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Engineering Structures 28 (2006) 1555–1565
ENGINEERING STRUCTURES
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CFRP strengthened RHS subjected to transverse end bearing force

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Received 2 November 2005; received in revised form 16 February 2006; accepted 17 February 2006
Available online 29 March 2006

Abstract

This paper reports the improved web crippling behaviour of RHS (rectangular hollow section) strengthened by CFRP (Carbon Fibre Reinforced Polymer). Several types of strengthening were adopted, such as wrapping CFRP sheeting outside the RHS or applying CFRP plates outside or/and inside the RHS. It was found that the CFRP strengthening significantly increases the web crippling capacity especially for those with large web depth-to-thickness ratio. Design models are proposed to predict the increased capacity for CFRP strengthened RHS subjected to transverse end bearing force.

Keywords: Bearing capacity; CFRP strengthening; Steel hollow section; Web crippling

1. Introduction

Web crippling of thin-walled steel members is often observed at loading or reaction points where concentrated forces exist. Extensive research on web crippling of RHS (rectangular hollow section) was carried out in the past [1–5]. The external corner radius (r_{ext}) in cold-formed RHS introduces load eccentricity to the webs, which reduces the web crippling capacity. It has been found in the previous studies that the most important parameter related to web crippling of cold-formed RHS is the web depth-to-thickness ratio $(d - 2r_{\text{ext}})/t$ where d is the overall depth and t is the wall thickness. Web crippling consists of two failure modes, namely web buckling and web yielding. Critical $(d - 2r_{\text{ext}})/t$ ratios beyond which web buckling occurs are given in [6]. Another important parameter influencing web crippling behaviour is the loading position, i.e. interior bearing where the distance between the edge of the section and the loading point is larger than $1.5d$ or otherwise end bearing. In general the web crippling capacity of an end bearing is lower than that for an interior bearing. This paper deals with the end bearing which is the worst case.

In the case of I-section members, it is common to provide welded transverse stiffeners to prevent web crippling. For cold-formed members such as C and Z purlins, the cleats that attach the members to support structures provide web stiffening [7,8]. However, it is difficult to provide load-bearing stiffeners at loading points or supports for RHS sections. Attempts were made before to increase the web crippling capacity of RHS especially for the end bearing load case. The techniques used include (i) partially filling the RHS with wood plus a bolt through the web [9] and (ii) partially filling the RHS with concrete [9,10].

The carbon fibre reinforced polymer (CFRP) has high strength to weight ratio, resistance to corrosion and environmental degradation [11]. CFRP has been widely used in strengthening concrete structures with extensive research being conducted (e.g. [12–16]). There is an increasing trend of CFRP to strengthen steel structures (e.g. [17–26]). This project investigates the possibility of using the CFRP strengthening technique to improve the web crippling capacity of cold-formed RHS.

Several types of strengthening technique were adopted in this project as shown in Fig. 1. They include wrapping CFRP sheets outside the RHS or applying CFRP plates outside or/and inside the RHS. It was found that the CFRP strengthening significantly increases the web crippling capacity especially for those with large web depth-to-thickness ratios. The main reasons are: (i) change of failure mode from web buckling to web yielding, (ii) increased restraints against web rotation and (iii) achievement of material strain hardening. The investigation was focused on Type 3 and Type 5 because of the simplicity for

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0141-0296/$ - see front matter
doi:10.1016/j.engstruct.2006.02.008

Notation

b	overall width of RHS
b_b	mechanism length used in design of RHS web crippling
b_s	bearing length
d	overall depth of RHS
f_u	ultimate tensile strength
f_y	yield stress
k_e	effective length factor for web buckling design
k_s	a factor used for web yielding design
$P_{\max}$	experimental ultimate load
$P_{\max,\mathrm{T1}}$	experimental ultimate load for Type 1 strengthening
$P_{\max,\mathrm{T}i}$	experimental ultimate load for Type i strengthening
P_p	predicted ultimate load carrying capacity
R_{bb}	web buckling capacity
R_{by}	web yielding capacity
r_{ext}	external corner radius of RHS
t	wall thickness
α_c	member slenderness reduction factor for web buckling design
α_p	mechanism reduction factor for web yielding design
$\Delta_{\max}$	experimental deformation at ultimate load
$\Delta_{\max,\mathrm{T1}}$	experimental deformation at ultimate load for Type 1 strengthening
$\Delta_{\max,\mathrm{T}i}$	experimental deformation at ultimate load for Type i strengthening
λ_n	modified member slenderness for web buckling design

construction in the case of Type 3 and because of the increased strength and ductile behaviour for Type 5. Design models are proposed to predict the increased web crippling capacity for RHS strengthened by Type 3 and Type 5 subjected to transverse end bearing force.

