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Deflection of simply supported box girder including effect of shear lag

Chartree Lertsima [a], Taweep Chaisomphob [a,*], Eiki Yamaguchi [b], Jaturong Sa-nguanmanasak [a]

[a] *Civil Engineering Program, Sirindhorn International Institute of Technology, Thammasat University, Pathumthani 12121, Thailand*
[b] *Department of Civil Engineering, Kyushu Institute of Technology, Tobata, Kitakyushu 804-8550, Japan*

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Abstract

The shear lag has been studied for many years. Nevertheless, most of the studies are related to the effect of the shear lag on stress distribution and very few have investigated the effect on deflection, although some design codes have formulas for the effect of the shear lag on deflection. In this conjunction, the present study carries out three-dimensional finite element analyses for various box girders to investigate the deflection at the mid-span. The multimesh extrapolation is employed to ensure the accuracy. The present study thus reveals the influence of the parameters that characterize the geometry of a box girder on the deflection. It is also shown that the formulas adopted in the design codes underestimate the deflection considerably. Based on the present numerical results, empirical formulas are proposed to compute the deflection magnification factors that account for the difference between the deflections due to the finite element analysis and the beam theory.

Keywords: Shear lag; Deflection; Simply supported box girder; Three-dimensional finite element analysis; Parametric study; Multimesh extrapolation

1. Introduction

The phenomenon of nonuniform normal stress distribution in the flange of a thin-walled member is called the shear lag. It has been known for many years and studied by many researchers. A concise but excellent literature review of research on the shear lag is provided by Tenchev [1]. However, most of the existing studies focus on stress distribution, and the effect of the shear lag on deflection is rarely discussed. Nevertheless, British Standards Institute [2] and Japan Road Association [3] have formulas to evaluate such effect in the form of the effective width and they have been used for years in practice. However, even the definition of the effective width for evaluating deflection does not seem to be very clear, while the effective width for the stress evaluation is defined explicitly in many papers [1,4–7].

In the past, analytical means was resorted to so as to investigate the shear lag phenomenon [7–13]. Some assumptions had to be employed to yield solutions inevitably in such an approach. The finite element method was also used, but the analysis model was often reduced to a two-dimensional problem due to the limitation of computer capacity [1,6]. With the advancement of computer technology, it is no longer an insurmountable task to deal with the shear lag phenomenon by the three-dimensional finite element method. In fact, recently the authors have conducted the finite element analysis by shell elements to study the effect of the shear lag on stress concentration in a simply supported box girder [14]. An effort was made to eliminate the discretization error by the multimesh extrapolation [15]. Loading conditions were also carefully treated.

* Corresponding author. Tel.: +66 2 986 9009x1907; fax: +66 2 986 9009x1900.
E-mail address: taweep@siit.tu.ac.th (T. Chaisomphob).

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In the present study, the deflection of a simply supported box girder at the mid-span, i.e. maximum deflection, is investigated by the three-dimensional finite element method with shell elements. To this end, a parametric study is conducted for various values that characterize the geometry of a box girder. The multimesh extrapolation [15] is utilized to ensure the accuracy. Empirical formulas are then proposed to account for the difference between the deflections due to the finite element analysis and the beam theory. In all the analyses, a finite element program, MARC [16], is used.

2. Box girders to be analyzed

Simply supported box girders (Fig. 1) under concentrated and uniformly distributed loads are analyzed. In the present study, an entire box girder is modeled as it is by shell elements: the shear lag problem is not reduced to a two-dimensional plane stress problem and no beam assumptions are implemented in the present analysis.

In the three-dimensional finite element model, the load that is unique in the beam theory can be applied in various ways and the shear lag effect may vary by the way the load is applied. Therefore, following the previous study [14], two types of concentrated load shown in Fig. 2 and two types of uniformly distributed load shown in Fig. 3 are considered in the present study. Note that many researchers do not describe their loading conditions explicitly. Tenchev [1] is one of the very few researchers that have provided this kind of information: he has employed Loads C-2 and D-1 for his concentrated and distributed loads, respectively as shown in Figs. 2 and 3.

