Journal of Constructional Steel Research 65 (2009) 1171–1186

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

journal homepage: www.elsevier.com/locate/jcsr

The shear lag effects on welded steel single angle tension members

H.T. Zhu [a], Michael C.H. Yam [b,*], Angus C.C. Lam [a], V.P. Iu [a]

[a] Department of Civil and Environmental Engineering, University of Macau, Macao, China

[b] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

ARTICLE INFO

Article history:
Received 28 March 2008
Accepted 7 October 2008

Keywords:
Shear lag
Tension member
Welded connections
Experiments
Angles
Design

ABSTRACT

This paper presents a study of the shear lag effects on the behaviour and strength of welded steel single angle tension members. A total of thirteen single angles with welded end connections were tested in tension. The test parameters included long and short leg connections, balanced and unbalanced weld arrangements and longitudinal fillet weld lengths. Out of the thirteen specimens, nine failed by fracture of the gross section and four failed in the welds. The efficiency of the specimens, which is defined as the ratio of the test ultimate load (P_{test}) to the tensile capacity (a product of the gross sectional area and the tensile strength of the material) of the specimens varied from 0.82 to 1.02. It can be observed from the test results that both the ultimate loads sustained by the short leg connected angles and the ductility of all the angle specimens were greater when the balanced weld arrangement was used in the connections than when the specimens were connected using the unbalanced welded arrangement. Finite element analyses of the specimens were conducted and the analysis results compared well with the test results. The capacities of the test specimens were also evaluated using various design approaches. In general the design specifications (AISC-LRFD, BS5950-1:2000, and CSA-S16-01) provided good predictions of the tensile capacity of the single angle specimens with a reasonable degree of conservatism. However, the design specifications underestimated the tensile capacity of specimens which were connected by the short leg and with a balanced weld arrangement.

1. Introduction

In steel construction, hot-rolled structural shapes such as angles, tee-sections and channels are often used as tension members. These members are either bolted or welded to the connecting elements (e.g. a gusset plate) as shown in Fig. 1. It is common practice with these shapes to connect only part of the cross-section at the connections. Because of this, only part of the section is effective in carrying the loads, and this leads to the phenomenon known as shear lag. Shear lag results in the non-uniform distribution of stress in tension members (Fig. 1). In addition, since the line of action of the load usually does not coincide with the centroidal axis of a tension member section, loading eccentricity is also created and hence secondary bending of the member is induced. The combined effects of shear lag, connection eccentricity and stress concentrations at the connected region would initiate premature fracture of the section and the tensile capacity of the member is significantly reduced.

The commonly used equation to account for the effects of shear lag in tension members was developed by Munse and Chesson [1,2]:

$$K_4 = 1 - \frac{\bar{x}}{L} \qquad (1)$$

where K_4 = shear lag coefficient, $\bar{x}$ = distance from the shear plane to the centre of gravity of the material connected to the shear plane and L = connection length, taken as the distance between the extreme fasteners as illustrated in Fig. 2. This equation was derived from tests on bolted and riveted connections and the product of the net area of the member and the shear lag coefficient, K_4, is defined as the effective net area. This equation was further verified by a comparison with data from more than 1000 tests (Munse and Chesson [1]) and the equation has been adopted in a number of design specifications such as the AISC-LRFD [3] and the CSA/CAN-S16-01 [4] for tension members with either bolted or welded end connections.

The shear lag effects on the strength and behaviour of tension members with welded end connections have been studied by a number of researchers. Davis and Boomsliter [5] conducted research to evaluate the strength of tension members composed of angles with welded or riveted joints. The ratio of the ultimate load to the full tensile capacity was established at 0.87 for double angles failing in the net section. The test results from Gibson and Wake [6] showed little difference between the ultimate strengths of welded angle specimens with balanced welds and those with unbalanced welds. Regan and Salter [7] conducted seventeen single angle tests with unbalanced equal longitudinal welds and transverse welds. Based on the test results, the proposed capacity equation for the angle tension members was $P_t = p_y[A_g - 0.2a_2]$, where P_t is

* Corresponding author. Tel.: +852 2766 4380; fax: +852 2764 5131.
E-mail address: bsmyam@polyu.edu.hk (M.C.H. Yam).

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doi:10.1016/j.jcsr.2008.10.004

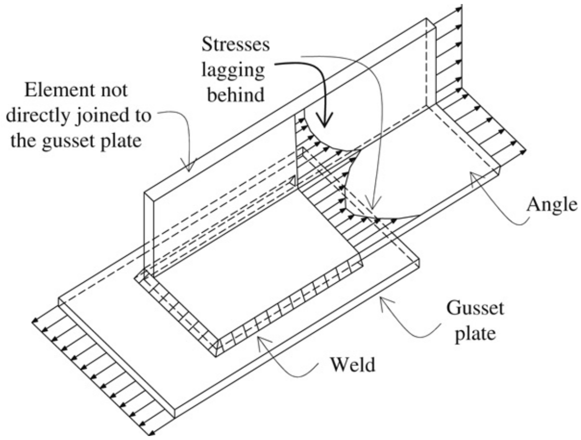

Fig. 1. Shear lag of an angle.

