

# NUMERICAL EVALUATION OF SHEAR PERFORMANCE IN COLD-FORMED STAINLESS STEEL SUPACEE SECTION WITH WEB OPENINGS

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## Abstract

Cold-formed stainless-steel (CFSS) members offer corrosion resistance and lightweight structural efficiency, making them suitable for a range of structural applications. Web openings are commonly introduced into CFSS SupaCee sections to accommodate building services and minimise storey height; however, they reduce the effective web area and consequently the shear capacity. Research on the shear strength reduction caused by circular web openings in CFSS SupaCee sections remains limited. This study presents a numerical investigation of the shear behaviour and capacity of cold-formed duplex stainless-steel (grade 1.4462) SupaCee sections containing unreinforced circular web openings. A parametric study comprising 120 finite element models was undertaken following validation against existing experimental shear test data to investigate the effect of circular web openings on shear capacity. The numerical results were used to develop a third-order polynomial equation for predicting the shear reduction factor. The proposed equation showed close agreement with the finite element results, with a mean FE-to-predicted ratio of 1.0010 and a coefficient of variation of 0.0640.

**Keywords:** Duplex stainless steel, Thin-walled member, Reduction factor, Circular web opening

## 1. Introduction

Cold-formed stainless-steel (CFSS) sections are increasingly utilised in structural applications due to their durability, corrosion resistance, and reduced maintenance requirements. Stainless steel exhibits a nonlinear stress–strain response with gradual yielding and pronounced strain hardening, which differs from the elastic–perfectly plastic behaviour commonly assumed for carbon steel [1]. Previous numerical and experimental studies have shown that material nonlinearity influences the buckling behaviour and ultimate strength of cold-formed stainless-steel members, particularly those subjected to shear [2], [3].

Web openings are commonly introduced into cold-formed sections to accommodate building services and minimise storey height; however, they can reduce the shear resistance of the member [4]. Previous studies have investigated the shear behaviour of carbon-steel SupaCee sections [5] and cold-formed stainless-steel lipped channel sections with web openings [4]. However, the shear behaviour of duplex stainless-steel SupaCee sections with circular web openings remains insufficiently investigated. Therefore, this study investigates the shear behaviour of cold-formed duplex stainless-steel (grade 1.4462) SupaCee sections containing unreinforced circular web openings. Finite element (FE) models were developed and validated against existing experimental shear test data, followed by a parametric study comprising 120 FE models. The numerical results were used to evaluate the effect of web openings on shear capacity and develop a polynomial equation for predicting the shear reduction factor.

2. Methodology

Pham and Hancock tested SupaCee sections with depths of 150 mm and 200 mm and thicknesses of 1.2 mm, 1.5 mm, and 2.4 mm [5]. Six test results were selected for FE validation. The corresponding models were developed in ABAQUS using S4R shell elements and incorporating material and geometric nonlinearities. The nonlinear stress–strain behaviour of stainless steel was represented using the Ramberg–Osgood formulation of Arrayago et al. [1], while cold-forming-induced strength enhancement in the corner regions was incorporated using the corner-enhancement relationships adopted from Ishqy et al. [4]. The experimental support and loading conditions were replicated, and the nonlinear response was obtained using the Static Riks method to capture post-buckling behaviour. Mesh sensitivity was assessed by refining the mesh in critical regions, and the selected mesh was used for the subsequent parametric analyses. Geometric imperfections were introduced using the Mode 2 eigenmode obtained from linear buckling analysis. Two imperfection amplitudes, 0.15t and 0.64t, where t is the web thickness, were considered during validation. Both amplitudes provided good agreement with the experimental results, giving a mean Test/FEA ratio of 0.98 and a coefficient of variation (COV) of 0.04, as summarised in Table 1. The corresponding experimental and FE load–displacement responses are compared in Figure 1. The 0.64t amplitude was subsequently adopted for the parametric FE models. Residual stresses arising from cold forming were not explicitly modelled, with their effects implicitly considered through the adopted material modelling and geometric imperfections.

