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Tying resistance of reverse channel connection to concrete filled square and rectangular tubular sections

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ABSTRACT

This paper presents the derivations of an analytical method to evaluate the tying resistance of reverse channel connection to rectangular/square concrete filled tube (CFT). The analytical derivations are based on results of an extensive series of numerical parametric study of this type of connection, covering a range of design parameters, including tubular section size, tubular section width to thickness ratio, reverse channel flange size and gap between the reverse channel flanges.

Under a tying force, the tubular section may fail in two modes: formation of yield line mechanism or fracture under tensile membrane action in the tubular wall. In most cases, the membrane resistance governs. However, if the tubular section is thick, the yield line resistance is higher than the membrane resistance and membrane action does not develop. The tying resistance of the connection is the higher of the two values.

This paper derives analytical equations for calculating these two typing resistance values. The membrane resistance depends on the ultimate lateral deformation of the tubular wall and this paper also presents a method for its calculation. Comparisons between the analytical calculation results and the numerical simulation results indicate that the proposed analytical equations give reasonably accurate calculations and the analytical method may be used in practical design.

1. Introduction

Connections are the most vulnerable elements in any structure and their failure may initiate progressive/disproportionate collapse of the structure. One of the methods of mitigating against disproportionate collapse is to ensure that connections between principal structural members have sufficient tying resistance [1] so that the structure acts as a whole. Providing a structure with sufficient tying resistance makes it more difficult for the structure to lose structural elements should unforeseen accidents (e.g. gas explosion) happen and also gives the structural some capability to activate an alternative load carrying mechanism, catenary action, in beams should the structure lose some members.

Information on tying resistance of common connections between beams and columns using open sections is readily available [2]. There is, however, a comparative lack of research into the behaviour of connections to hollow or concrete-filled tubular (CFT) columns. This type of columns are increasingly used in tall, multi-storey buildings and, as well as pleasing aesthetic properties, they possess structural advantages such as allowing for a comparatively reduced column cross-sectional area and inherent fire-resistance properties due to the insulative properties of the concrete in-fill. For this type of columns, Jones [3] and Jones and Wang [4] appear to be the only ones to have proposed a method to calculate tying resistance for fin plate connection to concrete filled tubular columns.

This paper deals with reverse channel connection to concrete filled square/rectangular tubular sections. Reverse channel connection, as illustrated in Fig. 1, is a relatively new connection type, invented to solve the difficulty of access to inside tubular sections when making beam–column connection. In this connection, the legs of a steel channel are welded to the face of the tube and the web of the channel is connected to the incoming steel beam. The results of relevant studies on this connection [13] confirm that according to the limits in EN 1993-1-8:2005 [5] this type of connection can be classified as partial-strength and semi-rigid. This type of connection has also been demonstrated to possess good ductility and tying resistance [6,7]. These features are highly desirable properties to help a structure retain its structural integrity under accidental loading conditions [8] in which the structure would develop catenary action and both column and connection should withstand the induced axial force.

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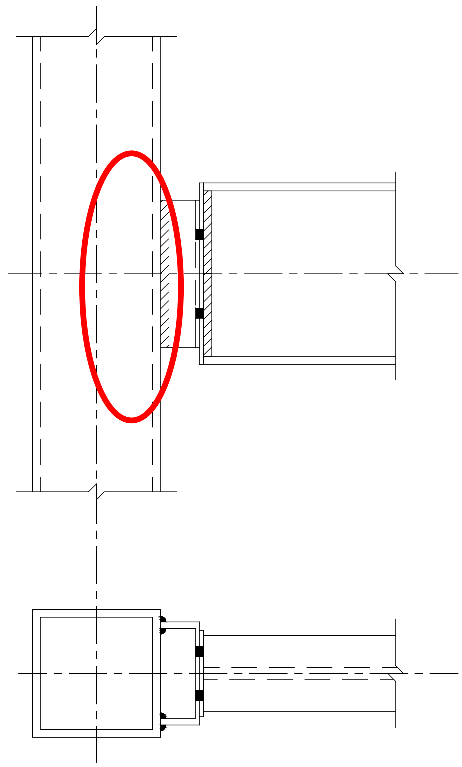

Fig. 1. Typical layout for reverse channel connection.

A number of studies have investigated different aspects of performance of this type of connection, including Elsawaf et al. [9] Elsawaf and Wang [10,11] who carried out numerical simulations to investigate methods of improving structural robustness in fire when using reverse channel connection, Malaga-Chuquitaype and Elghazouli [12] who performed numerical simulations and analytical derivations to obtain elastic stiffness for the reverse channel web under bolt tensile force, Wang and Xue [13] who carried out an experimental investigation to obtain the moment–rotation characteristics of this type of connection at ambient temperature, Lopes et al. [14] who reported some experimental results of reverse channel connection under axial force in the connection at ambient and elevated temperatures, and Jafarian and Wang [15–18] who carried out component tests on the reverse channel web under bolt tensile force at ambient and elevated temperatures and derived analytical formulations to obtain the complete force–deformation relationship.

This paper deals with tying resistance of this type of connection. In reverse channel connection to tubular column, there are two components: the reverse channel and the column surface. Tying resistance of the reverse channel web component can be calculated according to the method in Jafarian and Wang [17]. The derivations are based on the results of numerical simulations. This paper deals with tying resistance of the reverse channel flanges (legs)/tubular section wall component (circled in Fig. 1).

Although there has been no direct investigation of the behaviour of this component under a lateral tying force from the legs of a reverse channel, a number of researchers and design guides [5,19–23] have recommended different analytical solutions for related structures including the web of I-section under a tying force, or tubular section under a lateral tensile force in bolts.

