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Experimental study and finite element analysis on the local buckling behavior of aluminium alloy beams under concentrated loads

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ABSTRACT

This paper presents an experimental investigation on local buckling behavior of extruded 6000 series alloy I-shaped aluminium alloy beams. A total of 10 specimens with a wide range of width-to-thickness ratios (4.4–15.0 of flange, 42.9–73.1 of web) of component plates were divided into two types: one with stiffeners at mid-span, and the other without intermediate stiffeners. Failure modes, ultimate loading capacities, load-deformation responses and load-strain curves of the specimens were studied. Local buckling occurred in the top flange and web of six specimens without intermediate stiffeners, and shear local buckling occurred in the other four specimens with intermediate stiffeners though which developed a tension field. A finite element model was developed and validated against the test results, which was used for parametric analysis of 24 specimens. The investigation focused on the effects of the intermediate stiffeners and width-to-thickness ratio on the buckling strength of the aluminium alloy beams. It was found that component plates with small width-to-thickness ratios could make material function to its fullest potential; And there was a significant increase in the post-buckling strength; Eurocode 9 underestimated the loading capacity of the specimens to be safe. For the specimens with thin (width-to-thickness ratio more than 40) web, the standards should be especially enhanced. Calculation results of the finite element model consist well with the experimental results.

1. Introduction

Over 6000 aluminium alloy space structures have been built in the world so far [1]. As an advanced structural material, aluminium alloy possesses many excellent advantages such as light weight, good corrosion resistance, high strength-to-weight ratio and good low temperature impact toughness, hence becomes more and more popular in structure engineering [2]. In the off-shore area, structures constructed by aluminium alloy with high corrosion resistance and good durability may be greatly optimized.

Aluminium alloy has been applied widely in construction all over the world such as bridges, buildings and other spacial structures, and has acquired good economic and social benefits. The world's first entire aluminium alloy bridge was built in Canada in 1949, which was 153 m in length and 88.4 m in span. In Brazil the Transamerica Expo Center was built in 1969 which used aluminium alloy space grid structure. In addition, aluminium alloy was applied in rotating crane bridges for large setting circular pools in water sewage in Italy [3].

In America and some European countries, comprehensive and systematic research on aluminium alloy structures have been conducted since 1950 s with national standards being developed [4,5]. In China, an amount of construction has been built with aluminium alloy, yet the national standards were not developed until 2007 because of a lacking in relevant research [6]. For the aluminium alloy material, its elastic modulus is very low, about 1/3 of the steel's. The instability problems caused by large deformation should be focused on in the practical design. However, research on the local buckling behavior of the aluminium alloy structures mostly concentrated on the axially loaded compression members [7–9]. Although beams are important structural components for aluminium alloy structures, their local buckling behavior was rarely investigated. Besides, research on the local buckling behavior of beams subjected to concentrated loads was even rarer. Though it is a common phenomenon in structural engineering that the beams subjected to concentrated loads buckle easily because of their thin web, few investigation has been conducted into this area, especially when it comes to aluminium alloy material. Some pivotal research works can only be found in terms of steel [10–15,17].

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Nomenclature

H	Web height
H_w	Web depth=clear distance between inside flanges
B_f	Flange width=distance from unsupported edge of element to toe of the fillet
W_f	Flange width
T_f	Thickness of flange
T_w	Thickness of web
L	The whole length of the beam
L_0	Span of the support points
I_w	Magnitude of web geometric imperfection
I_f	Magnitude of flange geometric imperfection
E	Initial elastic modulus of aluminium alloy
$f_{0.2}$	Stress at 0.2% residual strain (nominal yield strength)
f_u	Ultimate strength of aluminium alloy material
n	Hardening exponent
F_{exp}	Experimental loading capacity of the specimen
F_u	Assumed physical quantity which means the yield strength of flange and web
F_{cr}	The critical local buckling strength
F_{fe},F_{si}	The loading capacity of the specimen of FE or the simulation
f_{fm}	The maximum stress of flange

This paper presents a comprehensive experimental program on the local buckling behavior of extruded I-shaped 6000 series aluminium alloy (6063-T5 and 6061-T6 which represent strong hardening and weak hardening alloys, respectively) beams under concentrated loads. Local buckling behavior of aluminium beams usually arises because of three actions, including shear stresses, axial compressive stresses and compressive normal stresses in the transverse direction [10]. The tests of specimens without intermediate stiffeners were conducted to investigate the influence of compressive normal stresses in the transverse direction which was not sufficiently studied in previous research. The tests of specimens with intermediate stiffeners were conducted to investigate the shear stresses. Besides, finite element model was developed for simulating the test results. Verified by the obtained test results in this paper, it lays a good foundation for further parametric analyses on 24 specimens.

