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Finite element analysis and simple design calculation method for rectangular CFSTs under local bearing forces

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ABSTRACT

Rectangular concrete-filled steel tube (CFST) may be subjected to local bearing forces transmitted from brace members while being used as a chord of a truss, and thus development of finite element analysis (FEA) and simple design calculation method for rectangular CFSTs under local bearing forces are very important to ensure the safety and reliable design of such a truss with rectangular CFST chords in engineering practices. A three-dimensional FEA model was developed using ABAQUS software package to predict the performance of thin-walled rectangular CFST under local bearing forces. The preciseness of the predicted results was evaluated by comparison with experimental results reported in the available literature. The comparison and analysis show that the predicted failure pattern, load versus deformation curves and bearing capacity of rectangular CFST under local bearing forces obtained from FEA modelling were generally in good agreement with the experimental observations. After the validation, the FEA model was adopted for the mechanism analysis of typical rectangular CFSTs under local bearing forces. Finally, based on the parametric analysis, simple design equations were proposed to be used to calculate the bearing capacity of rectangular CFST under local bearing forces.

1. Introduction

Concrete-filled steel tube (CFST) members are widely used in engineering practices owing to their excellent structural performance and pleasuring building aesthetics [1]. In particular, rectangular CFST members are very popular in use for high-rise, transmission and large-span structures. However, comparing with circular CFST, the rectangular CFST has a weakness, or the confinement of steel tube to its concrete core is weaker if both members have the same steel ratio and material properties, although the rectangular CFST has advantages of simple joint configuration, good stability and regular shape which well satisfy the requirements of architectural design. In recent years, experimental and theoretical studies on performance of rectangular CFSTs have been conducted diffusely, such as members under static and cyclic loadings [2–5], fire and post-fire performance of columns [6–8], beam to column joints and frame structures [9,10], etc.

Since the 1980s, the studies on the structural performance, theoretical model and design method for cold-formed rectangular steel tube subjected to concentrated forces transmitted from the welded braces have been systematically and comprehensively performed [11,12], and it has been found that the buckling of tube webs and the yielding of tube flange are the main failure pattern which is determined by the breadth ratio (β) between the rectangular brace and tube. Zhao et al. [13] proposed the simple design equations for the case of web buckling ($\beta \geq 0.8$) and flange buckling ($\beta < 0.8$) of cold-formed rectangular steel tube subjected to concentrated forces based on a comparative analysis of design methods available from literature. Compared with hollow steel tube, the CFST has a better performance and a evidently different failure pattern while subjected to transverse local bearing forces owing to the interaction between steel tube and core concrete [14–18].

The studies on the performance of CFST subjected to local bearing forces have been carried out worldwide. Professor Packer and his colleagues [14–16] experimentally studied the performance of fourteen rectangular CFST specimens under transverse local compression with different concrete lengths, ratios of bearing plate breadth to chord breadth and loading orientations. The results showed that the existence of concrete evidently improved the bearing capacity and deformation-resistant ability of steel tubular joints. In addition, they proposed a conservative design calculation method for predicting the bearing capacity of T- and X-tubular joints with rectangular CFST chord on the basis of the aforementioned test results, and the formulae was adopted by the latest CIDECT design guide [19]. The experimental and theoretical studies on concrete-filled rectangular stainless steel tubular T- and

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X- joints with the transverse bearing forces applied by rectangular brace member or bearing plate were conducted by Feng and Young [20–22], and based on an extensive parametric analysis using finite element models, the simple design formulae for the bearing capacity of concrete-filled rectangular stainless steel tubular T- and X- joints with the transverse bearing forces applied by bearing plate were suggested. Hou et al. [17,23] performed experimental study and finite element modelling of circular CFST subjected to local bearing forces applied by circular bearing member (BM) with the included angle between BM and compression member (θ) of 45° and 90°, and simplified formulae for calculating the strength of circular CFST under local bearing forces were proposed. Yang et al. [18,24] experimentally studied the behaviour of rectangular CFST and concrete-filled double-skin steel tube (CFDST) with transverse bearing forces applied by rectangular BM, and two loading cases with θ of 45° and 90° were considered in their tests.

