Strengthening of Reinforced Concrete Stepped Beam Using Cotton Belt (New Technique)

Zahraa Abd Alhussein and Abdulkhaliq A Jaafer
Civil Engineering Department, Engineering College, University of Misan
E-mail: zahraa1995@uomisan.edu.iq

Abstract. The stepped beam is a type of non-prismatic beams that extend the stepped joint by stress collection and require adequate detail for this joint to prevent early failure. This research demonstrates an experimental study aimed at the behaviour of reinforced concrete stepped beams. The status issue is the premature failure of the stepped joint. The experimental program consists of eight concrete beams. All beams are tested under a four-point load. Three variables are studied in this work, the first of which is compressive strength, which is normal strength of 40 MPa and high strength of 80 MPa. The second variable is the details of the steel reinforcement at the stepped joint and the third variable is the strengthening with a cotton belt. Models achieved increases ranging from (26.3-37.4) kN, (1.88-3.95) mm, and (31.75-116.882) kN.mm in the ultimate capacity, deflection, and energy absorption respectively. Whereas it showed a decrease ranging (14.38-27.68) in the initial stiffness for the compression strength variable. As for the rebar detail variable, it showed an increase ranging between (39-138) kN, (7.5-28.29) mm, (244-3099.619) kN.mm, and (22.285-31.425) kN/mm, for the maximum load, deflection, energy absorption, and initial stiffness, respectively. On the other hand, the strengthened beams achieved an increase in the maximum load by 120% with a slight decrease in stiffness by 3.5% concerning an unstrengthened beam.

Keywords. Concrete stepped beam, Cotton belt, deflection.

1. Introduction
The stepped beam is an example of non-prismatic beams. It is used in different structures such as buildings and bridges. It is utilized for aesthetic, servicing, and structural purposes. The most common applications of stepped beam appear in theaters and support –level floors. The problem in this study is premature failure of the stepped joint, so external strengthening is used by the cotton belt as well as internal strengthening by changing the reinforcement details to prevent early failure. No previous studies dealt with the use of locally available cotton fibers in the name of cotton belt in strengthening. It is known that the characteristic of fiber-reinforced polymer (FRP) composite material compared to other reinforcing materials make it a reasonable choice for applications in civil engineering. Such materials may be designed and used in the form of rods, laminates, dry fibers (sheets) adhesively attached to the concrete, surface-based wet lay-up sheets or laminate strips in the concrete cover or bars mounted near the surface [1]. In order to develop the best method for installing CFRP fabric sheets and/or strips, a significant number of experiments on the behavior of CFRP reinforced beams have been carried out over the years in order to have a deeper understanding of their behavior under various loading conditions. There are some drawbacks associated with the application of CFRPs attributed to the CFRP reinforcing schemes currently applicable for commercial properties.
Yet, the strength of CFRPs is high, and they are very brittle. FRPs show linearly stress-strain conduct up to failure when loaded in tension, without showing a yield plateau or any indication of an impending failure. Because FRPs behave differently from steel and therefore suffer a great loss in the beam ductility, especially when CFRPs are used for RC beam flexural reinforcement [2–7]. Hussain and Safiq [8] offered an experimental investigation of eight stepped beams rehabilitated with CFRP. The results revealed that the improvement of the flexural strength of strengthened beams depends on the bond strength interface between concrete substrate and CFRP. Shallan et al. [9] studied the behavior of a stepped reinforced concrete beam under static loads. They provided an experimental and analytical study to verify the ultimate capacity of the stepped reinforced concrete beam. Analytical results showed good agreement with the experimental results. Shree and Kumar [10] introduced a numerical investigation using the ANSYS program to study the influence of transverse cracks on the performance of a stepped reinforced concrete beam strengthened with CFRP. The study suggested different configurations for the CFRP strip to prevent the progress of the cracks under the effect of seismic loading. Atta and El-Shafiey [11] performed an experimental study of the torsional behavior of recessed RC beams and investigated the torsional application of FRP sheets, FRP laminates, and external pre-stressing steel. The important finding of these experiments is that relative to other reinforcement techniques, the use of external pre-stress reinforcement techniques improved cracking loads, failure loads, and ductility. In Gold et al. [12], several strengthened FRPs dapped end beams were used on three floors Parking Garage. A series of tests were carried out to verify effectiveness of FRP as well as the predictive performance in their design approach, and they found that they had double the capacity of the reference samples. Gyorgy et al [13] studied experimentally and numerically the efficiency of strengthening dapped-end reinforced concrete beams using externally bonded carbon FRP.