Table 1: Comparison of experimental and FE shear capacities.

| No | SupaCee Section | Test Shear Capacity (kN) | Test/FEA     |              |
|----|-----------------|--------------------------|--------------|--------------|
|    |                 |                          | Mode 2 0.15t | Mode 2 0.64t |
| 1  | SC15012         | 168.72                   | 0.99         | 0.97         |
| 2  | SC15015         | 222.24                   | 0.96         | 0.96         |
| 3  | SC15024         | 391.44                   | 1.01         | 1.02         |
| 4  | SC20012         | 186.01                   | 0.94         | 0.93         |
| 5  | SC20015         | 248.13                   | 0.94         | 0.97         |
| 6  | SC20024         | 495.81                   | 1.03         | 1.03         |
|    |                 | Mean                     | 0.98         | 0.98         |
|    |                 | COV                      | 0.04         | 0.04         |

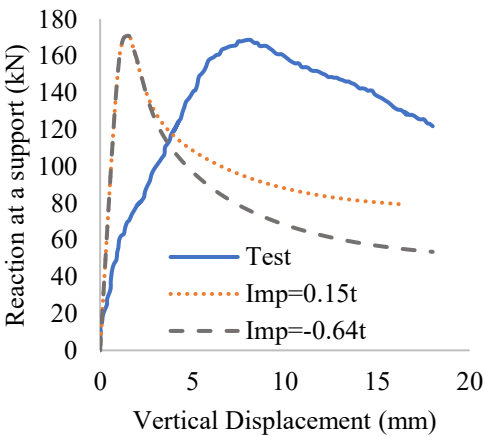


Figure 1: Comparison of experimental and FE load–displacement responses.

Following validation, a parametric study was conducted on duplex stainless steel EN 1.4462 SupaCee sections to investigate the influence of circular web openings on shear capacity. The same FE modelling methodology was retained, with the material properties in ABAQUS modified for EN 1.4462. Three section depths (100, 150, and 200 mm), four thicknesses (1.2, 1.5, 2.0, and 3.0 mm), and opening ratios ranging from 0 to 0.85 were investigated, with an opening-to-web-depth aspect ratio of 1.0. A total of 120 FE models were analysed. The resulting numerical database was used to quantify the reduction in shear capacity with increasing opening size and to develop a regression-based shear-capacity reduction relationship for duplex stainless-steel SupaCee sections.

### 3. Results

The validated FE model was used to investigate the shear behaviour of duplex stainless steel (EN 1.4462) SupaCee sections with circular web openings. The FE results showed a progressive reduction in shear capacity with increasing web opening ratio. Three shear reduction formulations, comprising one linear and two polynomial equations, were evaluated using the FE database. The third-order polynomial equation resulted in the lowest coefficient of variation (COV) of 0.0640, with a mean FE-to-predicted ratio of 1.0010, and was therefore selected to represent the shear-capacity reduction of duplex stainless-steel SupaCee sections. The proposed equation and its comparison with the FE results are presented in Figure 2.

$$q_s = 1.6992\left(\frac{d_{wh}}{d_l}\right)^3 - 2.3694\left(\frac{d_{wh}}{d_l}\right)^2 - 0.0703\left(\frac{d_{wh}}{d_l}\right) + 1.0075$$

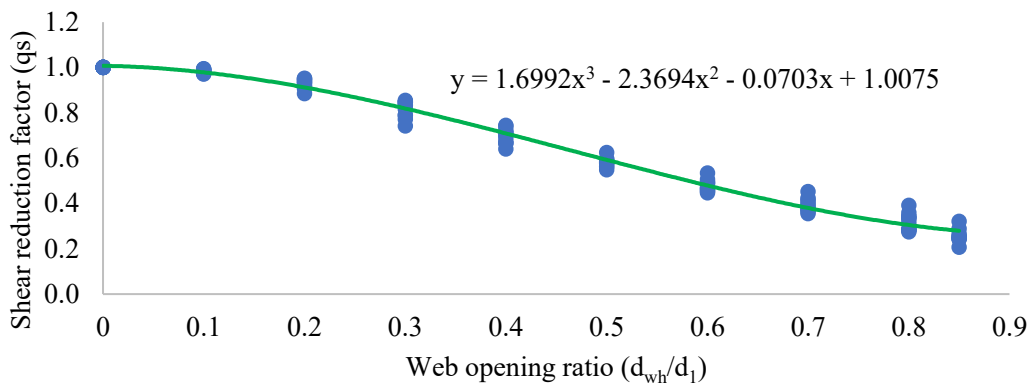


Figure 2: FE results and proposed third-order polynomial equation.

