Repair of reinforced concrete beam by adding external reinforcement

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Abstract. The negligence in construction are usually due to error in replace or calculation of required reinforcement. The mistake known after construction and must be corrected as soon as possible. Some actions should be taken namely, add some pretension, augmented the beam size, use the FRP, and add some external reinforcement. Studies on rehabilitation and retrofitting are gaining importance due to the need for restoration of partially damaged structures due to wind load and earthquake. To prevent any disaster during the future earthquakes, the existing deficient buildings need to be retrofitted. The external tension reinforcement added when the flexural beam capacity inadequate, and the stirrups added when the shear beam capacity inadequate. The adding with external reinforcement also done after some tensile failure or cracks in the beam. In this case some damage of concrete must being consider in reducing stiffness and strength. The objective of this research is studied about the adding of external tensile reinforcement and stirrup after tensile failure and explore the influence of those action to the beam and then compared the strength, stiffness, ductility and crack pattern of beams before and after retrofit. The specimens were 12 original beam, and 12 retrofitted beam. The original beams have dimensions of 15 cm x 15 cm x 100cm, the tensile reinforcement were 4ф6 and compression reinforcement 2ф6. The stirrups were ф6-200 along the beam. Retrofit strategies were adding bottom tensile reinforcement 2ф6 and 3ф6, and adding stirrups ф6-60 in the shear span. The experiment shown the increase of beam ultimate load after retrofitting, but decrease the ductility and stiffness of the beam. The pattern of cracks also changed between original and retrofitted beam.

1. Introduction

In recent years, repair and retrofit of existing structures have been among the most important challenges in civil engineering. Strengthening or retrofitting purpose enhancing the structural performance of an existing structure. By strengthening of some selected elements, the life of the whole structure may be extended. Studies on rehabilitation and retrofitting are gaining importance due to the need for restoration of partially damaged structures due to wind load and earthquake. Many existing buildings lack collapsed or were damaged during the earthquake. To prevent any disaster during the future earthquakes, the existing deficient buildings need to be retrofitted. Low steel ratio also causes of cracks and needs some repair.

Many researchers have worked on rehabilitation and retrofitting of beams. Many methods have been developed in the recent past. Kothandarman et al [1] used an external bar and showed the reduced in crack width and increase the beam capacity. Alanwar et al [2] used U-shape jacketing mesh and steel bars, showed the increase in both flexural and shear capacity of reinforced concrete beam after retrofit. Narayanan et al [3] introducing additional continuous bottom bars. For an effective
concrete jacket, the use of closed stirrups as dowels involves closely spaced drilling of the existing beam. The other options of retrofitting a beam are the fiber-reinforced polymer (FRP) wrapping. Many researchers used this method i.e. Krishna [4], Soliman [5], and Ramana [6]. Basha et al [7] used Cementitious composite material to retrofitted the beam after preloading about 58% of failure load. Zhang [8], used the near surface mounted (NSM) FRP strengthening technique.

Ground Granulated Blast Furnace Slag (GGBFS) and Fly Ash (FA) has been widely used in some countries to partially replace the Ordinary Portland Cement (OPC) as Pozzolanic material. Many research studied the behavior of GGBFS as replacing part of OPC. Saresh [9], Kapoor [10], and Arivalagan [11] reported the benefit of using GGBFS in concrete. Some advantages in using cementitious material like GGBFS and Fly Ash are increasing concrete durability and reduce the crack width.

In Indonesia GGBFS produce by PT Krakatau Semen Indonesia. For these product, Dewi et al [12], showed that 40%GGBFS from PT Krakatau Semen Indonesia results an optimum workability and strength of concrete.

This study presents investigation about the repair on 12 beams with external reinforcement. The main objective was to explore the effectiveness of adding external reinforcement to repair and increase the beam capacity. The main parameter investigated were concrete quality, failure mechanism, ultimate load, ductility, and stiffness. The other parameter was looks is the difference between normal concrete and concrete had adding of cementitious aggregates.

2. Experimental Program

2.1. Material and specimen fabrication

The normal concrete and concrete added with GGBFS and Fly Ash were used to make beam specimen. There were 4 types of concrete (1) normal concrete, (2) used 20% FA, (3) used 40% GGBFS, and (4) used 40% GGBFS + 20% FA. All concrete mixed to had same concrete quality fc 22.5 MPa.

