Simplified method of strengthening RC continuous T beam in the hogging zone using carbon fiber reinforced polymer laminate – A numerical investigation

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Though Reinforced Concrete (RC) continuous beams are vastly used in civil engineering, little experimental work on repairing and strengthening of continuous T beams has been carried out; especially, experiments on strengthening the hogging zone of continuous T beams are very rare. This paper attempts to address an important practical issue which is not considered in existing conventional strengthening technique that is, the installation constrains due to the presence of column. This paper also presents a straightforward technique of applying CFRP laminate for strengthening the hogging zone of continuous T beam considering the constrains caused by the column. The beams are modelled using FEM (LUSAS). Existing two well-known research works on strengthening continuous beams are also modelled using this FEM as case study, where a good agreement between the test results and results from FEM is observed. Finally, it is concluded that the proposed method is very easy and effective, and for obtaining complete design guideline for strengthening T beam; future recommendations are also visualized through this paper.

Key words: Carbon fiber, strengthening, hogging zone, continuous beam, numerical investigation.

INTRODUCTION

Concrete structures can become deficient during their service life and may require strengthening and repair. This need may arise due to design, construction errors, functional changes, design codes updates, damage accumulated over time or caused by accidental overloading, fires, or earthquakes. Since replacement of deficient structures requires huge investments, strengthening has become the suitable way for improving their load carrying capacity and prolonging their service life. While complete replacement of a deficient/ deteriorated structure is a desirable option, strengthening/repair is often the more economical one. While many methods of strengthening structures are available, strengthening structures via external bonding of advanced fiber-reinforced polymer composite (FRP) has become very popular worldwide. In the past decade, their application in this field has been rising due to the well-known advantages of FRP composites over other materials. Consequently, a great quantity of research, both experimental and theoretical, has been conducted on the behaviour of FRP strengthened reinforced concrete (RC) structures, including beams, slabs, and columns (Teng et al., 2002). In this regard, the evolving technology of using carbon-bonded fibre reinforced polymers (CFRP), for strengthening simply supported RC beams, has attracted much attention in recent years. Fibre reinforced polymer materials (FRP) such as pultruded plates, fabrics, and sheets have been used as strengthening materials for RC beams. In particular, their practical implementations for flexural strengthening are

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PREVIOUS RESEARCHES ON CONTINUOUS BEAMS

Although several research studies have been conducted on the strengthening and repair of simply supported reinforced concrete beams using external plates, there are few reported works on the behaviour of strengthened continuous beams. In addition, most design guidelines have been developed for simple supported beams with external FRP laminates (JSCE, 2001, Concrete Society 2000, TR 55, ACI 440R-1996). An exhaustive literature review revealed that a minimum amount of research work had been done for addressing the possibility of strengthening the hogging zone of continuous beam using FRP materials.

On the field of strengthened continuous beam, Grace et al. (1999) tested five continuous beams. Later, Grace et al. (2001) also investigated the experimental performance of CFRP strips used for flexural strengthening in the hogging region of a full-scale reinforced concrete beam. Grace et al. (2005) also worked on another research where three continuous beams were tested. On the other hand, El-Refaie et al. (2003a) examined eleven reinforced concrete (RC) two-span beams strengthened in flexure with external bonded CFRP sheets. In another research, El-Refaie et al. (2003b) tested five reinforced concrete continuous beams strengthened in flexure with external CFRP laminates. Ashour et al. (2004) tested 16 reinforced concrete (RC) continuous beams with different arrangements of internal steel bars and external CFRP laminates. Aiello et al. (2007) compared the behaviour between continuous RC beams strengthened with CFRP sheets at hogging or sagging regions and RC beams strengthened at both sagging and hogging regions.

Recently, Maghsoudi et al. (2008) examined the flexural behaviour and moment redistribution of reinforced high strength concrete (RHSC) continuous beams strengthened with CFRP. Finally, Akbarzadeh and Maghsoudi (2010) conducted an experimental program to study the flexural behaviour and moment redistribution of reinforced high strength concrete (RHSC) continuous beams strengthened with CFRP and GFRP sheets.

In all the above cases it is seen that all the researches were conducted on RC rectangular sections which are not representative of the fact that most RC beams would have a T-Section due to the presence of a top slab.

PROBLEMS OF STRENGTHENING THE HOGGING ZONE OF CONTINUOUS T BEAM

The hogging zone, namely the support region, of continuous reinforced concrete (RC) beams is a critical zone due to the simultaneous occurrence of maximum moment and shear. In addition, the presence of columns and other components such as electric and plumbing lines or HVAC ducts make difficult to strengthen this region using conventional techniques, like steel plate bonding, section enlargement, external stirrups etc. In the hogging zone, the strengthening is not as simple as in the case of sagging zone because the columns prevent the application of FRP system over the web portion of the beam. Another important point is that, the use of thick steel plates bonded to the floor surface will raise the floor level, which might be undesirable.

PROPOSED METHOD OF STRENGTHENING THE HOGGING ZONE OF T BEAM

To overcome the problems of strengthening the hogging zone of continuous T beam, a new method is proposed in Figure 1. In this proposed method, CFRP is applied on both sides of the column according to Figure 1. This method of applying CFRP will be easy to implement in existing concrete structures. In this context, due to its high strength ratio and ease of installation, CFRP can be used to provide an economical and versatile solution for extending the service life of concrete structures.

