NUMERICAL ANALYSIS OF INTERFACE STRESSES OF RC BEAMS STRENGTHENED WITH PRE-STRESSED HYBRID CFS-GFS

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ABSTRACT

The application of fibre reinforced polymer (FRP) as tension reinforcement has been widely used in repair and strengthening of concrete structures. The hybrid FRP sheets, which consist of a combination of carbon fibre sheets (CFS) and glass fibre sheets (GFS), have non-linear behavior. In this paper, firstly, the FEM analysis model of interfacial stresses of RC beams strengthened with hybrid CFS-GFS is created. The simulation results indicate the shear stress of the beams strengthened with hybrid CFS-GFS is smaller than that of the beams strengthened with double layered CFS, which shows that the interface of the beams reinforced with hybrid CFS-GFS is better than that with CFS. Secondly, FEM is employed to analyze the RC beams strengthened with pre-stressed hybrid CFS-GFS. The results show that the maximum interfacial stresses can be reduced considerably and the efficiency of the high strength fibre sheet is improved when the anchor fastnesses are employed at the strengthening ends.

KEYWORDS

Hybrid strengthening, Interface stress, Pre-stress, Nonlinear FEM

INTRODUCTION

Carbon fibre reinforced polymer offers advantages of composite materials, such as the low ratio of volume to weight, high corrosion resistance, good durability and ease of application (Youssef et al. 2006; Li et al. 2006a). The application of Carbon fiber sheet (CFS) as tension reinforcement has been widely used in repair and strengthening of concrete structures. Whereas the poor material performance of CFS is low specific elongation, brittle and easily broken off after cured adhesive. The material brittleness restrains the stress redistribution in concrete strengthening component and embarrasses its wider application (Guo et al. 2006a; Li et al. 2006b).

When two different fibre reinforced polymer (FRP) sheets are used together to strengthen reinforced concrete beams, high ductility of glass fiber sheets (GFS) and high strength of CFS can compensate each other, and the failure of concrete beams from micro to macro process can be stayed. When two type of fibre sheets are mixed to strengthen concrete beams, the average rupturing strain energy of concrete beams can be improved (Guo et al. 2006b; Li et al. 2005). The mechanical property of single fibre sheet is improved and the the strengthening cost is reduced. Therefore hybrid strengthening of CFS-GFS will be widely used for strengthening engineering structures.

The property of high strength of FRP is adequately brought into use for strengthening efficiency when steel reinforcement yield. FRP takes the limited role before main reinforcement yield and may be difficult to control structural deformation and crack propagation. In order to fully utilize the property of high strength of fibre material and obtain perfect strengthening effect, Huang (2005) used theoretical analysis method to deduce the computational formula of the effective pre-stress, loss of pre-stress and allowable stretching pre-stress in RC beams pre-stressed by FRP. Also, comparative study between RC beams strengthened with FRP under two groups of pre-stress is presented. Samer (2007) deduced simplified computational formula of loss of pre-stressing and stress variation of pre-stressed concrete under long-term loading, which considered the influence of creep and shrinkage of concrete. The experimental investigation of four-point bending failure mode in RC beams pre-stressed by CFS carried out by Garden (1998) showed that cracking of adhesive layer and shear failure were restrained by the present of pre-stress. This paper attempts to analysis the mechanical behaviour of interfacial
adhesive layer of RC beams under different pre-stress and pre-stressed hybrid fibre sheet (CFS-GFS) and to
discusses the feasibility of the new strengthening technique by numerical method.

DESCRIPTION OF FINITE ELEMENT MODEL AND MATERIAL MODELS

The CFS and GFS are considered as linear elastic material as shown in Fig.1 (a). The hybrid composite material
of CFS-GFS can be seen as the new property material as shown in Fig.1 (b).

There exists new material performance for the hybrid CFS-GFS composite, for the load is chiefly born by CFS
which has higher modulus of elasticity before the appearance of material yielding, whereas GFS has higher
ductility, which continues to bear the load after CFS is snapped as the load increases, then the deformation of the
beam carries over, the strain energy of the beam releases and the stress of the beam redistributes via the cracking
and deformation in the concrete. This collapse mode of concrete beams strengthened with CFS-GFS has certain
plastic performance which avoids the obvious brittle failure caused by single strengthening material.

COMPARING OF INTERFACIAL PERFORMANCE

As Fig.1 shows, for the present analysis model, there are three parts in a strengthening beam, i.e. concrete, FRP
composite and adhesive layer. Two point loads are symmetrically positioned.

The local finite element model is shown in Fig.3. 4-node element of plane stress is used for the concrete,
interfacial adhesive layer and fibre sheet. Refined elements are used on the place near the end of FRP
considering the upper interfacial stress concentration.
The material property is shown in Table 1. There are two types of strengthening models for analysis, which includes mono-layer CFS strengthening model with 0.11mm thickness of CFS, and double layer CFS strengthening model, with 0.22mm thickness of CFS. The thickness of adhesive is 0.2mm in both cases.