2. Material properties

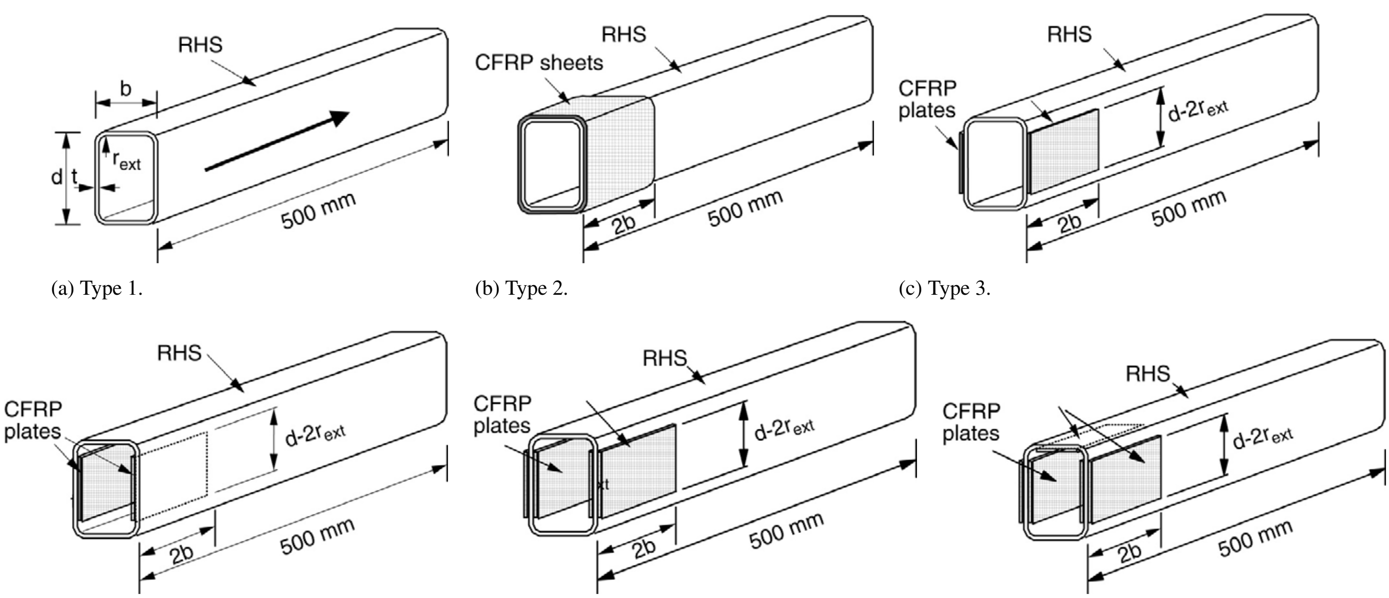
The RHS sections used in the tests were produced by OneSteel Market Mills, Australia. They are "in-line" galvanizing cold-formed rectangular hollow sections (also called "DuraGal" RHS). A section identification number is assigned to each RHS section as shown in Table 1. The average measured dimensions are given in Table 1. Tensile coupon tests were conducted according to [27] to determine the tensile yield stress (0.2% proof stress) and the ultimate tensile strength. Average measured values are presented in Table 1. The 0.2% proof stress is used later on in the paper as the yield stress of RHS. This is a common practice in dealing with cold-formed RHS [6].

The CFRP sheeting used in the tests is MBrace fibre CF130 which has a nominal modulus of elasticity of 240 GPa, a nominal ultimate tensile strength of 3800 MPa and a nominal thickness of 0.18 mm [28]. The CFRP plates used in the current project are MBrace S&K laminate 150/2000 with a nominal modulus of elasticity of 165 GPa, a nominal ultimate tensile strength of 2700 MPa and a nominal thickness of 1.2 mm. The adhesive adopted is Araldite 420 as used in previous research by the authors [25,28,29]. The thickness of adhesive for CFRP sheets is about 0.3 mm whereas the thickness of adhesive for CFRP plates is about 1 mm. This gives a reinforcement thickness for Type 2 about 1 mm ($\approx 2 \times (0.18 + 0.3)$).

3. Test specimens and set up

3.1. Types of strengthening technique

A schematic view of various types of strengthening technique is shown in Fig. 1. Type 1 has no CFRP strengthening



(a) Type 1. (b) Type 2. (c) Type 3.

(d) Type 4. (e) Type 5. (f) Type 6.

Fig. 1. Types of CFRP strengthening — a schematic view (not to scale).