6 repaired by full jacketing, 3 are repaired by steel plates and tested again. The values of strengthened beam and reference beam are examined and compared each other. Here are the results:

- Jacketing with additional reinforcement and an additional concrete layer method, as can be deducted from the load-displacement curve, is successful as far as the load bearing values of the repaired beams (Tables 3 and 4), ductility (Table 5), bending rigidities (Table 6) and energy consuming capacities (Table 7) were considered. In other words, the moment load-bearing capacity of the strengthened beams is close to the load bearing capacity of the post-strengthened section (equivalent reference beam). Similarly, repairs with steel plates are also successful.
- Similar to the reference beams, it is observed that capillary cracks that emerged on the beams strengthen with all three methods.
- It is observed that workmanship and the quality of the materials used are two factors that directly effect behavior.
- In the experiment set, the beams that are repaired while still bearing a load on them could not show sufficient strength and could not reach the load bearing values of the reference beams. However, those beams repaired without bearing a load could reach the sufficient load bearing values.
- As far as ductility and energy consuming go, the strengthening-on-four-sides method is more successful than the strengthening-with-a-u-shaped-reinforcement and strengthening-with-steel-plates methods.
- It is observed that increasing the plate thickness is not a successful strength increasing method and causes unwanted failure (brittle)
- Other studies on this subject and the experimental studies disclosed here show that the length of plate effects failure and load bearing capacity of the beam when it comes to the repairs made by steel plates.
- The breaking load increase of the specimens subject to experiment by being jacketed on 4 sides as compared to the reference beams corresponding to the initial section (100x160 mm) is 200%. When compared to the reference beams corresponding to the section after strengthening, this increase is around 122%. The increase of the breaking load belonging to the u-shaped stirrups from underneath and one-sided jacketing applied by extra reinforcements is 156% when compared with the initial section and 68% when compared with the reference beams that had been repaired
- When compared to the reference beams, the ductility increase of the strengthening method of reinforcement with a u-shaped stirrups from underneath is 68% whereas, this increase is 151% with the full jacketing method.

As far as these results are concerned, the following suggestions can be made about strengthening with concrete steel jacketing:

- It should be considered that there could be a decrease of 5-15% in the strength and load bearing capacities of the elements assuming that the application circumstances are not as good as laboratory conditions.
- The number of cracks and the width of the beams that are repaired after having been damaged affect the bending rigidity. Hence, the strengthening of the cracks should be made by injecting epoxy and the rigidity of the elements should be determined without applying jacketing or steel plate bonding.
- During the repair and strengthening of the reinforced concrete load bearing elements, it should not be forgotten that workmanship is of great importance and the details should be applied thoroughly.
- To be able to get the desired results while strengthening the load bearing elements, the element should be free of load.
- The connections of the beam reinforcements at hand and the reinforcements loaded onto the strengthening purpose should be set very well.
- During the experiment including beams that are repaired by adhering strengthening steel, the steel broke off the old concrete. In order to prevent this, anchorage with bolt could be provided.
- Plates used in this study are adhered in a vertical direction and parallel to the beam. Usage of horizontal plate will cause an increase in the experimental results and although they are harder to apply, their usage is also suitable.

5 SYMBOLS

- d : Useful height
- f_{ck} : Characteristic compressive strength of concrete
- f_{cd} : Concrete strength calculation
- f_{yk} : Characteristic compressive strength of reinforcement
- f_{yd} : Reinforcement strength calculation
- f_{su} : Maximum tensile strength of reinforcement
- C : Concrete class
- E : Elasticity module
- M : Moment
- S : Reinforcement class
- δ : Lateral displacement

ϕ : Reinforcement diameter

Δy : Yielding moment ductility

Δu : Breaking moment ductility

$\mu\Delta$: Ductility

REFERENCES

Celep , Z., Boduroğlu,H., 1997, Dinar Öğretmen Evi Kooperatif Binalarının Deprem Davranışı ve Yapılan Güçlendirme Sistemi 4. Ulusal Deprem Mühendisliği Konferansı, s173-180.

Canbay, E., Sucuoğlu, H., 1998. Seismic Assessment of Damaged/Strengthened Reinforced Concrete Building". Repair and Strengthened of Existing Building, Second Japan-Turkey Workshop on Eartquake Engineering. İstanbul, 132-151.

Atımtay, E., Tekel, E., 1997, Hasarlı Bir Yapının Deprem Davranışının İnclenmesi ve Öğrenilen Dersler, 4. Ulusal Deprem Mühendisliği Konferansı, İstanbul, 567-576,

Demir, H., 2000, Depremlerden Hasar Görmüş Betonarme Yapıların Onarım ve Güçlendirilmesi, İstanbul.

Gomes, A.M., Appleton, J., 1998, Repair and Strengthening of Reinforced Concrete Elements under Cyclic Loading, Proceedings of the 11th European Conference on Earthquake Engineering, Rotterdam.

