

A Comparative Study on the Strengthening of RC Beams with Steel Plates and Steel Angles

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Abstract

The techniques of strengthening reinforced concrete beams have been widely used in civil engineering. RC beams often need strengthening due to defective construction, having higher loads than those foreseen in the initial design of the structure, or as a result of material deterioration or accidental damage. The need for strengthening concrete structures has become a crucial problem all over the world. Rehabilitation of structures results in less construction waste materials, reserve natural resources, reduces the negative effects of the environment, saves time and cost, etc. The structural behavior of reinforced concrete beams strengthened by addition of steel plates or steel angles has been investigated in the undertaken research. The main aim of this research is to demonstrate the best method of the investigated strengthening techniques. The experimental work comprised of 18 RC beams divided into three groups; the first group consists of 6 normal RC beams, the second group contains 6 RC beams strengthened by addition of steel plates and the third group contains 6 RC beams strengthened by addition of steel angles.

Keywords: Steel Plate, Steel Angle, RC Beam, Concrete

1. Introduction

Concrete is a composite material which is commonly used for activities of construction purpose. Concrete is also a relatively brittle material that performs significantly well in compression, but is considerably less effective in tension and its tensile strength is only approximately one tenth of the compressive strength. Tensile stresses are induced in concrete due to its shrinkage in both plastic and hardened stage resulting the cracking of concrete. Historically, steel reinforcement is used to absorb these tensile stresses and to prevent the cracking to some extent. The addition of steel reinforcement significantly increases the strength of concrete but to produce concrete with homogeneous tensile properties the micro cracks develops in concrete should be suppress. (Raut and Kulkarni, 2014)

The need to strengthen 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 caused by new utilization of the building. Other cause can be like publication of new design codes that increases the actions, such as seismic action.

In view of the simplicity and popularity of the external steel angles as endorsed by its proliferation in field application, laboratory investigation into the performance of this technique started in the 1960s. Since then, considerable experimental work has been reported on the performance of this strengthening technique when employed for strengthening of existing structural beams. However, only limited data has been published on the performance of beams when strengthened by external steel angles. (Gul *et al*, 2015)

These papers present a stark comparison between two methods for the bending and shear strengthening of RC beams by addition of external reinforcement. Over the past few decades, there were researches that have tried to strengthen concrete beams by addition of steel plates.

This work aims at strengthening the RC beams which are deficient in flexural resistance. An experimental study was carried out to evaluate the enhanced flexural strength capacity of RC beams by placing steel angles to their bottom with the help of welding. This technique will make use of the locally available materials and is hoped to be easy in use and could be applied effectively while the structure is in use with minimum disruption.

2. Research Aim and Objectives

2.1 The Aim

The structural behavior of RC beams strengthened with steel plates or steel angles has been investigated in the undertaken research both theoretically and experimentally. The main aim of the research is to demonstrate the best among these investigated strengthening techniques.

2.2 The Objectives

The main objective of this work is to understand in depth the dissimilarities of RC beam strengthening by applying the steel plate method and the steel angle method, and exploring which method is better. The research work is intended to achieve the following objectives:

- Review theoretical study of the strengthening systems applied to the samples.
- Present experimental investigation of concrete strengthening by adding steel plates.
- Present a comparison between two systems of strengthening RC beam; (steel plate and angles).
- Provide recommendations for future research.
- Provide a practical recommendation in strengthening RC beams using steel plates or steel angles.

3. Strengthening RC Beams with Steel Plates

This technique will make use of the locally available materials and is hoped to be easy in use and could be applied effectively. It will not increase the size of the beam substantially. (Gul et al, 2015)

3.1 Application

Bloxham *et al*, 2008 mentioned that the performance of a structure is determined by the behavior of its component members which in turn depend on the properties of the materials and the methods adopted for their design.

Applicable to:

- Change in the functional usage of existing buildings.
- Degradation of the characteristics of the materials along the time.
- Corrosion of the internal steel reinforcement.
- Exposure to unfavorable condition like earthquakes and blasts.