Although experimental study on rectangular CFSTs under local bearing forces and theoretical modelling of concrete-filled rectangular stainless steel tubular T- and X- joints were performed in the past, there is no theoretical modelling and further mechanism analysis on rectangular CFSTs under local bearing forces. Furthermore, the design methods for bearing capacity of rectangular CFSTs under local bearing forces need to be further explored based on a systematically parametric analysis using the finite element analysis (FEA) model.

In this study, a nonlinear FEA model for predicting the behaviour of the thin-walled rectangular CFSTs under local bearing forces is developed. The main objectives of this research are thus fourfold: first, to present a FEA model that can be used to predict the failure pattern, load versus deformation relationship and bearing capacity of rectangular CFSTs under local bearing forces with the loads applied by rectangular steel bearing member (BM); second, to verify the results obtained from the FEA model by comparison with experimental results; third, to investigate the influence of typical parameters on the mechanism of rectangular CFSTs under local bearing forces; and finally, to propose the simple design calculation method to assess the bearing capacity of rectangular CFSTs under local bearing forces.

Table 1.
Summary of the tested specimens in the literature and comparison of predicted and experimental bearing capacities.

No.	Label	Dimensions of specimen (mm)		Dimension of BM (mm)		β	θ (°)	$P_{u,e}$ (kN)	$P_{u,FEA}$ (kN)	$\frac{P_{u,FEA}}{P_{u,e}}$	Ref.
		$b_0 \times h_0 \times t_0$	L_0	$b_1 \times h_1$	L_1						
1	CB-1	127.5 × 177.8 × 4.75	750	127 × 127	16	1.00	90	1421	1401.4	0.986	[16]
2	CB-2	127.5 × 177.8 × 4.75	750	63.5 × 127	16	0.50	90	721	731.2	1.014	
3	CB-3	177.8 × 127.8 × 4.75	750	63.5 × 127	16	0.36	90	1317	1445.5	1.098	
4	CB-4	177.8 × 127.8 × 4.75	750	127 × 63.5	16	0.71	90	991	731.8	0.738	
5	CA-1	110.0 × 110.0 × 2.6	400	40 × 40	50	0.36	90	419.1	416.6	0.994	[18]
6	CA-2	110.0 × 110.0 × 2.6	400	60 × 60	50	0.55	90	650.6	619.7	0.953	
7	CA-3	110.0 × 110.0 × 2.6	400	60 × 60	50	0.55	90	646.5	619.7	0.959	
8	CA-4	110.0 × 110.0 × 3.7	400	60 × 60	50	0.55	90	626.0	687.6	1.098	
9	CA-5	110.0 × 110.0 × 2.6	400	80 × 80	50	0.73	90	835.2	890.5	1.066	
10	CC-1	110.0 × 110.0 × 2.6	400	40 × 40	75	0.36	45	592.9	632.1	1.066	
11	CC-2	110.0 × 110.0 × 2.6	400	60 × 60	85	0.55	45	804.3	926.5	1.152	
12	CC-3	110.0 × 110.0 × 2.6	400	60 × 60	85	0.55	45	873.8	926.5	1.060	