### References

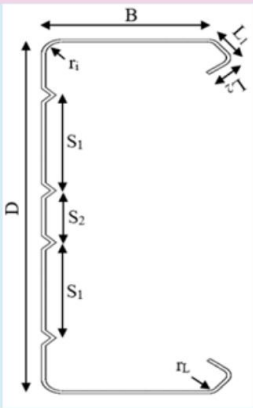
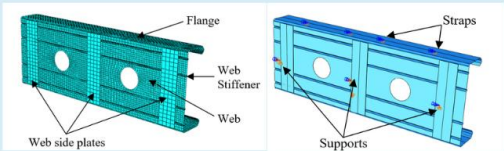
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# Cold-Formed Stainless Steel SupaCee Sections with Circular Web Openings

This research investigates the shear behaviour of cold-formed stainless steel SupaCee sections with circular web openings. Two stainless steel grades were examined: austenitic (1.4301) and duplex (1.4462). A total of 240 finite element (FE) models were developed, validated against experimental data, and used in a parametric study to propose new shear reduction factor equations for design practice.

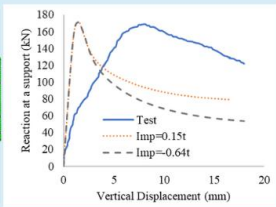
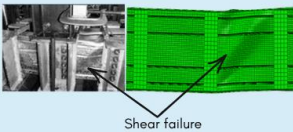
## SupaCee Cross-Section Geometry

The SupaCee section features a lipped channel profile with a circular web opening. Key geometric parameters include dwh (opening diameter) and d1 (clear web depth). The opening ratio dwh/d1 governs shear capacity reduction and is the primary variable in the parametric study.



## FEA Validation Results

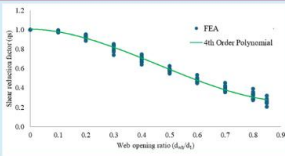
FE models were validated against experimental test results. The mean Test/FEA ratio was 0.98 with a coefficient of variation (COV) of 0.04, confirming excellent agreement between numerical predictions and physical tests. This high accuracy validates the FE modelling methodology for the parametric study.



| Section | Thickness(mm)      | Steel type           | $d_{wh}/d_1$                                               | Number of models |
|---------|--------------------|----------------------|------------------------------------------------------------|------------------|
| SC100   | 1.2, 1.5, 2.0, 3.0 | EN 1.4301, EN 1.4462 | 0.00, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.85 | 80               |
| SC150   | 1.2, 1.5, 2.0, 3.0 | EN 1.4301, EN 1.4462 | 0.00, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.85 | 80               |
| SC200   | 1.2, 1.5, 2.0, 3.0 | EN 1.4301, EN 1.4462 | 0.00, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.85 | 80               |
| Total   |                    |                      |                                                            | 240              |

## FE Modelling

A total of 240 finite element models were developed in ABAQUS using shell elements (S4R). Models incorporated geometric and material nonlinearities, initial geometric imperfections, and residual stresses. The parametric study varied dwh/d1 ratios, section sizes, and steel grades systematically.



## Proposed Reduction Factor Equations

$$\phi_v = -3.4278\left(\frac{d_{wh}}{d_1}\right)^4 + 7.4843\left(\frac{d_{wh}}{d_1}\right)^3 - 5.4085\left(\frac{d_{wh}}{d_1}\right)^2 + 0.4345\left(\frac{d_{wh}}{d_1}\right) + 0.9973$$