Table 1
Comparison between available analytical solutions and yield resistance of numerical results (values in brackets indicate % differences).

t_w (mm)	b (mm)	b/a	SCI-P212* (BS 5950-1:2000)	Gomes et al. [29]	Silva et al. [19]	Liu et al. [20]	EN 1993-1-8	ISO/FDIS 14346	F_b (kN)
6	75	0.32	86.11[−13%]	83.97[−16%]	623.10[526%]	52.19[−48%]	78.37[−21%]	93.25[−6%]	99.48
8		0.32	156.16[5%]	149.27[1%]	810.69[446%]	92.79[−37%]	139.33[−6%]	165.33[11%]	148.41
10		0.33	249.20[13%]	233.24[5%]	996.73[350%]	144.99[−35%]	217.70[−2%]	257.60[16%]	221.41
12.5		0.33	400.51[24%]	364.44[13%]	1227.25[279%]	226.54[−30%]	340.15[5%]	401.02[24%]	323.76
14.2		0.34	527.55[16%]	470.31[3%]	1382.75[204%]	292.35[−36%]	438.96[−3%]	516.15[13%]	454.86
16		0.34	685.32[3%]	597.10[−10%]	1546.30[132%]	371.16[−44%]	557.30[−16%]	653.39[−2%]	665.14
30		0.34	3065.66[6%]	2099.17[−28%]	2780.80[−4%]	1304.87[−55%]	1959.27[−32%]	2254.32[−22%]	2895.61
6	100	0.42	97.41[−7%]	83.97[−20%]	518.83[396%]	62.01[−41%]	90.31[−14%]	103.11[−1%]	104.58
8		0.43	177.74[−2%]	149.27[−18%]	675.27[273%]	110.25[−39%]	160.56[−11%]	182.67[1%]	181.27
10		0.43	285.55[6%]	233.24[−14%]	829.79[207%]	172.26[−36%]	250.87[−7%]	284.38[5%]	270.43
12.5		0.44	463.26[18%]	364.44[−7%]	1020.31[161%]	269.16[−31%]	391.99[0%]	442.17[13%]	391.51
14.2		0.45	614.55[11%]	470.31[−15%]	1148.24[107%]	347.35[−37%]	505.86[−9%]	568.60[2%]	555.57
16		0.46	804.94[14%]	597.10[−15%]	1282.26[82%]	440.99[−38%]	642.24[−9%]	719.05[2%]	706.27
6	150	0.63	137.95[3%]	2099.17[1463%]	7913.44[5793%]	69.05[−49%]	129.61[−3%]	135.37[1%]	134.29
8		0.64	257.90[18%]	221.60[1%]	1072.31[389%]	122.75[−44%]	230.43[5%]	239.39[9%]	219.20
10		0.65	426.00[29%]	346.25[5%]	745.75[126%]	191.80[−42%]	360.04[9%]	371.96[13%]	330.30
12.5		0.67	719.86[36%]	541.01[2%]	909.98[72%]	299.68[−43%]	562.56[6%]	576.75[9%]	528.48
14.2		0.68	986.54[45%]	698.17[3%]	1018.07[50%]	386.74[−43%]	725.98[7%]	740.09[9%]	678.58
16		0.69	1344.82[57%]	886.39[4%]	1129.38[32%]	491.00[−43%]	921.70[8%]	933.55[9%]	854.06
6	200	0.84	286.04[19%]	208.85[−13%]	305.38[27%]	97.65[−59%]	235.53[−2%]	221.16[−8%]	239.85
8		0.85	598.75[26%]	371.29[−22%]	385.63[−19%]	173.59[−63%]	418.72[−12%]	390.36[−18%]	473.4
10		0.87	1156.42[74%]	580.14[−13%]	456.96[−31%]	271.24[−59%]	654.25[−2%]	525.62[−21%]	665.14
12.5		0.89	2676.86[131%]	906.47[−22%]	533.57[−54%]	423.82[−63%]	1022.27[−12%]	808.77[−30%]	1159.9
14.2		0.90	5445.04[180%]	1169.79[−40%]	577.71[−70%]	546.93[−72%]	1319.23[−32%]	1076.94[−45%]	1946.5
16		0.92	22749.54[835%]	1485.15[−39%]	617.43[−75%]	694.38[−71%]	1674.89[−31%]	1402.93[−42%]	2433.9
6	200	0.84	199.16[21%]	153.25[−7%]	161.45[−2%]	97.65[−40%]	235.53[44%]	174.54[6%]	164.02
8		0.85	408.66[50%]	272.44[0%]	199.98[−27%]	173.59[−36%]	418.72[53%]	308.78[13%]	273.14
10		0.87	770.30[42%]	425.69[−22%]	231.96[−57%]	271.24[−50%]	654.25[20%]	479.94[−12%]	543.35
12.5		0.89	1711.56[84%]	665.14[−28%]	262.73[−72%]	423.82[−54%]	1022.27[10%]	744.62[−20%]	928.69
14.2	200	0.90	3340.79[154%]	858.36[−35%]	277.82[−79%]	546.93[−58%]	1319.23[0%]	955.92[−27%]	1315.03
16		0.92	12864.86[706%]	1089.77[−32%]	288.64[−82%]	694.38[−57%]	1674.89[5%]	1206.46[−24%]	1596.41

SCI-P212: Joints in steel construction: Simple Connections.
Difference = 100 × (Analytical − Simulation)/Simulation.