2. Experimental program

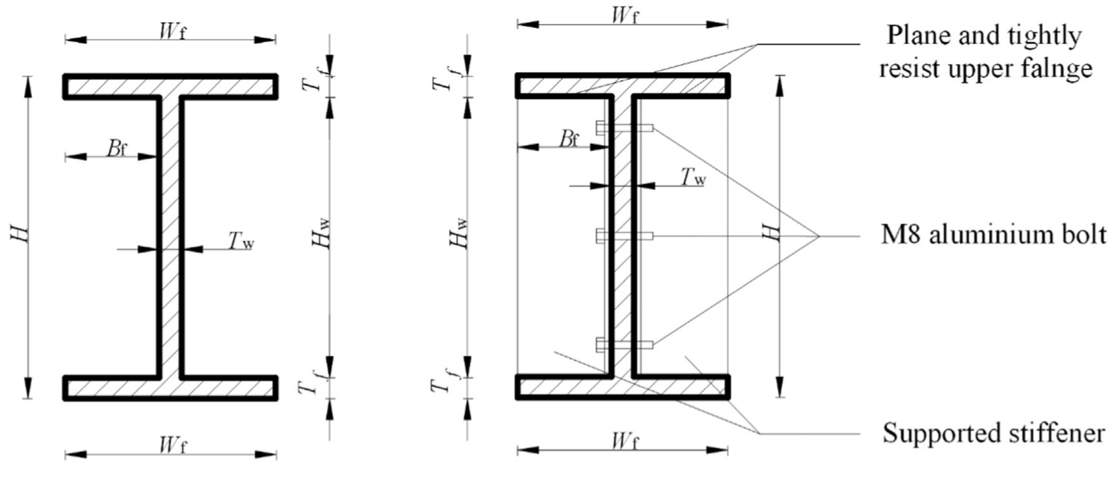
2.1. Test specimens

The purpose of the test is to analyze influence factors of the local buckling behavior of aluminum alloy beams by changing their width-to-thickness ratios of the component plates and the layout of stiffeners.

10 extruded specimens without welding included 3 6061-T6 specimens and 7 6063-T5 specimens. Fig. 1 is a schematic diagram of the I-shaped cross-section. Fig. 1(a) is for the specimens without stiffeners at the mid-span, and Fig. 1(b) is for the specimens with intermediate stiffeners. Measured dimensions of the specimens are summarized in Table 1.

The stiffeners of the 4 test specimens were installed by using bolted connection with consideration of the strength reduction induced by welding. The material of the stiffener is 6061-T6 aluminium alloy. Because of the potential electrochemical corrosion when the aluminium alloy specimens contact other metal, the connection bolt M8 × 50 was made of 6061-T6 aluminium alloy.

In order to make the experiment more well-grounded in practical engineering circumstance, the tests involved a wide range of width-to-thickness ratios of the specimens' component plates. The width-to-thickness ratio of flanges ranges from 4.4 to 15.0, and the width-to-thickness ratio of webs ranges from 42.9 to 73.1, both of which are within the practical range. In order to limit the experimental study to the local buckling only, the slenderness ratio of the beams was designed to be small enough. The span of simply-supported points was taken as about three times the depth of the section, according to the Guide of Structural Stability Research Council [18]. To study shear local buckling behavior of the beams, stiffeners were set up for four specimens at the mid-span. The stiffeners made of aluminium angle were fixed by aluminium bolts on the web of the beams (Fig. 1(b)). All of the beams were labelled by their material type and width-to-thickness ratio. For example, label T5-15.0-55.5-S represents a beam of 6063-T5 aluminium alloy with a width-to-thickness ratio of 15.0 for the flange and a height-to-thickness ratio of 55.5 for the web; the symbol 'S'



(a) Specimen without intermediate stiffeners (b) Specimen without intermediate stiffeners

Fig. 1. Schematic diagram of I-shaped beam.