2.2. Original beam specimen

Three cylinder samples of each concrete type were test in compression, the results shown in Table 1.

| Concrete Type | Concrete strength MPa | Average |
|---------------|------------------------|---------|
| A1, Type-1    | 21.8                   | 22.46   |
|               | 23.2                   |         |
|               | 22.4                   |         |
| A1FA, Type-2  | 22.1                   | 22.7    |
|               | 23.4                   |         |
|               | 22.6                   |         |
| A3, Type-3    | 23.1                   | 22.67   |
|               | 22.8                   |         |
|               | 22.1                   |         |
| A3FA, Type-4  | 23.1                   | 22.8    |
|               | 22.7                   |         |
|               | 22.6                   |         |

2.3. Retrofitted Beam Specimen

After tested in four points load and had bending failure, all the beams were retrofitted by throw away the broken part of concrete, restore deflection to previous. For ensuring the composite action then it was infilled with Sika-Grout mortar. On the beam that has been repaired the additional tensile reinforcement then glued to with Sika-bond. After that the additional external U-stirrups envelop the
beam, glued with Sika-bond. There were two type of additional tensile reinforcement 2φ6 for type-1 and type-3 concrete, and 3φ6 for type-2 and type-4 concrete. The arrangement of retrofit beam shown in Figure 1. The sectional details of the specimen are shown in Figure 2, and the image of retrofitted bar showed in Figure 3.

![Figure 1. Retrofitted Stirrups and Bottom Tensile Steel](image1)

![Figure 2. B1 and B2 Retrofitted Cross Section](image2)

![Figure 3. Retrofitted stirrups and bottom tensile steel](image3)
3. Test setup
Simply supported beam specimens are tested under a two-point loading to study the mid-span positive flexural capacity. An actuator was used to apply displacement controlled loading. The applied load was measured by a load cell. Linear variable differential transducers (LVDTs) were used to measure the deformations. The arrangement of loading setup showed in Figure 4.

![Diagram of loading setup]

**Figure 4.** Test setup of beam specimen

4. Test results

4.1. Loading of original specimen
Ten of twelve specimen had flexural failure mode, one had shear failure mode, and one had transition from flexural to shear failure mode. The beam with flexural failure mode had average ultimate load 40 kN, beam with shear failure mode had ultimate load 35 kN. The Load deformation curve shown in Figure 5.

![Load deflection curve of original beam]

**Figure 5.** Load deflection curve of original beam

![Load deformation curve of retrofitted beams]

**Figure 6.** Load deformation curve of retrofitted beams
4.2. Loading of retrofitted specimen

The retrofitted specimen loaded with the same load position with original specimen. The load deformation curve of retrofitted beams showed the less ductility than the original ones except two beams, as shown in Figure 6.

4.3. Comparison between original and retrofitted beam

The ultimate loads and crack loads of original and retrofit specimen shown in Table 2. The average increase of ultimate loads and crack loads were 123% until 163%.

Table 2. Flexural loads original and retrofitted beams

| Specimen | Original beam load kN | Retrofitted beam load kN | Ratio      |
|----------|-----------------------|--------------------------|------------|
|          | failed | crack | failed | crack | failed | Crack         |
| A1       | 42     | 21    | 60     | 31    | 1.25   | 1.27          |
| B1       | 40     | 21    | 44     | 23    |         |               |
| Type-1   | 48     | 24    | 59     | 30    |         |               |
| A1FA     | 47     | 23    | 50     | 25    | 1.3     | 1.31          |
| B2       | 46     | 23    | 50     | 25    |         |               |
| Type-2   | 49     | 24    | 85     | 42    |         |               |
| A3       | 50     | 24    | 63     | 31    | 1.2     | 1.23          |
| B1       | 52     | 25    | 53     | 27    |         |               |
| Type-3   | 48     | 23    | 64     | 31    |         |               |
| A3FA     | 50     | 25    | 78     | 38    | 1.57    | 1.63          |
| B2       | 48     | 23    | 75     | 37    |         |               |
| Type-4   | 46     | 21    | 77     | 38    |         |               |

To compare the results, four sample of load deflection curve original beam and retrofitted beam shown in Figure 7.

![Graphs showing load deflection comparison](https://via.placeholder.com/150.png)

Figure 7. Sample comparison of load deflection original and retrofitted beam.
It is shown in Figure-7 that there were a slightly reduce of stiffness before cracks, then it was increased until the yield point. Use of BBGFS and Fly Ash increase the capacity of original beams but there was no influence in capacity increasing after retrofitted. Number of steel bar adding influence the increasing capacity after retrofitted.

Failure mode of all specimens were flexural failure with crack number less than the original specimen. Positions of cracks also different than the original position. It was indicating that grouting in retrofitting process were satisfied. The crack width of retrofitted beam also less than the crack width of the original beam, because adding of reinforcement increase the steel ratio then reduce the ductility. Two sample of beam cracks mode before and after retrofitting shown in Figure 8.

Figure 8. The cracks pattern of original and retrofitted beam

5. Conclusion
The present research has investigated the effect of retrofitting by repair cracks and adding stirrups and bottom tensile bars on the beam. Performance of beams strength, ductility, stiffness, and cracks pattern has been illustrated. Following conclusions have been obtained from the present research.

- The repair of cracks by grouting reduce small stiffness before crack.
- Crack repair with Sika-Grout increase the cracks load.
- Adding of bottom tensile steel should increase the strength but reduce the ductility.
- Adding of stirrups prevent the flexural failure of the beams.
- Crack width were reduced after retrofitting because it had been increase of steel ratio.
- Changed position of cracks before and after retrofitting indicate satisfied performance of grouting adhesive.
- Cementitious material has no effect on crack width.

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