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Experimental and theoretical investigation of cold-formed single lipped sigma columns

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ABSTRACT

Experimental and theoretical studies are carried out to investigate the behavior and strength of cold-formed single lipped sigma columns. The local, distortional and overall geometric imperfections of sixteen specimens are measured in the laboratory. In addition, the residual stress pattern of the sections is concluded. Only eight specimens of cold-formed sigma columns with different variables are chosen. The tested specimens are subjected to an axial compressive load. A finite element model is developed using a software program (ANSYS). The developed model includes both geometric and material nonlinearities. Numerous models of slender sigma column sections with different variables such as flange width–thickness ratios, web return ratios, and overall slenderness ratios are chosen. The behavior of sigma columns along with different failure modes illustrated local, distortional, and global buckling is investigated. Complete ultimate strength curves are drawn as well as different failure modes are discussed for different cross-sections and member lengths. Finite element axial capacities are compared with the predicted capacities using AISI and DSM methods. Both AISI and DSM results are comparable with the finite element results. Eventually, A reliability analysis is carried out.

1. Introduction

In the past decades, the designers and the contractors had chosen the cold-formed channel studs as the only option when selecting a cross section for load bearing compression members in the wall bearing system. The sigma shaped section has recently used as an alternative to the channel section. This is because the sigma shaped section having an intermediate web return and multi stiffeners. El Aghoury, et al. [1] measured local, distortional, and overall geometric imperfection of eight single sigma specimens in the lab. They have determined the residual stress pattern and the average local, distortional, and overall geometric imperfections. Furthermore, a numerical verification and an experimental study are carried out for the purpose of evaluating the effect of initial imperfections on the ultimate capacity of the sigma section columns. Zeinoddini and Schafer, [2] introduced three methods to simulate imperfection fields. Further, they investigated material and geometric nonlinear finite element collapse modeling to simulate the strength and behavior of the cold-formed steel members by using the effect of these different approaches. They concluded that the third method (the 1D model approach) is the most accurate approach for predicting the strength, axial flexibility, and failure mechanism of such members. Schafer and Ádany [3,4] provided technical background and illustrative examples for stability analysis of cold-formed steel members using the conventional and constrained finite strip methods, CFSM. The constrained finite strip method can calculate the pure buckling modes directly, and extended to determine the contribution of local, distortional, and overall buckling modes in the general buckling mode. As a part of the study carried out by Li, et al. [5], they considered channel and sigma sections as an illustrative example to explain the sensitivity of the conventional stability solution, modal decomposition, and modal identification solutions. They concentrated on global modes solutions for the channel and sigma under compression. For global modes, the natural basis allowed a pure separation of deformations (e.g., flexural, torsional,..etc.), while the modal basis allowed for direct solutions with a single mode(e.g., flexural-torsional). Klingshirn, et al. [6] tested fifty-eight sigma shaped specimens subjected to concentrated axial compression at various lengths to generate local, distortional, and global buckling failure modes. The specimens with or without holes are tested. Finally, they concluded that, AISI design methods, effective width and DSM, are good predictors for ultimate strength of sigma sections. Schafer [7] summarized his recent researches and his experiences with computational modeling of cold-formed which conducted within his research group. He focused primarily on the use of the semi-analytical finite strip method and collapse modeling using shell finite elements. A full comparison between the finite strip and finite element solutions and the importance of imperfections, residual stresses, boundary conditions, element choice, element discretization, and solution controls in the collapse modeling of cold-formed steel are included. Weng and Pekoz [8], investigated experimentally the magnitude of the residual stresses of cold-formed sections using the electrical

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Nomenclature

a	horizontal recess of the web middle part (Inner web return dimension)
a/B	ratio of the horizontal recess of the web middle part to the flange width (Inner web return ratio)
B	Flange width dimension
D	Lip Depth
β	Reliability index,
β_t	Target reliability index
Δ	Overall imperfection amplitude
δ_d	Distortional imperfection amplitude
δ_L	Local imperfection amplitude
E	Elastic modulus of elasticity
F_y	yield stress of the steel material
G	Shear modulus
L	Specimen or column overall length
λ_b	Flange slenderness ratio
λ_c	Column overall slenderness ratio
P_{crd}	Distortional buckling load
P_{cre}	Elastic buckling load
P_{crl}	local buckling load
P_{Exp}	Experimental ultimate load
P_{FEM}	Finite element ultimate load
P_n	Nominal axial capacity, strength
r	radius of gyration of column

discharge machining (EDM) technique and the conventional saw-cutting method. Garstecki et al. [9] presented the initial geometric imperfection measurement results of cold-formed sigma profiles. They compared the initial imperfections with the linear buckling modes. In addition, limit values of imperfections were evaluated using the statistical analysis based on Gauss distribution. Furthermore, they concluded that the distribution and intensity of the initial imperfections could be used in the generation of FEM of imperfect steel structures as a starting point for nonlinear analysis.

