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Experiments on cold-formed steel columns with holes

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Abstract

The objective of this paper is to observe and quantify the relationship between elastic buckling and the tested response of cold-formed steel columns with holes. Compression tests were conducted on 24 short and intermediate length cold-formed steel columns with and without slotted web holes. For each specimen, a shell finite element eigenbuckling analysis was also conducted such that the influence of the boundary conditions and the hole on local, distortional, and global elastic buckling response could also be captured. Slotted web holes may modify the local and distortional elastic buckling half-wavelengths, and may also change the critical elastic buckling loads. Experimentally, slotted web holes are shown to have a minimal influence on the tested ultimate strength in the specimens considered, although post-peak ductility is decreased in some cases. Tangible connections are observed between elastic buckling and load–displacement response during the tests, including mode switching between local and distortional buckling. The columns are tested with friction-bearing boundary conditions where the columns ends are milled flat and parallel, and bear directly on steel platens. These boundary conditions, which greatly speed specimen preparation, are determined to be viable for evaluating the tested response of short and intermediate length columns, although the post-peak response of intermediate length specimens must be considered with care.
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1. Introduction

Cold-formed steel structural members are commonly provided with holes to accommodate plumbing, electrical, and heating conduits in the walls and ceilings of buildings. These holes are typically pre-punched perforations located in the web of Cee or Zee sections and can alter the elastic stiffness and ultimate strength of a structural member. The majority of existing experimental data on cold-formed steel columns with holes has been obtained from stub column tests, where the ultimate strength is driven by local buckling and yielding of the cross-section [1–8]. Stub column tests in [1] demonstrated that ultimate strength decreased as circular hole diameter increased, relative to web depth. Similar conclusions when evaluating the influence of circular, slotted, and rectangular web holes on stub column ultimate strength have also been reported [2–4]. The impact of the location of the hole in the stub column [5–7] as well as the length of the hole [8] have also all been studied. In addition to the stub column testing, 25 intermediate and long column tests were completed by [1] and demonstrated that a single hole at the mid-height of a pinned–pinned column did not affect ultimate strength.

The motivation for this experimental program is to expand the existing column data set with tests on short and intermediate length columns with holes. The column lengths and cross-section dimensions are specifically chosen to explore the connection between local, distortional, and global elastic buckling modes, ultimate strength, and the resulting failure mechanisms. The elastic buckling behavior is evaluated for each specimen with a finite element eigenbuckling analysis, taking care to accurately simulate the tested boundary conditions and measured specimen dimensions. These elastic buckling results are used to provide a means of understanding the varied deformation response under load.

The columns are tested with friction-bearing boundary conditions where the ends of each specimen are milled flat and parallel, and bear directly against steel platens.

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The influence of holes on column elastic buckling behavior, ultimate strength, and post-peak ductility are presented and discussed. Recommendations are made to advise other researchers on the viability of the friction-bearing boundary conditions when testing short and intermediate length columns. This study is one component of a multi-level research program where the Direct Strength Method (DSM) [9] is being extended as a general strength prediction approach for columns (and beams) with holes.

2. Testing program

Twenty-four cold-formed steel lipped Cee channel columns with and without pre-punched slotted web holes were tested to failure. The primary experimental parameters are column cross-section, column length, and the presence or absence of slotted web holes. The specimen naming convention, as it relates to the testing parameters, is defined in Fig. 1. The rationale for selecting these experimental parameters is discussed in Section 2.1.

2.1. *Rationale for selecting specimen dimensions*

2.1.1. *Cross-section types*

Two industry standard cross-sections from the Steel Stud Manufacturers Association (SSMA) [10], 362S162-33 and 600S162-33, were evaluated in this study. The 362S162-33 cross-section has a nominal web width of 92 mm (3.62 in), while the 600S162-33 web is wider at 152 mm (6.00 in). Both sections have a 41 mm (1.62 in) flange and nominal sheet thickness of 0.88 mm (0.0346 in). Specific measured dimensions are provided in Section 2.4.