3.2 Advantages

Steel plating has the following advantages:

- The plate provides additional stiffness against bending and contributes to flexural strength, too.
- Possible increasing the load carrying capacities of RC beams.
- Time required for installation is very little.
- Minimum change in the overall size of the structure after plate bonding.

4. Strengthening RC Beams with Steel Angles

There are massive methods for strengthening RC beams; by the use of different elements and materials but very limited researches have been published on the performance of beams when strengthened by steel angles.

In view of the simplicity, popularity and variability of standard steel angles, as its dimensions and properties are globally well known. This eases the choice and use of steel angles as strengthening element.

However, only limited data has been published on the performance of beams when strengthened by external steel bars and steel angles. It has been reported that the overall response of the strengthened beams was significantly enhanced by using structural steel angles for partially confinement of RC beams. (Hamad *et al,* 2011).

5. Test Program

5.1 Material Properties

- **Cement:** It is preferable to measure cement in terms of its weight, and not in terms of volume. The volume of cement changes with the conditions of measurement. In our country, cement is supplied in bags, each bag weighing 50 kg. Under normal conditions, the volume of cement is shoveled, the bag is considered equivalent to 34.5 liters. However, if the same cement is shoveled, the bag may measure up to 42 liters. Before mixing, therefore, cement is measured in terms of mass.
- **Aggregates**: make up about 75% of the volume of concrete, so their properties have a large influence on the properties of the concrete. Aggregates are granular materials, most commonly natural gravels and

sand or crushed stone, although occasionally synthetic materials such as slags or expanded clays are used. Most aggregates have specific gravities in the range of 2.6 to 2.7. In general, aggregates are much stronger than the cement paste, so their exact mechanical properties are not considered to be of much importance (except for very high-strength concretes). The most important aggregate properties are the particle grading (or particle-size distribution), shape, and porosity, as well as possible reactivity with the cement.

- **Sieve Analysis:** The particle-size distribution in a sample of aggregate, referred to as the grading, is generally expressed in terms of the cumulative percentage of particles passing (or retained on) a specific series of sieves.

The sieve analysis of aggregate was done according to ASTM C136 and the final results are in Table 1 and Figure 1 below.

Table 1. Sieve Analysis Results for Aggregate

sample no.	weight "kg"	depth "cm"	length "cm"	width "cm"	failure load "kg"	volume "cm^3"	density "kg/cm^3"	stress "kg/cm^2"
1	42	15.8	70	14.6	12000	16147.6	0.0026	11.74
2	41.6	15.8	70	15.2	12800	16811.2	0.0025	12.03
3	43	15.9	70	15	14000	16695	0.0026	13.33
Average	**42**	**16**	**70**	**15**	**12933**			

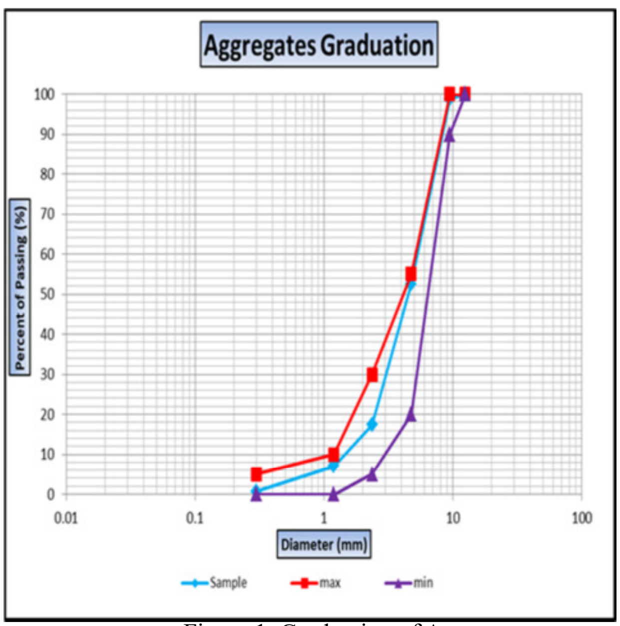

Figure 1. Graduation of Aggregate

- **Steel bars:** The steel reinforcing bars used for the construction of RC beams were as follows:

For the longitudinal reinforcement; 12 mm diameter steel bars were used for top and bottom reinforcement and 6 mm diameter steel bars were used for stirrups. The average value of f_y is 3600 kg/cm^2.

