FATIGUE TEST ON CFRP PLATE REPAIRED RECTANGULAR HOLLOW SECTION (RHS) STEEL BEAMS WITH INITIAL CRACKS

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Abstract
This paper presents the fatigue test on rectangular hollow section (RHS) steel beams with an initial crack. The crack was artificial cut on the bottom of the mid-span with certain depth. They were patched with normal modulus and high modulus carbon fibre reinforced polymer (CFRP) plates. It was recognized that prestressed CFRP plate can increase the utilization efficiency of the materials. Therefore, prestressed CFRP plates were prepared with self-balanced instrumentation and patched to the cracked specimens. Crack propagation, failure modes and number of cycles were recorded during the fatigue test. The results were discussed with modulus and prestressing level. It was found that both the patching and prestressing technique can improve the fatigue performance.

1. Introduction
Carbon fibre reinforced polymer (CFRP) materials have been widely used to improve the fatigue performance of cracked metallic elements [1]. The technique has been developed for its convenience to construction and reversible merit. CFRP patching repair decrease both stress range and stress intensity factor at the crack tip. Both test and theoretical results indicate that directly patching method can increase the fatigue lives by several times [2-3]. However, stress level in CFRP has been observed at a relative low range comparing to the tensile strength. Prestressed CFRP patching method has been employed to introduce compressive stress in the steel element and this can greatly improve the CFRP utilization efficiency. The previous research has focused on the prestressed CFRP patched elements subjected to uniaxial loading [2]. Limited study has been conducted on I shaped beams under fatigue loading with or without prestressing. [4-5]. Rectangular hollow section (RHS) steel beam was also investigated [6-8]. But systematic research has not been conducted.

This paper presents an experimental study on the fatigue performance of RHS steel beams. The influence of the prestressing level was examined by comparing the fatigue crack propagation life. Besides this, the Young's modulus of CFRP was also considered.

2. Experimental Investigation

2.1. Geometry Configurations
A schematic presentation of a typical RHS steel beam 50 mm ×100 mm × 6 mm is shown in Figure 1. The overall length of the steel beam is 700 mm. An initial notch was cut with saw at the bottom side of
mid-span. The depth $d$ is 3 mm for all tested specimens. CFRP plate was prestressed and patched on the bottom of the steel beam. Table 1 summarizes the configurations of all four specimens.

**Figure 1.** Geometry configurations of steel beams.

### 2.2. Retrofit Materials

The steel material properties were determined by coupon test as shown in Table 2. Two types of CFRP materials were used and their properties were supplied by manufacturers. The two-part adhesive was used as shown in Table 1. CFRP plate was patched to the steel beam with anchorage system at both ends. The bolt anchorage details, prestressing instrumentation and patching process can be referred to Chen et al. (2015).

<table>
<thead>
<tr>
<th>No.</th>
<th>Prestressing level* (%)</th>
<th>CFRP</th>
<th>Maximum load (kN)</th>
<th>Minimum load (kN)</th>
<th>$N_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-3-0</td>
<td>0</td>
<td>CFRP-1</td>
<td>100</td>
<td>10</td>
<td>113,892</td>
</tr>
<tr>
<td>A-3-15</td>
<td>15</td>
<td>CFRP-1</td>
<td>100</td>
<td>10</td>
<td>198,269</td>
</tr>
<tr>
<td>A-3-30</td>
<td>30</td>
<td>CFRP-1</td>
<td>100</td>
<td>10</td>
<td>256,100</td>
</tr>
<tr>
<td>D-3-0</td>
<td>0</td>
<td>CFRP-2</td>
<td>100</td>
<td>10</td>
<td>194,180</td>
</tr>
</tbody>
</table>

*Prestressing level is defined as stress ratio between the stress in CFRP plate and ultimate tensile strength.

### 2.3. Test Setup and Instrumentation

The four beams were tested statically to failure under four-point bending fatigue loading at room temperature. The span for the test was 600 mm and the two loading supports were positioned at 50 mm on either side of the mid-span of the beam (spaced at a 300 mm distance). Three displacement transducers were placed above the beam to monitor mid-span deflection and support movements. The positions of the longitudinal strain gauges mounted on steel beam are shown in Figure 2. Strain gauges were also mounted on the surface of CFRP plate. The test set-up for the repaired specimens is shown in Figure 3.

### 3. Fatigue Tests and Results

#### 3.1. Fatigue tests

The fatigue tests were conducted under constant amplitude cyclic loading with a frequency of 8 Hz, as shown in Table 1. The maximum fatigue load is 100 kN while the minimum fatigue load is 10 kN, resulting in a load ratio of 0.1. Static loading was conducted during the intervals of fatigue test. This can give information on stiffness degradation. Meanwhile, crack depths were measured against

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The fatigue tests were stopped when the final fracture was observed. And the number of cycles to failure was tabulated in the last column of Table 1.

![Figure 2. Arrangements of strain gauges and displacement transducers.](image)

![Figure 3. Fatigue test setup.](image)

![Figure 4. Fatigue test failure modes.](image)

### 3.2. Failure Modes
Failure pictures of four specimens were taken after the tests, as shown in Figure 4. It was observed that all steel beams fractured at the mid-span. Further observation shows that CFRP-1 plates were pulled out from the anchorage system of the specimens. Whereas, CFRP-2 plate fractured at the location of mid-span. The difference may attributed to various tensile strengths.

### 3.3 Fatigue Crack Propagation
Figure 5 illustrates the records of crack depth and number of cycles. It is obvious that prestressed CFRP patched specimens achieved longer fatigue life. Slower crack propagation rate was observed for specimen with highest prestressed level. This means the prestressing technique can retard the crack propagation. It is also found that specimen D-3-0 patched with high modulus CFRP plate has better fatigue performance than specimen with normal modulus CFRP plate. The fatigue life of D-3-0 is almost same to the fatigue life of specimen repaired with 15% prestressed CFRP plate.
4. Conclusions

The laboratory tests show that it is possible to improve the fatigue life by using prestressing CFRP plate bonded to cracked RHS steel beam. For the tested specimens, two types of failure modes were observed. With regard to the specimens repaired with CFRP-1 of normal modulus, CFRP plate was pulled out in anchorage system. Whereas, CFRP plate ruptured for the specimen repaired with CFRP-2 of high modulus. Higher modulus of CFRP can enhance the fatigue life. And prestressing technique can significantly increase the fatigue life.

Acknowledgments

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References