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Comparison of design and application criteria for various methods used in reinforced concrete beam strengthening

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Abstract

The design of the buildings to the earthquakes is a very critical issue. Some of existing reinforced concrete buildings does not have sufficient performance in terms of earthquake. These buildings must be demolished or strengthened. Strengthening design is not a simple engineering account but requires deep knowledge of composite material behaviour. In this study, the structural advantages and disadvantages of various strengthening types of reinforced concrete beams are investigated. In the analyses, the reinforced concrete jacketing increased the bending and shear strength of the existing beam but the difficulty of this application was found to make it difficult for such designers to be preferred in beams. Also, the addition of new reinforced concrete section to be added to the lower zone of the beam has also contributed to the bending capacity by increasing the useful height of the beam.

Keywords: Beam, strengthening, design, earthquake.

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1. Introduction

In recent years, a large number of damages have occurred in many reinforced concrete buildings in the earthquakes in Turkey. This situation revealed the necessity of demolition or strengthening of buildings with insufficient earthquake safety. An important part of Turkey's building stock consists of reinforced concrete structures. Reinforced concrete structures may need to be repaired or strengthened due to earthquakes that have taken place over time, due to changes in usage purpose, due to the insufficient concrete strength and reinforcement details and due to the differentiation of external influences affecting the structure. In addition, a number of deficiencies in the design or production process cause the structures to have a lower capacity than the capacity to be.

The removal of the existing capacity of the damaged elements is called repairing. The strengthening is the load carrying capacity of the structure and the strengthening of the operations to raise the rigidity above the previous or existing condition. The methods to be selected for strengthening vary depending on the strength, ductility and rigidity of the existing structure. The architectural condition is also has main effects on the selecting the strengthening type.

Strengthening on the structures can be evaluated in two different scopes. These are element strengthening and system strengthening. The operations of the building such as columns, beams, shear walls and connection areas are called as member strengthening. Addition of new elements to the building, mass reduction and strengthening of the carrier system is called as system strengthening.

The purpose of use is to strengthen the structures that will continue to be used in changing structures and strengthening after the earthquake; it provides both material and time-wise benefits, depending on whether you destroy it or do it again.

Strengthening is also one of the important topics to strengthen the beams. The most common problems in beams are shear and bending cracks. Very different studies have been done in the literature on strengthening beams. Almusallam and Al-Salloum (2001); Anania, Badala and Failla (2005); Arya, Clarke, Kay and O'regean (2002); Bonacci and Maalej (2001); Cetinkaya, Kaplan and Senel (2004); Esfahani, Kianoush and Tajari (2007); Kankal (2011); Mert and Elmas (2007); Sevinc (2008); Vulas (2010) have studied beam strengthening with fibre reinforced polymers (FRP)/carbon fibre reinforced polymers (CFRP). Taslibeyaz (2005); Uysal (2006) and Yesilyurt (2001) examined the strengthening of beams by steel plates. Cakiroglu (2007) and Kocak, Onal and Sonmez (2007) have experimentally investigated damaged beams strengthening by reinforced concrete jacketing in their work.

Columns and beams form the structural system of the structure. In an earthquake, the behaviour of the beams affects the behaviour of the columns. Controlling damage in the beams also controls damage to the columns. Therefore, it is very important to adjust the beam capacities according to the capacity design. The main principle in capacity design is that the first flexural damage occurs in beams during the earthquake. Flexural failure is important for system ductility. Flexural failure is a ductility failure. It includes the ability to sustain large deformations and a capacity to absorb energy. Shear failure is a brittle failure. For obvious reasons, brittle failure must be avoided.

In this study, the reinforced concrete beam that cannot meet the existing loads (insufficient capacity) will be strengthened in the direction of shear force and bending moment. The purpose of this study is to determine the advantages and disadvantages of each strengthening methods of reinforced concrete beams by comparing the different uses of these methods with each other.