<table>
<thead>
<tr>
<th>Material style</th>
<th>Theoretical Thickness</th>
<th>Tensile strength</th>
<th>Young’s modulus</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>200mm</td>
<td></td>
<td>30GPa</td>
<td>0.20</td>
</tr>
<tr>
<td>Adhesive</td>
<td>0.2mm</td>
<td></td>
<td>2GPa</td>
<td>0.35</td>
</tr>
<tr>
<td>CFS</td>
<td>0.11mm</td>
<td>4100MPa</td>
<td>235GPa</td>
<td>0.30</td>
</tr>
<tr>
<td>GFS</td>
<td>0.19mm</td>
<td>1800MPa</td>
<td>81.6GPa</td>
<td>0.30</td>
</tr>
</tbody>
</table>

The FEM solutions are compared with the theoretical solutions (Smith and Teng, 2001) and the interfacial shear and normal stress distributions near the FRP end are shown in Fig.4. It is shown that the FEM results agree well with the analytical results. The interfacial normal stress is seen to change sign at a short distance away from the plate end. In the region of negative interfacial normal stresses, the additional bending deformations in the FRP due to interfacial shear stresses were taken into account for the predictions of those solutions (Tounsi, 2006).

Fig.5 presents the comparing of interfacial stress of concrete beam strengthened with CFS-GFS and concrete beam strengthened with double layer of CFS. Compared with double-layer CFS strengthening, the shear stress of adhesive layer will be reduced considerably by CFS-GFS strengthening technique, but the decrease of normal stress is not so obvious. It can been seen from Fig.5 that larger plate thickness was used for CFS-GFS than double layer CFS, which means that the decrease of shear stress conceration at the plate-end using CFS-GFS is due to the hybrid effects of CFS and GFS rather than the decrease of tension stiffness of FRP (in other word the FRP amount).
INTERFACIAL PERFORMANCE OF PRE-STRESSED CONCRETE BEAMS

The results of numerical calculation of interfacial stress of pre-stressed concrete beam strengthened with CFS-GFS are shown in Fig.6, which contains the interface stress, the stress of the lower side of the concrete and the stress of CFS-GFS. The different pre-stressed level of 20MPa, 40MPa, 60MPa at hybrid fibre sheet is chosen respectively to analysis the effects of pre-stress on mechanical performance of interface. The end of CFS-GFS is anchored in calculation model. The pre-stress was applied to FRP by setting anisotropic temperature strain coefficients. The same train effects can be obtained with pre-stress case under certain difference in temperature when heat was not considered. It can be seen from Fig. 6(a) that the shear and normal stress of concrete decrease non-linearly with the increase of distance away from the FRP end. The stress of concrete near the end of interface increases with the increase of pre-stress. The stress of concrete for different pre-stress level is basically indeclinable when the distance away from the end is over 20mm.

The distribution of shear and normal stress in the interfacial adhesive layer near the end of CFS-GFS is shown in Fig.6 (b). On account of the anchoring of CFS-GFS, stress level falls largely and has sudden change at the end of CFS-GFS. The shear stress reaches its maximal value at the end of CFS-GFS and goes up as the pre-stress grows. The shear and normal stress of the interfacial adhesive layer at the end of CFS-GFS have little difference between the beams with and without pre-stress. When the pre-stress is small, the maximal value of stress in the interfacial adhesive layer is smaller than that of the beam without pre-stress.

The axial stress of CFS-GFS is presented in Fig.6(c), which goes up pro rata as a result of an increase in the pre-stress. Consequently, the adding of pre-stress increases the use ratio of high strength fiber sheet effectively.
CONCLUSIONS

When two different FRP sheets are used together to strengthen reinforced concrete beams, high ductility of GFS and high strength of CFS can compensate each other. The numerical results indicate it is an effective method with CFS-GFS hybrid strengthening, which can efficiently control high interfacial shear and normal stress concentrations at the end of FRP. Therefore, hybrid FRP strengthening method can reduce the possibilities of debonding failure initiation from the cut-off point of FRP. The following conclusions can be drawn according to analysis on mechanical performances of RC beams with pre-stressed hybrid fibre sheets.

(1) The shear and normal stresses of concrete at the end of interface reach the maximum when the pre-stress is brought to bear the load and the end of FRP is anchored. The maximal stresses decrease non-linearly with the increase of distance away from the beam end. The stress of concrete near the end of interface increases with the increase of pre-stress. The stress of concrete for different pre-stress level is basically indeclinable when the distance away from the end is over 20mm.

(2) The shear and normal stresses in the interfacial adhesive layer at the end of FRP have little difference between the pre-stressed and without pre-stressed beam. When the pre-stress is small, the maximal value of stress in the interfacial adhesive layer is smaller than that of the beam without pre-stress. The maximal shear stress appears at the end of FRP and the maximal normal stress takes place near the end of FRP.

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