- **Steel plate:** Steel plate used for strengthening of RC beams is (PL 60 mm*2 mm).
- **Steel angle:** Steel angle used for strengthening of RC beams is (L 60 mm*60 mm*2 mm)

Table 2 shows the properties of steel angles used in the study.

Table 2. Properties of (60 mm*60 mm*2 mm) Steel Angle

Designation		Mass Per Meter Kg	Radius		Area of Section cm2	Distance Of Center Of Gravity cx and cy cm	Second Moment Of Area			Radius Of Gyration			Elastic Modulus Axis x-x, y-y cm3
Size A A mm	Thickness t mm		Root r1 mm	Toe r2 mm			Axis x-x, y-y cm4	Axis u-u cm4	Axis v-v cm4	Axis x-x, y-y cm4	Axis u-u cm4	Axis v-v cm4	
60*60	2	2.12	8	2.4	2.7	1.54	10.7	16.55	13.06	8.44	2.35	1.87	2.22

6. Experimental Work on Specimens

6.1 Slump Test for Fresh Concrete

The concrete slump test is an empirical test that measures the workability of fresh concrete.

The test is popular due to the simplicity of apparatus used and simple procedure.

In this experimental program, the slump test was done for a sample of fresh concrete using a metal mold, in the shape of the frustum of a cone, open at both ends, and provided with the handle as shown in Figure 2. The test sample gave a slump of 7cm.

Figure 2. Slump Test

7. Tests on Hardened Concrete

7.1 Compressive Strength Test for Cubes

7.1.1 Preparing Beam Specimens

The beams are categorized into three groups; these groups are:

- **Preparation of group (a)**

Group a: Comprised of six RC beams (from N1to N6), all of them are in the natural state; these RC beams consist of concrete and internal reinforcement of longitudinal 2Φ12B & 2Φ12T and stirrup Φ6@15cm reinforcement.

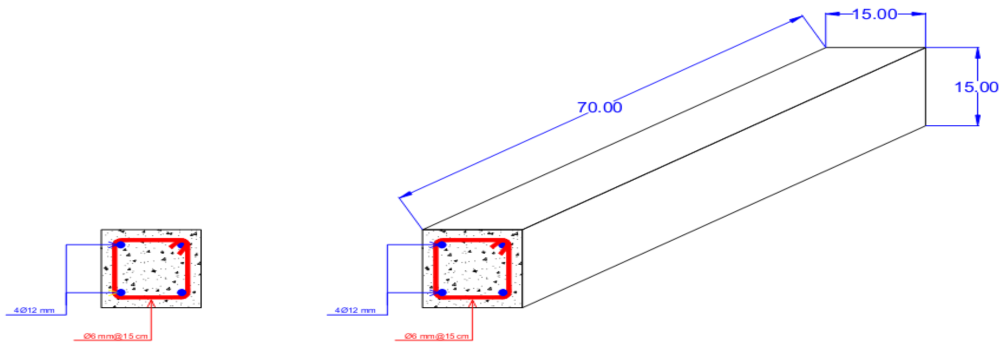

Figure 3. Group (a)

- **Procedure of constructing group (a):**

1- Longitudinal reinforcement 12 mm diameter bars, transverse reinforcement 6 mm diameter bars, wire ties and plastic cover have been prepared.

2- Wooden formwork at the site has been constructed, as shown in Figure 4

Figure 4. Wooden Formwork of Specimens

3- Steel cages were constructed which consist of longitudinal and transverse reinforcement, Wire ties were used to keep the longitudinal reinforcement in place. Figure 5 shows the steel cages.