In addition, in the numerical application made in this study, an example of a reinforced concrete beam that cannot meet the existing loads due to shear force and bending moment. In this study, some strengthening methods used for beams are investigated. The methods are (a) reinforced concrete jacketing (b) additional steel plate and jacketing (c) CFRP confinement (d) additional layer with new steel (e) external stirrups (clamps) (f) additional steel plate and (g) adding C-FRP plate. A comparative study has been made on the types of strengthening.

2. Beam strengthening methods

1. FRP: the use of composite materials such as FRP in strengthening and repairing of structural elements, particularly those made of reinforced concrete, is widely spreading (Figure 1). FRPs have higher tensile strength than steel and are lighter materials than steel. Not rusting over time, lack of maintenance, less workmanship than the other strengthening types and less inconvenience caused by strengthening are the advantages of FRP. Strengthening with FRP is also advantageous as in that sufficient ductility can be achieved. FRP has CFRP, glass FRP and high performance (Hi-FRP) polymer types. In Figure 1, the strengthened beams are from the renovation project of the new office building of Beijing Bank of China Bank. Because of the change of function, the local structure of six, ten, thirteen and seventeen layers is strengthened and reconstructed. The carbon fibre material is used for strengthening the structure, and the weight per unit area is 200 g/m^2. The construction of carbon fibre cloth is two layers (www.horsen.com).

Figure 1. Strengthening with FRP

2. Adding Steel Plate and Steel Jacketing: Strengthening with steel plates is also the biggest advantage that steel can deform (Figure 2). They can be applied to the tensile zone, side surfaces of the beams or by means of clamping. Applying a steel plate to the lower face of the beams (tensile zone) increases the bending capacity of the beam. Applying a steel plate to the side of the beams increases the shear capacity of the beam. To reduce the problem of ductility, a perforated steel plate can be used or a solution can be produced by applying it together with the FRP.

Figure 2. Strengthening with steel profil0065

3. Reinforced Concrete Jacketing and External Stirrups: Application of reinforced concrete jacketing to beams is quite difficult (Figure 3). The cover of the beam is removed and steel anchors are applied. The anchors allow the old concrete and the newly added jacket concrete to work together. Applying this jacketing method to the beams increases the shear and moment capacity. External stirrups only increase shear capacity as expected.

This process is done when the reinforcement in the beam is not capable to carry the stresses applied to it. In this process, first the concrete cover is removed from both upper and lower steel bars. Then, the steel bars are cleaned well and they are coated with a specific material which would prevent corrosion. Holes of 10–20 mm diameter are made along the whole span of the beam under the slab with a spacing of 100–250 mm. These holes are extended to the total width of the beam and are filled with an epoxy material with low viscosity. The steel connectors are installed for fastening the new stirrups. In order to fasten the steel bars added to the beam, steel connectors are installed into the columns. The added stirrups are closed using steel wires and the new steel is installed into these stirrups. The surface is then coated with a bonding epoxy material. The concrete cover is poured over the new steel and the new stirrups.

Figure 3. Strengthening with Jacketting or External Strirrups (Seckinli, 2018) and www.imagenesmy.com

This process is done when both the steel and the concrete are not capable to bear the stresses on the beam due to the additional loads. The steps involved here are almost same as the above procedure which is as follows:

Remove the concrete cover; after cleaning the reinforcement steel, coat it with the material which will prevent the corrosion. Make holes in the whole span of beam and to the full width under the slab with a spacing of about 150–250 mm. These holes are filled with cement mortar with low viscosity. Steel connectors are installed to fasten the new stirrups. And in order to fasten the steel bars added to the beam, steel connectors are installed in the columns (https://civildigital.com/strengthening-of-reinforced-concrete-beam-rc-beam-methods/).

3. Numerical application

The properties of the selected beam (Figure 4) for numerical application are listed below. The typical sections and reinforcement layout are also given in Figure 4. In Figure 4, typical bending moment and shear force diagrams are given. Table 1 shows the comparison of existing beams capacity according to the shear and bending moment forces. As seen from the table, the shear and bending capacity of the beam is insufficient for support and mid-section. The general properties of the beam are as follows.

- The beam assumed as the inner beam.

The beam was not well designed to the Turkish EQ (TEC-2007 and 2018) and Turkish Building Code (TS-500-2000).