2. Research significance
   1. Studying the behavior of stepped reinforced concrete beams.
   2. Increasing the strength of stepped reinforcement concrete beams that are strengthened by the cotton belt.
   3. Determining the effects of cotton belt strengthening on stepped reinforcement concrete.
   4. Improving the strength of stepped concrete reinforcement beams by changing the internal reinforcement details.

3. Experimental program
A total of eight identical RC stepped beam samples each with a dimension of 150 mm wide, 300 mm deep, and 2300 mm long are fabricated and tested up to failure. The arrangement of longitudinal and transverse reinforcement of all tested beam specimens are summarized in Figures (1) to (5). Beams N, H, Ni, Hi are left as the control specimen. The remaining beams are strengthened with internal steel reinforcement or externally using belt strips. Beam (H-int) is strengthened using internal horizontal and vertical reinforcement using a steel bar of 8 mm diameter spaced 30 and 40 mm, respectively. Beam (H-inc) is strengthened using internal horizontal, vertical, and inclined reinforcement using a steel bar of 8 mm diameter spaced 50 mm. Beams Nw1 and Hw1 are externally strengthened using a belt strip (natural cotton) of U configuration, Table 1.
### Table 1. Details of beams.

| Specimen | Compressive strength | Average compressive strength (Mpa) | Additional rebar | Strengthening |
|----------|----------------------|------------------------------------|------------------|---------------|
| N        | Normal 45.6          | 45.68                              | -                | -             |
|          | 46                   |                                    |                  |               |
|          | 45.2                 |                                    |                  |               |
|          | 45.52                |                                    |                  |               |
|          | 46.1                 |                                    |                  |               |
|          | 45.68                |                                    |                  |               |
| H        | High 85.9            | 85.81                              | -                | -             |
|          | 86.462               |                                    |                  |               |
|          | 85.806               |                                    |                  |               |
|          | 86.2                 |                                    |                  |               |
|          | 85.3                 |                                    |                  |               |
|          | 85.2                 |                                    |                  |               |
| Ni       | Normal 45.6          | 45.68                              | -                | -             |
| Hi       | High 85.81           |                                    |                  | -             |
| H-int    | High 85.81           |                                    |                  | -             |
|          | the additional bar at stepped (20 vertical and 10 horizontal) | Additional rebar |               |
|          |                       |                                     |                  |               |
| H-inc    | High 85.81           |                                    | additional inclination stirrups (3 at 50 mm) | - |
| Nw1      | Normal 45.68         |                                    | -                | Using cotton belt in the middle part were U shape |
| Hw1      | High 85.81           |                                    | -                | Using cotton belt in the middle part were U shape |

![Figure 1. Details of beams N and H.](image1)

![Figure 2. Details of beams Ni and Hi.](image2)
The concrete used is normal and high strength concrete of 40 and 80 MPa, respectively. The transverse steel form was mild steel with a yield strength of 420 MPa and an ultimate tensile strength of 530 MPa. The Young modulus of elasticity is 200 GPa for both types of reinforcements.

3.1. Belt strip

A belt is a textile product that is supplied as woven tape, tie, or ribbon. The belt unfolds when cut, a feature that distinguishes it from cordage. Specifications for ropes, cordage, and girders include building materials, dimensions, characteristics, applications, and structural features. The belt is often made from synthetic or polymeric materials and natural fibers such as cotton, wool, acetate, and triacetate fibers. Material type choices also include acrylic, metallic acrylic, aramide, elastomers, nylon or polyamide, olivine or polyolefin, polyester, polyethylene, polypropylene, rayon, and polyvinyl chloride (PVC). Some cords, ropes, and straps are made of glass, fiberglass, ceramic, or mineral fiber. Others are made from blended fiber structures. Leather, hemp, jute, linen, and linen textile products are also available. The type used in the present study is a cotton belt. The cotton belt has good heat resistance. When it is below 110 °C, it will only cause evaporation of moisture on the webbing and will not damage the fiber. Therefore, the pure cotton webbing is used at normal temperatures, and all
the processes of washing, printing, and dyeing will not damage the cotton webbing. So, the cotton webbing has a strong resistance to damage. It is available in the local markets of different sizes. It is a very cheap material. Its dimensions of the cotton belt used are 75 mm wide with (3mm) thick, as shown in Figure 6.