Figure 5. Steel Cage of Specimens

4- The steel cage was placed in the wooden formwork.

5- The concrete mix has been prepared with proper proportions of fine aggregate, coarse aggregate, water and cement using the mixture.

6- Fresh concrete was casted in the formwork on layers with compaction. Figure 6 shows the fresh concrete at the moment when it had been casted in the formwork.

Figure 6. Casted Concrete in the Formworks

7- Immediately after casing the concrete, leveling was made for the surface and plastic cover was placed on the face.

8- After one day, the formwork was removed.

9- Curing for the specimens was made by spraying water for 7 days.

By following the previous steps the specimens got ready. Figure 7 shows the specimens after 7 days which are in that day became ready to be tested the first test that had given us indication about the results.

Figure 7. Ready-Made Specimens

- **Preparation of group (b)**

Group b: Comprised of six beams (from SP1 to SP6) all of them are consist of concrete and internal reinforcement of longitudinal 2Φ12B & 2Φ12T and stirrup Φ6@15cm reinforcement and additional addition external steel plate (PL60 mm*2 mm) for the two bottom corners of each beam on two the sides. They have been installed by connection of welded steel bars that have a length of 5 cm and diameter of 6 mm.

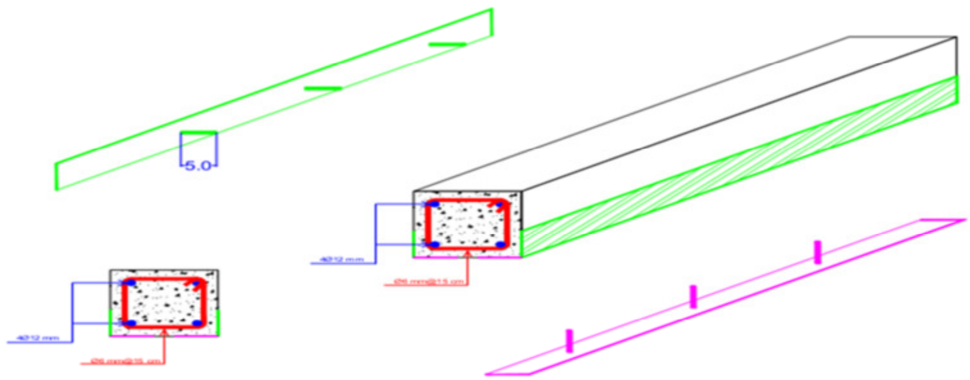

Figure 8. Group (b)

- **Procedure of constructing group (b):**

The procedure for preparing group b is same as preparing group a, but there are two additional steps which are:

1- After step 1 which has been mentioned in the preparation of group (a), steel plates have been prepared, (PL 60 mm*2 mm) have been used ,then connections were made. The connections are steel bars of 5 cm length and 6 mm diameter; the connections were welded with the plate.

2- After step 4 which has been mentioned in the preparation of group (a), a steel plate was placed in the formwork.

- **Preparation of group (c)**

Group c: Comprised of six beams (from SA1 to SA6) and all of them consist of concrete and internal reinforcement of longitudinal 2Φ12B & 2Φ12T and stirrup Φ6@15cm reinforcement as well as additional external steel angle (L 60 mm*60 mm*2 mm) for the two bottom corners of each beam on the two sides. They have been installed by connection of welded steel bars that have a length of 5 cm and diameter of 6mm.