Fukuyama, K., Higashibata, Y., Miyauchi, Y., 2000, Studies on Repair and Strengthening Methods of Damaged Reinforced Concrete Columns, Cement and Concrete Compozites, 22, 1, 81-88.

Ramirez, J.L., 1996, Ten Concrete Colum Repair Methods, Construction and Building Materials, 10,3,195-202.

Frangou, M., Pilakoutas, K., Dritsos, S., 1995, Structural Repair/Strengthening of R/C Columns, Construction and Building Materials, 9, 5, 259-266.

Ersoy, U., Tankut, A.., 1993, Behaviour of Jacketed Columns, Structural Journal ACI, 90, 3.

Aykaç, S., 2000, Onarılmış/Güçlendirilmiş Betonarme Kirişlerin Deprem Davranışı Doktora Tezi, Gazi Üniversitesi, Fen Bilimleri Enstitüsü, Ankara.

Sharma,A.K., 1986, Shear Strength of Steel Fiber Reinforced Concrete Beams, ACI Proceedings, 83, 624-628.

Can, H., 1994, Deprem Etkisindeki Betonarme Kirişlerin Onarılması, İMO,Teknik Dergi, 771, Ankara.

Yazar, E., 1997, Hasar Görmüş Kirişlerin Takviyesi, Celal Bayar Üniversitesi, Fen Bilimleri Enstitüsü.

Basunbul,A.I.,Gubati,A.A.,Al-SulaimaniG.J, BaluchM.H 1990, Repaired Reinforced Concrete Beams, ACI Materıals Journal, s348-354.

Ünsal, Ç.T., 1989, Güçlendirilmiş Betonarme Kirişlerin Davranış ve Dayanımları, Yüksek Lisans Tezi, Gazi Üniversitesi, Fen Bilimleri Enstitüsü, Ankara.

Sharif, A., Al-Sulaimani, G.J., Basunbul, I.A., Baluch, M.H., Husain, M., 1995, Strengthening of Shear-Damaged RC Beams by External Bonding of Stell Plates, Magazine of Concrete Research,47, 173, 329-334, London.

Ecemiş, A.,Ş., 2000, Hasar Görmüş Betonarme Kirişlerin Epoksi İla Çelik Levha Yapıştırılarak Güçlendirilmesi Üzerine Deneysel Bir İnceleme, Yüksek Lisans Tezi, Selçuk Üniversitesi Fen Bilimleri Enstitüsü, Konya.

Altın, S., Anıl, Ö., 2001, "Betonarme Kirişlerin Dıştan Yapıştırılan Çelik Plakalarla Kesmeye Karşı Güçlendirilmesi" Tübitak İnşaat ve Çevre Teknolojileri Araştırmaları Grubu, Yapı Mekaniği Laboratuarları Toplantısı,13.

Shahawy, M.A., Beitelman, T., 1996, Flexural Behavior of Reinforced Concrete Beams Strengthened with Advanced Composite Materials, International SAMPE Symposium and Exhibition, Anaheim, USA.

Swamy, R. N., Jones, R., Ang, T.H., 1992, Under and over reinforced concrete beams with glued steel plates, International Journal Cement Composites Ligtweigth Concrete, 4, 19-32.

Swamy, R. N., Jones, R., Bloxham, J. W., 1987, Structural behavior of reinforced concrete beams strengthened by epoxy-bonded steel plates, Structural Engineer, 65, 59-68.

Saafi, M., Toutanji, H. A. And Li, Z., 1999, Behavior of concrete columns confined with fiber reinforced polymer tubes, ACI Materials Journal, Vol. 96, No. 4, pp. 500-509.

Lam, L. And Teng, J. G., 2001, Strength models for FRP-confined concrete, Journal of Structural Engineering, ASCE

Purba, B.K. and Mufti, A.A.,1999, Investigation of the behavior of circular concrete columns reinforced with carbon fiber reinforced polymer (CFRP) jackets, Canadian Journal of Civil Engineering, Vol. 26, pp. 560-596.

Kumbasar, N., İlki, A., 2001, Karbon Lif Takviyeli Polimer Kompozitlerin Yapı Elemanlarının Onarım ve Güçlendirilmesinde Kullanılması, Tübitak İnşaat ve Çevre Teknolojileri Araştırma Grubu, Yapı Mekaniği Laboratuvarları Toplantısı, 105.

Norris, T., Saadatmanesh, H., Ehsani, M.R., 1997, Shear and flexural strengthening of R/C beams with carbon fiber sheets, Journal of Structural Engineering, 123, 903-911.

Önal, M.,M., 2002, Hasar Görmüş Dikdörtgen Kesitli Kirişlerin Mantolama Yöntemiyle Onarımı Üzerine Deneysel Bir Araştırma, Doktora Tezi, Gazi Üniversitesi.