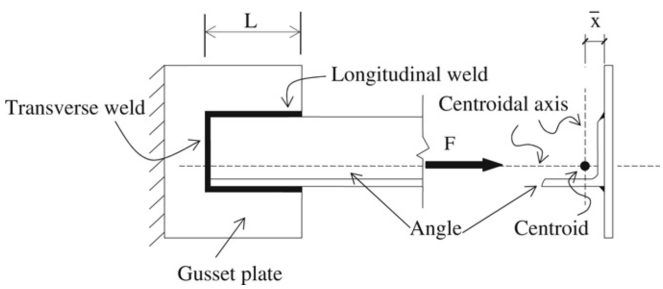

Fig. 2. Definition of $\bar{x}$ and L from Munse and Chesson.

the design tension capacity; p_y is the design material strength of steel; A_g is the gross cross-sectional area; and a_2 is the gross area of the unconnected leg. However, it should be noted that the majority of the specimens in the study were of relatively small size. Gonzalez and Easterling [8] conducted tension tests on double angles, plates and channels welded to a gusset plate. The test results indicated that the shear lag coefficients for angles in tension were not affected by the presence of the transverse welds.

Uzoegbo [9] concluded that the shear lag effect should be evaluated individually for each leg of the angle specimen based on his test results for steel angles with welded connections. Petretta [10] tested 23 double angle specimens with welded end connections. The author recommended a modification to the Munse and Chesson shear lag equation to better fit the test results. Bauer and Benaddi [11] tested six specimens with welded double angles. Based on their limited test data, they concluded that the CSA/CAN-S16-01 [4] specification provides conservative predictions of the ultimate strength of welded double angles under conditions of shear lag effects. Abi-Saad and Bauer [12] proposed to calculate the reduced strength of steel tension members allowing for the shear lag effects based on an assumed distribution of forces in the member end.

Although the research work described above has investigated the effect of shear lag effect on the strength and behaviour of welded angles, channels and plates, more experimental data is required to properly examine the effects of shear lag on the strength and behaviour of single angle tension members connected by welds. The main objective of this study, therefore, was to provide more experimental data on the shear lag effects on larger size single angle tension members with welded end connections. The evaluation of the ultimate strength of the test specimens using current design specifications (AISC-LRFD [3], BS5950-1:2000 [13], CSA/CAN-S16.1 [4], BS EN 1993-1-8:2005 [14] and AS 4100-1998 [15]) is also presented below.

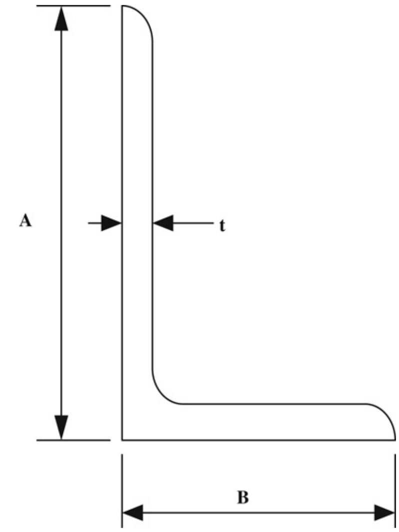

Fig. 3. Definition of symbols for the test specimens.

Table 1
Cross-section dimensions of the test angles.

Designation	Section size	*A* (mm)	*B* (mm)	*t* (mm)	Note
A1	125 × 75 × 10	125.00	75.00	10.00	Nominal
		125.40	75.00	10.11	Measured
A2	150 × 75 × 10	150.00	75.00	10.00	Nominal
		149.90	75.10	10.50	Measured

2. Experimental program

2.1. Test specimens

A total of thirteen single angles with welded end connections were tested in tension. The details of the specimens are shown in Tables 1 and 2. These tables should be read together with Figs. 3 and 4. The test parameters were as follows: (1) lengths of the longitudinal weld; (2) balanced and unbalanced weld arrangements (for balanced welds the longitudinal welds along the heel and the toe of the angle are designed to produce no eccentric moment about the centroidal line of the angle; for unbalanced welds equal lengths of longitudinal welds are used along the heel and toe of the angle as shown in Fig. 4); and (3) long and short leg connections. It should be noted that transverse welds were used for all the specimens. The specimen designation includes the type of section, length of weld, weld arrangement and the element which is connected. For example, A1-200BL represents type A1 (125 × 75 × 10) angle with a longitudinal weld length of 200 mm, balanced weld arrangement (B) and connected by the long leg (L).

Two angle sections (Type A1 and A2) were used to fabricate the test specimens (SCI Guide [16]) as illustrated in Table 1. Grade S275 steel conforming to BS EN 10025-2:2004 [17] was originally requested for the angle specimens. However, it can be seen below from the material test results that the steel materials were believed to be S235 instead of S275. All the gusset plates were fabricated with 400 mm wide and 16 mm thick steel plates conforming to BS EN 10025-2:2004 [17] Grade 355 steel with different lengths to meet the required connection dimensions.

A clear space between the two inner edges of gusset plates was maintained at 800 mm for all the specimens in order to fit the tension testing machine as shown in Fig. 5. The total length of the specimens varied from 1200 mm to 1460 mm to allow for different longitudinal weld lengths. The distance from the start of the angle to the free edge of the gusset plate was 170 mm for all specimens. Specimens were designed to ensure that failure would occur at the