![Cotton belt](image)

**Figure 6.** Cotton belt.

### 3.2. Cotton belt installation

The surface was sprayed with fine sand firstly then a primer (Sika floor) is used. The cotton belt is cut to the required lengths. The work included Mix Part A and B together according to the manufacturer's technical data until light gray. The adhesive consisted of two parts (white and gray) (comp. A and comp. B). To the concrete surface, a thin layer of mixed epoxy was applied. This will impregnate the cotton belt after applying them to the concrete component. The adhesive is applied to the cotton belt with the same thickness. The cotton belt is put on the concrete, so, the epoxy is on the epoxy, and a rubber roller is used with direction of the cotton belt to remove the air bubbles trapped behind the cotton belt properly by applying enough pressure so that the epoxy was forced to exit on both sides of cotton belt. Figure 7 shows the steps for adjusting the webbing on the concrete beam.

![Concrete preparation steps](image)

**Figure 7.** Preparing and setting the cotton belt.
4. Result and discussion

All failure features resulting after the total collapse of beams were presented in Table 2. The parameters are mostly related to the failure modes for reference beams and cotton belt strengthened beams are discussed in detail in the following. The parameters considered include failure mode, relationship of load-deflection, ductility, toughness, ultimate capacity, initial stiffness and cracking load.

Table 2. Failure characteristics and experimental results after the complete failure of all beams.

| Specimen | Ultimate load (KN) | Crack load (KN) | Pcr/pu | Deflection (mm) | Toughness (kN.mm) | Ductility index (∆u/∆y) | Initial stiffness (kN/mm) | Mode of failure |
|----------|--------------------|-----------------|--------|-----------------|-------------------|------------------------|--------------------------|-----------------|
| N        | 26.3               | 21              | 0.80   | 1.88            | 31.75             | 1.97                   | 27.68                    | Flexural failure |
| H        | 37.4               | 27.3            | 0.73   | 3.95            | 116.88            | 4.38                   | 41.55                    | Flexural failure |
| Ni       | 36.2               | 22.9            | 0.63   | 5.52            | 133.32            | 2.12                   | 13.92                    | Flexural failure |
| Hi       | 39                 | 28.3            | 0.72   | 7.5             | 244.50            | 4.28                   | 22.28                    | Flexural failure |
| H-int    | 138                | 62              | 0.45   | 28.29           | 3099.61           | 5.65                   | 27.60                    | Flexural failure |
| H-inc    | 125.7              | 90.7            | 0.72   | 23.31           | 2326.82           | 5.82                   | 31.42                    | Flexural failure |
| Nw1      | 51.4               | 45.2            | 0.88   | 19.22           | 899.25            | 8.73                   | 23.36                    | Rupture of cotton belt followed by flexural failure |
| Hw1      | 86                 | 63              | 0.73   | 10.10           | 584.23            | 3.48                   | 29.65                    | Rupture of cotton belt followed by flexural failure |

4.1. Modes of failure

The mode of failure of the N-beam is a flexural failure mode where the cracks began to appear in the tension zone of the stepped joint kink in a concentrated load of 21 kN. The increase in load led to an increase in the spread of the diagonal cracks in the stepped joint until there is a complete collapse of the beam in the flexural mode of failure. When changing the compressive strength of concrete from normal (40 MPa) to high strength (80 MPa) in the H-beam, a delay resulted in in the appearance of a crack, durability increased, and the crack began to appear at a load of 27.3 kN. When changing the rebar details in the beams (Ni and Hi) crack began to appear at the loads 22.9 and 28.3, respectively. The formation of cracks is hindered by the use of inclined stirrups within the stepped joint of the beam, which started to occur at a vertical load of around 90.7 kN. When the steel reinforcement is distributed intensely in the stepped joint of the (H-int) beam, it reduced the spread of the crack as it began to appear at the vertical load 62kN. The beams (H-int, H-inc) showed a behavior similar to the behavior of the beam (Hi) even failure except that the spread of cracks is less than that of the Hi-beam. In the beam (Nw1) the failure was a rupture in the cotton belt followed by flexural failure. The crack began to appear at a vertical load of about 45.2 kN. When the load is increased, it produced rupture in the cotton belt. Failure in the Hw1 beam is similar to that of the Nw1 beam where the strengthened pattern is the same, the crack began at 63kN load. The results showed that the beam strengthened by the cotton belt with high strength concrete gave a better result than the beam of normal strength concrete by 67.3%. The (H-int) beam showed the best results. The failure properties have significantly changed. Cracks appeared and the final capacity improved. The beam (N) exhibited a failure mechanism similar to that of beam H, excluding vertical load which was lower than that of beam (H). 