- Average compressive strength of existing concrete (f_{cm}) is assumed as 11 MPa.
- Reinforcement bar is plane and bar type is S220 (yield strength f_{ym} = 220 MPa).
- Existing stirrups are Ø8/15/20.

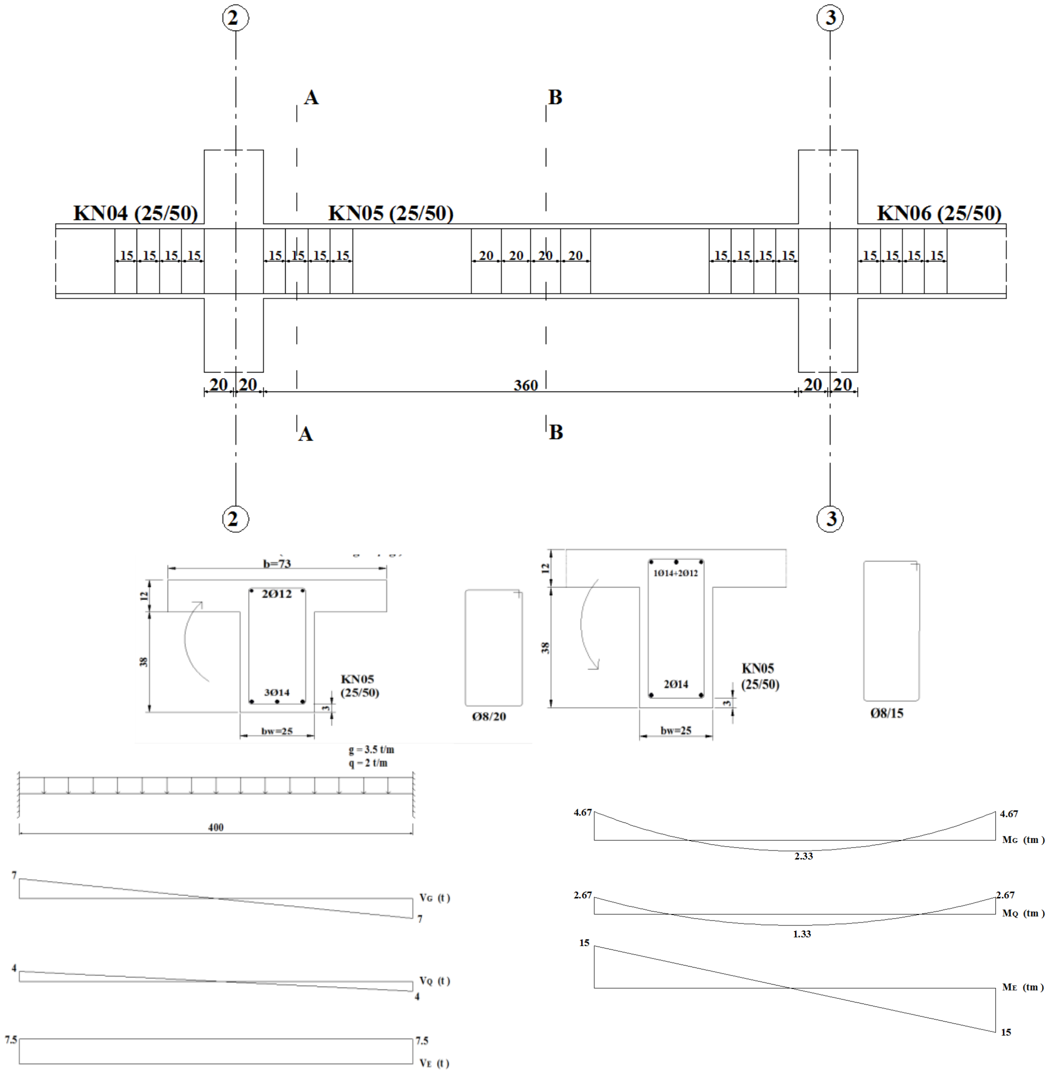

Figure 4. The properties of the selected beam

Table 1. Comparison of the capacity of the existing (bare) beam

	M_r/M_d		V_r/V_d	
	1.4*G* + 1.6*Q**	***G* + *Q* + *E****	**1.4*G* + 1.6*Q****	***G* + *Q* + *E****
Section A-A	0.35	0.169	1.244	0.869
Section B-B	0.872	1.284	1.646	0.896

*: Load combo given in Turkish Building Code.