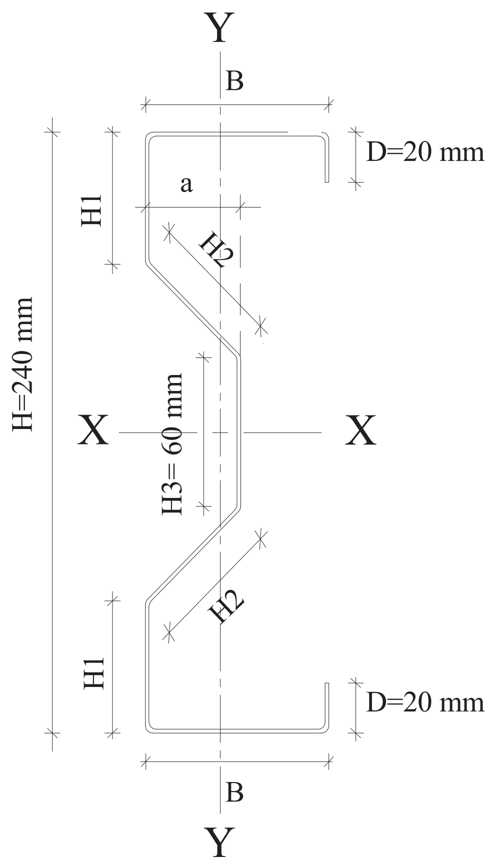

Fig. 1. Cross section shape and dimensions.

In fact, the behavior of sigma sections is slightly more complicated than the other sections like the conventional lipped channel due to the change of the web cross section profile. These sections might contain two minimal distortional loads depending on the geometry of the web. Moreover, to determine the capacity of these sections by AISI-2012 requires a lot of calculations, and it is not part of the prequalified section listed in the DSM. Therefore, the present work is part of ongoing research aiming to find a simpler approach to determine the axial capacity of single sigma sections. As such, experimental and numerical studies are carried out to investigate the behavior and strength of axially loaded cold-formed single lipped sigma columns. Different parameters such as flange width-to-thickness ratios, web recess to flange width ratios, and overall slenderness ratios are chosen in this study. The sigma column behavior is discussed along with different failure modes such as local, distortional, and global buckling. The strength of axially loaded members is predicted using different design codes, and compared with the finite element results.

2. Experimental work

2.1. Section size

Eight columns having sigma sections profile as shown in Fig. 1 have been tested. These sections have constant total web depth, H, as well as the lip depth, D, equal to 240 mm, and 20 mm; respectively. However, the flange width was set equal to 60 mm, and 75 mm. This means that the flange width to web depth ratios, B/H, are equal to 0.25, and 0.312. In addition, the lip depth, D, to the flange width ratios are 0.33, and 0.26. The mentioned values represent the out to out dimensions of the cross section. Further, the middle part of the web is equal to 60 mm,

Table 1
Tested specimens.

Specimen	L (mm)	λ_c	B (mm)	H1 (mm)	H2 (mm)	B/H	D/B	a/B
S60-25-50	1060	50	60	75.00	21.21	0.25	0.33	0.25
S60-75-50	1036	50	60	45.00	63.64	0.25	0.33	0.75
S75-25-50	1318	50	75	71.25	26.52	0.313	0.27	0.25
S75-75-50	1279	50	75	33.75	79.53	0.313	0.27	0.75
S60-25-100	2060	100	60	75.00	21.21	0.25	0.33	0.25
S60-75-100	2013	100	60	45.00	63.64	0.25	0.33	0.75
S75-25-100	2500	100	75	71.25	26.52	0.313	0.27	0.25
S75-75-100	2500	100	75	33.75	79.53	0.313	0.27	0.75