FEM MODELLING FOR THE PROPOSED METHOD

Discretization

A finite element program (LUSAS) is used to investigate the structural behavior of continuous T beam. Two beams are modeled. The first one is control, that is, devoid of strengthening while the second one is strengthened with CFRP laminate. The stem in the strengthened beam is representing the column and the loading arrangement is made in such a way that the flange portion of the T beam is in tension to represent the practical situation. The superposition of nodal degrees of freedom assumes that the concrete and reinforcement are perfectly bonded. It is assumed that
the self-weight of the beam is negligible compared with the applied load and that the effects of any shear reinforcement can be ignored. CFRP surface elements are attached to the surface of the concrete directly and perfect bonding between strengthening plate and the concrete surface is assumed to avoid premature debonding failure. The concrete as well as CFRP section is represented by plane stress (QPM8) elements, and the reinforcement bars are represented by bar (BAR3) elements. A nonlinear concrete cracking material model (cracking model 94) is applied to the plane stress elements and a von Mises plastic material is applied to the reinforcement bars. Units of N, mm, t, s, C are used throughout.

Control beam, strengthened beam and material properties

Details of the control beam are shown in Figures 2 to 6; that of the strengthened beam are shown in Figures 7 to 9; and material properties of concrete beam for numerical modeling are shown in Table 1.

RESULTS OF FEM AND CASE STUDY

The results obtained from the FEM are shown in Table 2. To validate the proposed model (case study), eight continuous beams based on previous research works are modeled and the results obtained from the modeling are compared with their experimental results. The following are the description of FEM of previously tested beams by other researchers:

Continuous beams testing

Details of continuous beams tested by Akbarzadeh and Maghsoudi (2010) are shown in Figures 10 to 15 and Table 3; and that tested by El-Refaie et al. (2003a, b) are shown in Figures 16 to 18 and Table 4.

DISCUSSION

Comparison and comments on results

Test results and FEM results are compared in Table 5. From Table 2, it is seen that 58% load increment is possible by this proposed method of applying CFRP for strengthening the hogging zone of continuous T beam. From the case study we observe a good relationship.
between the experimental results and the FEM results. It can be concluded that the proposed method of applying CFRP for strengthening the continuous T beams in the hogging zone is very effective, efficient and easy.

**FUTURE NEEDS AND CONCLUSION**

A review on existing research works shows that strengthening RC continuous beams, especially continuous T beam is still in its infancy. The parameters such as effective length, width, thickness and appropriate anchorage system of CFRP for strengthening RC continuous T beams are in the need of extensive research. In other words, to prepare a complete design guideline for strengthening RC continuous T beam with CFRP, further research is necessary.

This paper modelled two existing well-known research works on continuous RC beams strengthened by CFRP. It addressed an important practical issue on strengthening the hogging of RC continuous T beam. A
Figure 9. Load versus Deflection graph of strengthened beam.

Table 1. Material properties of concrete beam used for numerical modeling.

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Steel bar</th>
<th>Strengthening plate</th>
<th>Span of the beam (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_c$ (MPa)</td>
<td>$E_c$ (MPa)</td>
<td>Poisson ratio</td>
<td>$f_y$ (MPa)</td>
</tr>
<tr>
<td>40</td>
<td>30000</td>
<td>0.2</td>
<td>560</td>
</tr>
</tbody>
</table>

Figure 10. Details of beams tested by Akbarzadeh and Maghsoudi (2010).
Table 2. Results from FEM.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Ultimate load (KN)</th>
<th>Increase over control beam (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control beam</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Strengthened beam</td>
<td>119</td>
<td>58</td>
</tr>
</tbody>
</table>

Figure 11. Meshing and loading pattern of beams.

Figure 12. Load versus Deflection graph of beam CB.

Figure 13. Load versus Deflection graph of beam SC1.
Figure 14. Load versus Deflection graph of beam SC3.

Table 3. Material properties of the beam tested by Akbarzadeh and Maghsoudi (2010).

<table>
<thead>
<tr>
<th>Beam no.</th>
<th>fc (MPa)</th>
<th>fy (MPa)</th>
<th>Type of FRP</th>
<th>Positive moment strengthening</th>
<th>Negative moment strengthening</th>
<th>Thickness of each layer (mm)</th>
<th>Width of CFRP (mm)</th>
<th>Young's Modulus of FRP E (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB</td>
<td>74.2</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC1</td>
<td>74.6</td>
<td>412.5</td>
<td>CFRP</td>
<td>0</td>
<td>0</td>
<td>0.11</td>
<td>145</td>
<td>242000</td>
</tr>
<tr>
<td>SC2</td>
<td>74.1</td>
<td></td>
<td>CFRP</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC3</td>
<td>74.4</td>
<td></td>
<td>CFRP</td>
<td>2, 1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 15. Load versus Deflection graph of beam E1.

<table>
<thead>
<tr>
<th>Beam no</th>
<th>$f_c$ (MPa)</th>
<th>$f_y$ (MPa)</th>
<th>Type of FRP</th>
<th>Positive moment strengthening</th>
<th>Negative moment strengthening</th>
<th>Thickness of each layer (mm)</th>
<th>Width of CFRP (mm)</th>
<th>Young’s Modulus of FRP $E_f$(MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>24.0</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>1.2</td>
<td>100</td>
<td>150000</td>
</tr>
<tr>
<td>E2</td>
<td>43.6</td>
<td>520</td>
<td>CFRP</td>
<td>0</td>
<td>1</td>
<td>2500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E3</td>
<td>47.8</td>
<td>13500</td>
<td>CFRP</td>
<td>1</td>
<td>0</td>
<td>3500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E4</td>
<td>46.1</td>
<td>12500</td>
<td>CFRP</td>
<td>1</td>
<td>1</td>
<td>3500</td>
<td></td>
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simple method of applying CFRP for strengthening the hogging zone of RC continuous T beam is proposed in this paper and its appropriateness is visualized through FEM and case studies. The FEM thus verified the proposed method of applying CFRP to strengthen the hogging zone of concrete T beam. It further proves that this method of strengthening is suitable for practical application.

REFERENCES