**: <1.0 is insufficient **: >1.0 is sufficient.

The bending moment capacity of the beam is calculated with Ultimate Limit Stage. According to the analysis, since the lack of capacity both in support and mid-section, the beam has to be strengthened by a suitable method for shear and bending moment. The selected method is listed below in Figure 5.

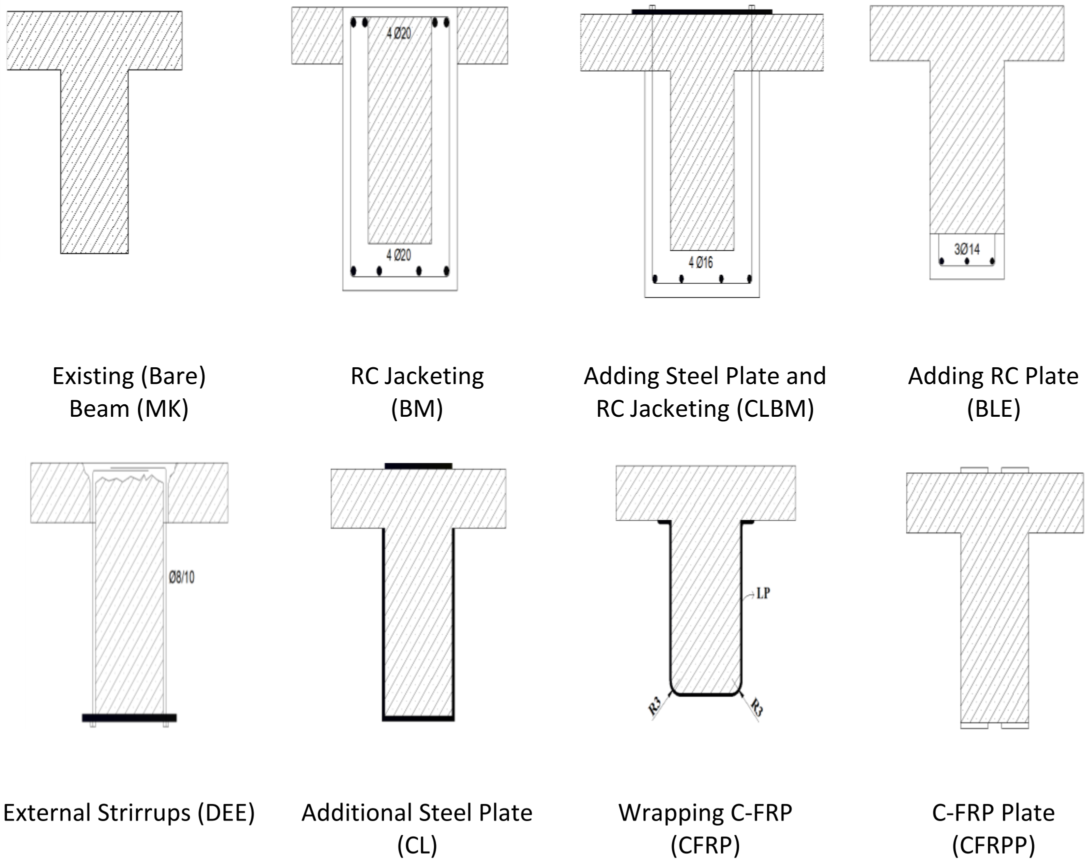

Figure 5. Strengthening types

The moment and shear capacity values obtained as a result of the application on a selected section are summarised in Table 2. The evaluation is given as the ratio of capacity and design values of bending moment and shear forces. New adding concrete compressive strength assumed as 30 MPa; new reinforcement type is selected as B420C (yielding stress is assumed as 420 MPa). For CFRP wrapping beams, layer thickness of FRP, ultimate strain, tensile strength and modulus of elasticity is accepted as 0.170, 0.0160, 3,750 Mpa and 230 GPa, respectively.