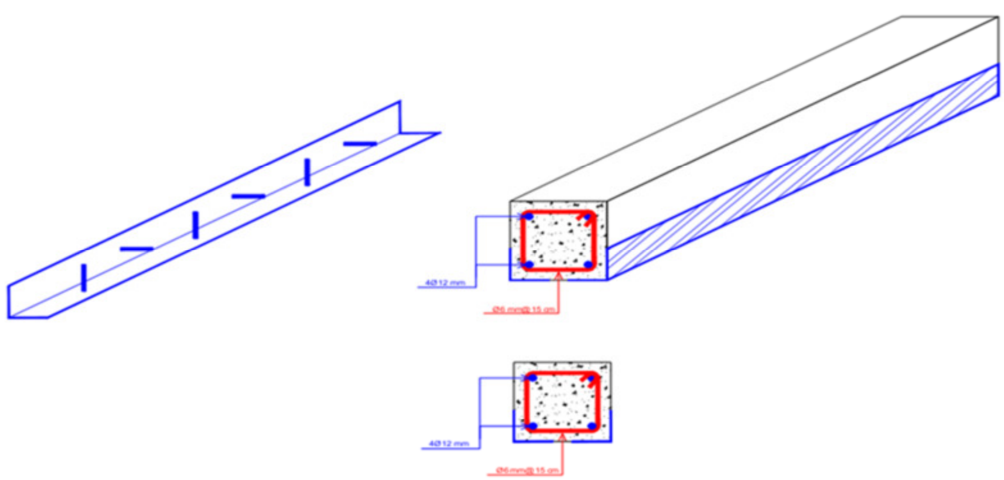

Figure 9. Group (c)

- **Procedure of constructing group (c):**

The procedure for preparing group c is same as preparing group a, but there are two additional steps shown in Figure 10 which are:

1- After step 1 which has been mentioned in the preparing of group (a), steel angles were prepared ,(L 60 mm*60 mm*2 mm) angles have been used, then the connections were made. The connections are steel bars of 5 cm length and 6 mm diameter; connections were welded with the angles.

2- After step 4 which had been mentioned in the preparing of group (a), steel angles were placed in the formwork.

Figure 10. Steel Angles with Connections in Formwork

7.1.2 Flexural Strength Test

The deflection and cracking behavior of R.C beam depend on the flexural tensile strength of concrete.

For implementing bending test for resistance, concrete had to be hardened to determine the flexure and the study of the behavior of concrete beams when exposed to bending loads, as well as the form of breakage resulting from the collapse of the beams.

The flexural strength is expressed as Modulus of Rupture (MR) in psi (MPa) and is determined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading).

Flexural Strength of Concrete Flexural MR is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design.

7.1.2.1 Procedure of Concrete Flexural Test

1. Molds work in the form of beams of internal dimensions 15 * 15 * 70 cm.

2. Preparation of reinforcing steel.

3. Mixing concrete then filling molds and compaction as well as curing in the same way as in the concrete cubes.

4. Beams are placed in the test device on two supports, as shown in Figure 11.

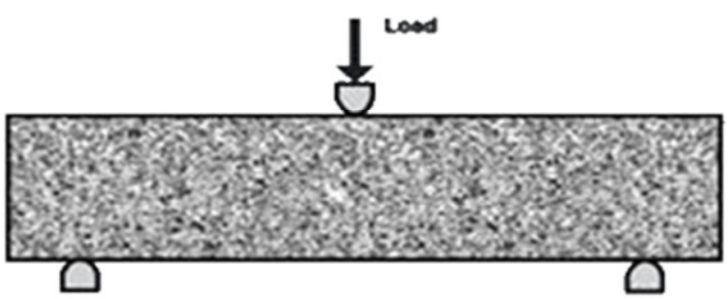

Figure 11. Beam on the Test Device

It should be noted that each of the support rods and load must be greater than the length of the beam width as the load gradually and regularly increases leading to the final terms load.

8. Results and Discussion

8.1 Conclusion

The results presented in this research lead to the following conclusions:

1- In the range of the adopted configurations in our research. Strengthening beams in shear by steel angles is better in terms of strength and deflection than using steel plates.

2- In both cases when steel plates and steel angles were added to RC beam, it was noticed that the shear failure had been delayed but not prevented.

3- In the range of configurations and arrangements in this research, steel angles can achieve a level of enhancement in shear better than the case of steel plating.

4- This study proved that in general, using steel angles is better than using steel plates for strengthening RC beam.

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