The failure patterns for all beams are seen in Figure 8.
4.2. Load–deflection response

Figure 9 shows the load-deflection curves for all tested specimens. It can be noted that the load against mid-span deflection response can be divided into three stages of behavior from the load-deflection curves of the tested beams. The linear behavior of the load-deflection response is observed in the first stage. In the second stage, the nonlinear behavior of the load-deflection response is noticed. Finally, when the applied load reaches its ultimate value in the third stage, the rate of increase in deflection greatly exceeds the rate of increase in the value of the applied load. Table 2 presents the deflection of all concrete beams. The results showed that the maximum deflection of the reference beams (N, H, Ni,
Hi) is (1.88,3.95,5.52,7.5) mm, respectively. When the compressive strength of concrete for the beams is changed from normal strength to high strength, it was noted that deflection results increased by (110 and 35.8)% in the beams (H and Hi ) when compared to (N and Ni), respectively. This means that changing the strength of the concrete positively affects the deflection. The cotton belt is used in (Nw1, Hw1) showed a gradual increase in the strengthened beams, the maximum deflection (19.22, 10.10) mm showed a 248 % increase in Nw1 compared to the Ni reference beam and 34.66 % in Hw1 compared to Hi. The results showed that changing the internal steel reinforcement details, beams, (H-int, H-inc) gave the maximum deflection (28.29,23.31) mm with an increase of (277.2,210)%, respectively. If a connection between the load failure and the maximum deflection was performed, it can be noticed that the beam (H-int) is the optimum.

Figure 9. Vertical load for all beams versus mid-span deflection.

4.2.1. Initial stiffness. The initial stiffness is the slope of the first part of the load-deflection curve. It is calculated by dividing the ultimate applied load (Pu) by the yield deflection (Dy). The equation used is shown below:

Initial stiffness=Pu/Dy.

The beams (N, H, Ni, Hi) recorded initial stiffness as (27.68,41.55,13.92,22.92) kN/mm, respectively, and the strengthened beams (Nw1, Hw1) recorded the initial stiffness (23.36 and 29.655) kN/mm with an increase by 87.2% in Nw1 when compared to Ni and 33.1% in the beam Hw1 when compared to Hi. While the beams H-int and H-inc have a stiffness of (27.6, 31.425) kN/mm. Note that the high strength beam achieved higher stiffness than the normal strength beam. The results are shown in Figure10.

4.3. Ultimate capacity, toughness, and cracking load

4.3.1. Ultimate capacity. The ultimate loads for all concrete beams are recorded and presented in Table 2. The beam (Hi) which represents the reference sample achieved the maximum failure load of (39kN), and when changing the internal strengthening, the maximum failure load reached (138 kN) in the beam (H-int) with an increased rate of 253% compared to the reference sample. This improvement in strength is attributed to the presence of intense reinforcement. For the beam (H-inc) the ultimate load is 125.7 with an increase of about 220% for the reference beam. This improvement in strength is attributed to the presence of an inclined reinforcement. As for the external strengthening, the ultimate load (51.4 kN) was observed with an increased rate of 41.89 % compared to the reference beam (Ni)
using a cotton belt for the beam Nw1. The Ni beam representing the reference beam achieved a maximum failure load of (36.2kN), when changing the compressive strength of concrete to high strength. For the same strengthening pattern in the beam Nw1, it is observed that the maximum failure load of the beam Hw1 is 86kN increased by 120.5 % compared to the reference beam (Hi). This improvement in strength is attributed to the presence of the cotton belt. Also, the presence of cotton belt gives another advantage, it shifts the crack from several widely spaced and large width cracks to many more closely spaced narrower cracks and when comparing the beam of high strength with normal strength (Hw1 with Nw1), an increase in strength is observed at 67.3 %. This increase is due to the different properties of resistance. High-strength concrete provides higher compressive strength, a higher modulus of elasticity, a higher tensile strength, and greater durability than normal-strength concrete. This indicates that the Hw1 beam is better in strengthening.

4.3.2. Toughness. Toughness is the ability of a material to absorb energy and plastically deform without fracturing. One definition of material toughness is the amount of energy per unit volume that a material can absorb before rupturing. It can be described as the region under the load-deflection curve. References beam recorded an energy absorption of (N, H, Ni, Hi) as (31.75, 116.882, 133.32, 244.5) kN.mm. This showed a very large increase in energy absorption due to changing the details of the internal reinforcing steel. The (H-int and H-inc) beams absorb energy (3099.619, 2326.823) kN.mm, which is greater than the reference beams by (1167.73, 851.66) %, respectively. Strengthened beams (Nw1, Hw1) increased by 574.5% for the beam Nw1 compared to Ni, and 138.9% for the beam Hw1 compared to Hi. The results showed that the high-strength concrete H-int achieved a higher failure load of 138 kN and a deflection of 28.29 mm; therefore, toughness of 3099.61 kN.mm was achieved. As for normal concrete Ni, it had a higher failure load of 36.2kn and a deflection of 5.52 mm, and a toughness of 133.32kN.mm was achieved. Therefore, the high compression strength is higher than the normal absorption of energy indices as per ASTM C1018 [14].

