

# Numerical Evaluation on Warping Constants of General Cold-Formed Steel Open Sections

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## Abstract

The calculation of warping constant ( $C_w$ ) for an open thin-walled open section is a tedious and difficult task and thus presenting an obstacle to routine design. Although  $C_w$  formulas and values for selective cold-formed steel sections are available in the AISI design manuals, most practicing engineers have limited idea of evaluating the warping constants for sections not listed in the AISI design manuals. This paper proposes a detailed step-by-step numerical procedure for evaluating the warping constant of a general open thin-walled section. Comparison shows virtually no difference between the calculated values and those listed in the AISI design manuals. The proposed procedure is a reliable and useful tool for computing the warping constant for an arbitrary cold-formed steel open section, which does not need a sophisticated computer software.

**Keywords:** warping constant, torsional stress, thin-walled section, cold-formed steel, torsional property

## 1. Introduction

Open thin-walled sections subjected to torsion will result in pure torsional shear stress, warping shear stress and warping normal stress. Evaluation of these torsion-induced stresses is not a routine job for practicing engineers as the major difficulty arises from the determination of sectional warping constant ( $C_w$ ). Complex formulas for  $C_w$ , usually involving mathematical integrations are available from previous researchers (Bleich, 1952; Galambos, 1968; Kollbrunner and Basler, 1969; Heins, 1975; Yu, 1991). Computation of warping constants for open thin-walled sections can be greatly simplified by recognizing the linear variation of unit warping properties between the two consecutive intersection points of plate elements. As a result, the sophisticated integral forms for  $C_w$  can be represented by numerical expressions suitable for computer coding as has been done in the past (Hancock, 1978; Yoo and Acra, 1986; Kubo and Fukumoto, 1988; Trahair, 1993; Lue and Ellifrit, 1993, 2003; Salmon and Johnson, 1994; Papangelis and Hancock, 1995; Ellifrit and Lue, 1998; Lin and Hsiao, 2003). Although the  $C_w$  values and formulas for nine selective practical sections are provided in the AISI design manual (2002), the formulas presented are rather complicated to most users. When the open section is irregular or not available in the AISI Manual, a guide for computing  $C_w$  for such shapes is warranted. A simple and reliable approach for evaluating  $C_w$  values

would be very useful for practicing engineers when dealing with torsional problems.

In this study, a step-by-step numerical procedure for  $C_w$  calculation is presented and discussed. A simple computer program was developed to facilitate the tedious calculation of  $C_w$  and a representative section was selected to illustrate the details of the proposed procedure. The accuracy of the proposed procedure was verified by comparing with the values tabulated in the AISI design manuals. The comparative study shows that the differences between the computed and tabulated  $C_w$  values are negligible. This implies that the proposed computational method to compute  $C_w$  for a cold-formed steel open section is accurate and reliable. The study will satisfy those who are looking for a better estimation on torsional evaluation of cold-formed steel open sections.

## 2. Integration Forms for Warping Constants of Open Thin-walled Sections

Integration forms for warping constants ( $C_w$ ) of open thin-walled sections are summarized as follows, based on Galambos (1968) and Heins (1975). To calculate the  $C_w$  value, the centroid ( $C$ ) and shear center ( $S$ ) of a section must be located first. By basic mechanics, the centroid ( $C$ ) coordinates of a section is given by Eq. (1).

$$X_c = \frac{1}{A} \int_A x dA \quad Y_c = \frac{1}{A} \int_A y dA \quad (1)$$

where  $x$  and  $y$  are the coordinates of infinitesimal area  $dA$  along the section and  $A$  is the total area of open thin-walled section. The origin of the coordinate system is

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