Table 2. Evaluation of the beams after and before strengthening

	M_r/M_d		V_r/V_d	
	Support	**Mid span**	**Support**	**Mid span**
MK	0.169	0.872	0.869	0.896
BM	1.109	4.564	1.605 (2.410)	1.924 (2.764)
CLBM	2.400	2.985	1.524 (2.329)	1.826 (2.666)
BLE	---	1.744	0.080 (0.948)	0.095 (0.992)
DEE	---	---	1.203 (2.071)	1.442 (2.338)
CL	1.049	5.412	6.806 (7.675)	8.159 (9.055)
CFRP	---	1.178	1.953 (2.822)	2.341 (3.238)
CFRPP	1.056	5.495	---	---

Note: The longitudinal reinforcement bars, steel plates and LPs in the compression zone are not accounted for in the calculation of moment carrying capacity. Also, the contribution of existing concrete and reinforcement bars has been neglected. Values only in parentheses in the shear calculation; the addition of existing concrete and stirrups.

4. Results and evaluation

Reinforced concrete structures may need to be repaired or strengthened due to earthquakes that have taken place over time, due to changes in usage purpose, due to the insufficient concrete strength and reinforcement details and due to the differentiation of external influences affecting the structure. In addition, a number of deficiencies in the design or production process cause the structures to have a lower capacity than the capacity to be. Consequently, the need to strength a structure is caused by problems due to a wrong design, the degradation of the characteristics of the materials along the time and the amplification of the load capacity.

In this study, the reinforced concrete beam, which cannot meet the existing loads (insufficient capacity), will be strengthened in the direction of shear force and bending moment. The purpose of this study is to determine the advantages and disadvantages of each strengthening methods of reinforced concrete beams by comparing the different uses of these methods with each other. In addition, in the numerical application made in this study, an example of a reinforced concrete beam that cannot meet the existing loads due to shear force and bending moment. In this study, some strengthening methods used for beams are investigated. The methods are (a) reinforced concrete jacketing (b) additional steel plate and jacketing (c) CFRP confinement (d) additional layer with new steel (e) external stirrups (clamps) (f) additional steel plate and (g) adding C-FRP plate. A comparative study has been made on the types of strengthening. In this study, the structural advantages and disadvantages of strengthened reinforced concrete beams are also investigated. In this context, strengthening types that can be done on beams are examined in detail and the parts where strengthening with numerical examples are affected are highlighted. The moment and shear capacity values obtained as a result of the application on a selected section are summarised in Table 2.

According to the table, the following results have been obtained.

1 BM strengthening type give sufficient capacity increases in shear and bending. The RC jacketing can enhance structural properties for the RC beams. However, this method is not practical and user friendly. Application of reinforced concrete jacketing to beams is quite difficult. The cover of the beam is removed and steel anchors are applied. The anchors allow the old concrete and the newly added jacket concrete to work together.

2 The method of BLE is more practical method according to the first and second methods (jacketing and adding steel plate and RC jacketing). The weakness of this method is not sufficient in support sections.

3 External stirrups (DEE) method is in TEC-2007 and this method is useful for increasing shear capacity. However, it is clear that this method has no effect on bending moment capacity.

4 In practice, additional steel plate (CL) is also common method and preferred by engineers in practice. This method has sufficient effect on bending moment and shear force capacities.

5 Wrapping C-FRP and adding CFRP plate are easy implicated to the beam and effective method. Use of externally bonded fibre reinforced polymer (FRP) sheets/strips/plates is a modern and convenient way for strengthening of RC beams.

In this study, the strengthening of the beams is examined only in terms of bending moment and shear force bearing capacity. It is well known that different strengthening types of beams also affect the sectional ductility. The damage in the beams during the earthquake is not only inadequate capacity; the rotation capacity of the members must be also analysed. However, it should be remembered that each structure has a different character. Therefore, it is necessary to decide not only the experimental and analytical results but also the other features of the structure.

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