4.3.3. First cracking load (Per) for a concrete beam. The first crack load for all concrete beams was recorded and presented in table (1). The first crack in the reference beams (N, H, Ni, and Hi) were at load (21, 27.3, 22.9, and 28.3) kN, respectively. Strengthened beams (Nw1, Hw1) increased by (97.3, 122.614)% when compared to (Ni and Hi), respectively. When changing the detail of steel reinforcement in the beams H-int and H-inc, it was noted that H-int increased by 119.2% and H-inc increased by 220% when compared to Hi. The cracking load to the final load is shown in Table 2.
5. Conclusion

1. Additional reinforcement in H-int and H-inc lead to an increase in the ultimate capacity by 253.8% and 222.3% when compared to the Hi beam. Adding more steel in the joint enhances the maximum capacity.
2. The externally strengthened reinforced concrete beams with a bonded belt strip generally show a significant increase in ultimate loads. This increase reaches up to 120% for a reinforced concrete beam.
3. The reinforced stepped beams strengthened with a cotton belt show lower deflections at corresponding loads compared to the reference beam due to the presence of the cotton belt.

6. References

[1] Etman EE 2011 Strengthening of T-Section RC Beams in Shear Using CFRP. In: Proceedings of Concrete Solutions (14th international conference on concrete repair, Dresden, Germany) vol 26–28 pp 649–60
[2] Arduini M and Nanni A 1997 Behavior of Pre-Cracked RC Beams Strengthened with Carbon FRP Sheets (Compos Constr) vol 1 no 2 pp 63–70
[3] Bencardino F, Spadea G and Swamy N 2002 Strength And Ductility Of Reinforced Concrete Beams Externally Reinforced with Carbon Fiber Fabric (ACI Struct) vol 99 pp 163–71
[4] Lee T, Pan A and Ma M 2004 Ductile Design of Reinforced Concrete Beams Retrofitted With Fiber-Reinforced Polymer Plates (J Compos Constr) vol 8 no 6 pp 489–500
[5] Saadatmanesh H and Ehsani M RC 1991 Beams Strengthened with GFRP Plates. I: An Experimental Study (Struct Eng.) vol 117 pp 3417–33
[6] Spadea G, Swamy RN and Bencardino F 2001 Strength, and Ductility of RC Beams Repaired With Bonded CFRP Laminates (Bridge Eng.) vol 6 pp 349–55
[7] Toutanji H, Zhao L and Zhang Y Flexural 2006 Behavior of Reinforced Concrete Beams Externally Strengthened with CFRP Sheets Bonded with an Inorganic Matrix (Eng. Struct. Vol 28 pp 557–66
[8] Hussain and Safiq 2016 Experimental Study for Stepped Reinforcement Concrete Beams (Engineering Challenges for Sustainable Future –Zawawi(Ed), 2016 Taylor & Francis Group, London) ISBN 978-1 vol 1 pp 138-02978
[9] Shalan, Mohamed, Abd-El-Mottaleb and Al-Ashmawy 2017 Behavior of Stepped Reinforced Concrete Beam Under Static Loads (International Journal of Engineering Research and Technology (IJERT), IJERT)
[10] Gobika Shree and Suresh Kumar 2018 Analysis of Stepped Beam with Multiple Transverse Cracks (SSRG International Journal of Civil Engineering (SSRG-IJCE)-Special Issue ICETSST)
[11] A M Atta and T F El-Shafey 2014 Strengthening of RC Dapped-End Beams under A Torsional Moment (Magazine of Concrete Research) vol 66 pp 1065–1072
[12] Gold WJ, Blaszak GJ, Mettemeyer M, Nanni A and Wuerthele MD 2000 Strengthening Dapped Ends of Precast Double Tees with Externally Bonded FRP Reinforcement (In: Elgaaly M, editor. ASCE Structures Congress, Philadelphia) p 9
[13] T Nagy-György, G Sas, A Dăescu, J A Barros and V Stoian 2012 Experimental and Numerical Assessment of the Effectiveness of FRP Based Strengthening Configurations for Dapped-End RC Beams (Engineering structures) vol 44 pp 291–303
[14] ASTM C 1018 1997 Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading) (American Society for Testing and Materials, 1997, West Conshohocken)