The buckling half-wavelengths that form along the length of the specimens are cross-section dependent, and can be calculated with the semi-analytical finite strip method (FSM) [11]. FSM assumes simply supported boundary conditions, and therefore the local and distortional half-wavelengths for the cross-sections studied here, as provided in Table 1, are only a guide as to the expected half-wavelength in the fixed–fixed tests. The FSM half-wavelengths are still a useful reference when deciding on specimen lengths (Section 2.1.2) and identifying buckling modes (Section 3.2.4), especially as specimen length increases and local and distortional buckling half-wavelengths converge to the fundamental (simply supported) half-wavelengths reported in Table 1.

2.1.2. *Column lengths*

More than 80% of the tested specimens with holes available in the literature (see full summary in [12]) are stub columns, as depicted in the specimen length histogram of tested specimens provided in Fig. 2. Stub columns

Table 1
FSM local and distortional buckling half-wavelengths for nominal 362S162-33 and 600S162-33 cross-sections

Cross-section	Elastic buckling half-wavelength	
	Local (*L*) (mm)	Distortional (*D*) (mm)
362S162-33	70	390
600S162-33	120	310

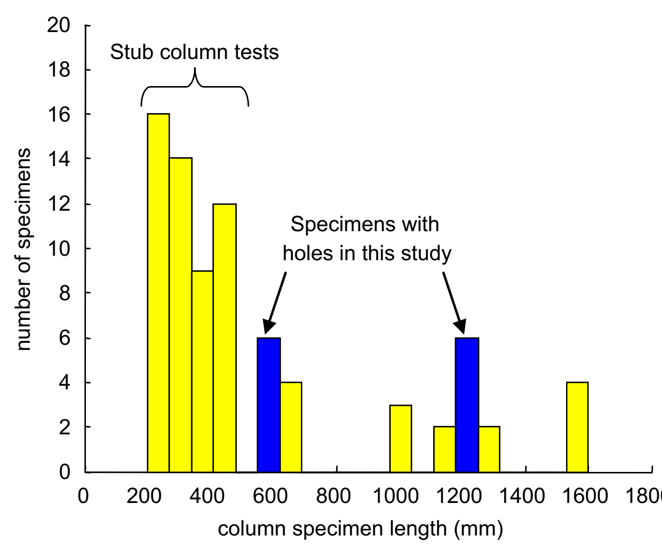

Fig. 2. Tested lengths of cold-formed steel columns with holes as summarized in [12].

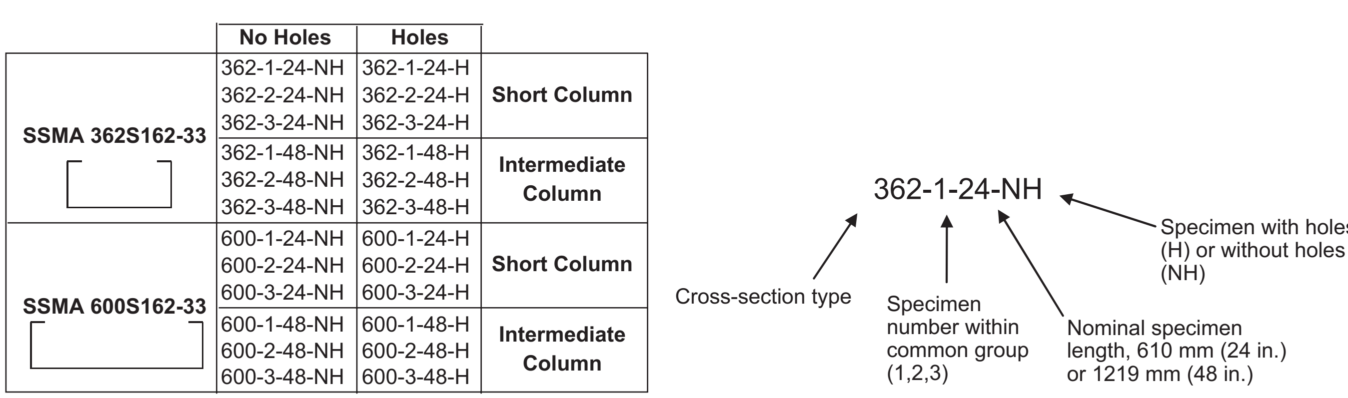

Fig. 1. Column testing parameters and naming convention.

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