13	CC-4	110.0 × 110.0 × 3.7	400	60 × 60	85	0.55	45	1045.0	1232.0	1.179	
14	CC-5	110.0 × 110.0 × 2.6	400	80 × 80	95	0.73	45	1049.0	1310.0	1.249	
15	SA-1	40.4 × 40.0 × 1.98	241	40 × 40	40	0.99	90	259.8	290.8	1.119	[20]
16	SA-2	50.1 × 50.2 × 1.54	300	50 × 50	40	1.00	90	248.1	305.9	1.233	
17	SA-3	150.1 × 150.0 × 5.88	900	150 × 150	40	1.00	90	2212.3	2921.9	1.321	
18	SA-4	40.1 × 40.1 × 2.00	241	40 × 40	40	1.00	90	200.4	234.2	1.169	
19	SA-5	80.1 × 80.1 × 1.87	443	40 × 40	40	0.50	90	283.2	228.3	0.806	
20	SA-6	40.0 × 40.0 × 3.92	241	40 × 40	40	1.00	90	308.5	366.2	1.187	
21	SA-7	40.1 × 40.1 × 3.82	241	40 × 40	40	1.00	90	319.8	356.2	1.114	
22	SA-8	80.0 × 140.2 × 3.14	740	40 × 40	40	0.50	90	232.9	285.0	1.224	
23	SA-9	80.6 × 160.3 × 2.89	843	40 × 40	40	0.50	90	272.8	261.4	0.958	
24	SA-10	80.0 × 140.1 × 3.09	750	50 × 50	40	0.63	90	323.1	382.7	1.184	
25	SA-11	80.4 × 160.4 × 2.89	853	50 × 50	40	0.62	90	300.4	371.9	1.238	
26	SA-12	80.0 × 140.1 × 3.15	841	80 × 140	40	1.00	90	734.1	850.5	1.159	
27	SA-13	196.0 × 110.0 × 4.00	703	150 × 150	40	0.77	90	3322.2	3854.2	1.160	
28	SA-14	80.6 × 160.4 × 2.89	939	80 × 140	40	0.99	90	635.4	844.7	1.329	
29	SA-15	109.2 × 197.0 × 4.02	1204	110 × 200	40	1.00	90	1003.9	1343.1	1.338	
30	SA-16	50.1 × 99.9 × 1.94	540	40 × 40	40	0.80	90	149.6	223.1	1.491	
31	SB-1	40.3 × 40.1 × 2.06	241	40 × 40	40	0.99	90	183.5	211.5	1.153	[21]
32	SB-2	50.2 × 50.4 × 1.56	299	50 × 50	40	1.00	90	184.1	204.7	1.112	
33	SB-3	50.2 × 50.6 × 1.54	300	50 × 50	40	1.00	90	183.8	202.4	1.101	
34	SB-4	150.4 × 150.4 × 5.81	900	150 × 150	40	1.00	90	1791.6	2235.5	1.248	
35	SB-5	40.2 × 40.2 × 2.02	241	40 × 40	40	1.00	90	178.1	189.1	1.062	
36	SB-6	40.1 × 40.1 × 3.92	240	40 × 40	40	1.00	90	359.2	379.9	1.058	
37	SB-7	40.1 × 40.2 × 3.95	240	40 × 40	40	1.00	90	401.4	461.2	1.149	
38	SB-8	80.5 × 140.4 × 3.09	739	40 × 40	40	0.50	90	150.7	160.8	1.067	
39	SB-9	80.4 × 140.4 × 3.09	740	50 × 50	40	0.62	90	181.6	192.5	1.060	
40	SB-10	80.4 × 140.8 × 3.10	751	50 × 50	40	0.62	90	164.2	194.3	1.183	
41	SB-11	80.7 × 160.8 × 2.89	851	50 × 50	40	0.62	90	173.1	193.1	1.116	
42	SB-12	80.4 × 140.4 × 3.10	840	80 × 140	40	1.00	90	535.8	720.3	1.344	
43	SB-13	80.8 × 160.7 × 2.98	941	80 × 140	40	0.99	90	495.7	543.8	1.097	
44	SB-14	198.0 × 109.2 × 3.97	699	150 × 150	40	0.76	90	2832.7	3367.8	1.189	
45	SB-15	197.2 × 109.8 × 3.98	691	150 × 150	40	0.76	90	2878.7	3312.6	1.151	
46	SB-16	109.0 × 197.8 × 3.98	1198	110 × 200	40	1.00	90	655.2	576.7	0.880	
AV										1.122	
SD										0.139	