3. Deflection evaluation

The structural model described in the previous chapter is analyzed by the finite element method using shell elements. Although the finite element method is very versatile and powerful, the result may depend largely on finite element mesh employed in the analysis. To this end, the influence of finite element mesh on the deflection is first studied: four finite element meshes of Meshes A–D are used to evaluate the deflection at the mid-span of a simply supported box girder ($H/L = 0.2$, $B/H = 1.0$, $T_f/T_w = 1.0$) under Load C-2. All the elements in each mesh are square and from Mesh A to Mesh D, the size of an element becomes finer in a consistent way, as may be realized in Fig. 4. Due to

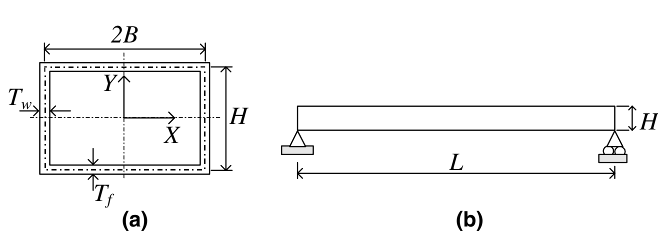

Fig. 1. Structural geometry of box girder: (a) cross section; (b) side view.

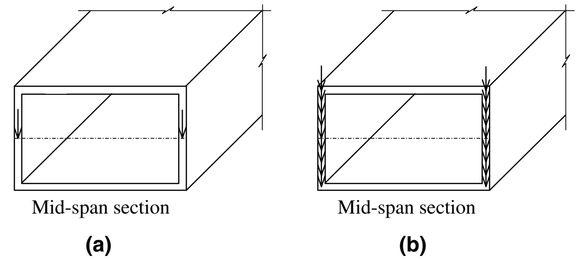

Fig. 2. Concentrated load: (a) Load C-1; (b) Load C-2.

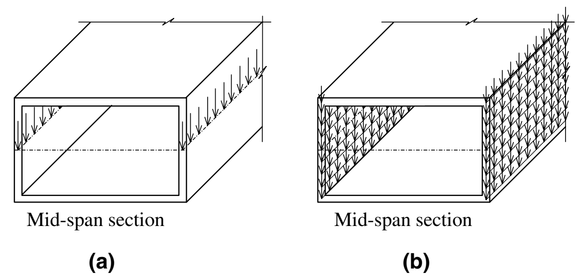

Fig. 3. Distributed load: (a) Load D-1; (b) Load D-2.

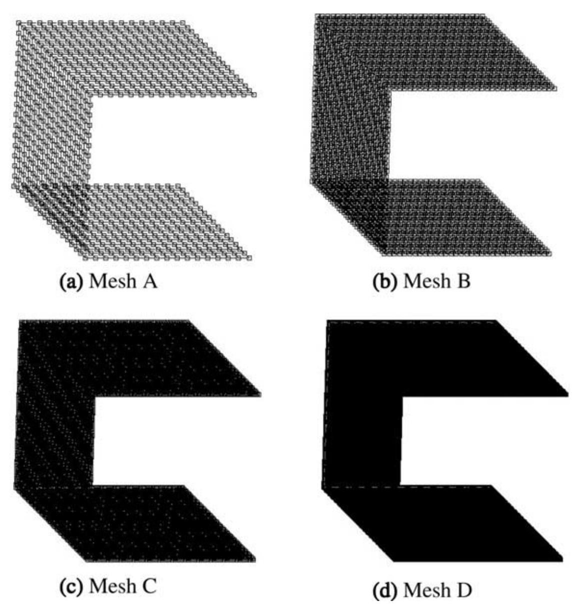

Fig. 4. Finite element meshes.

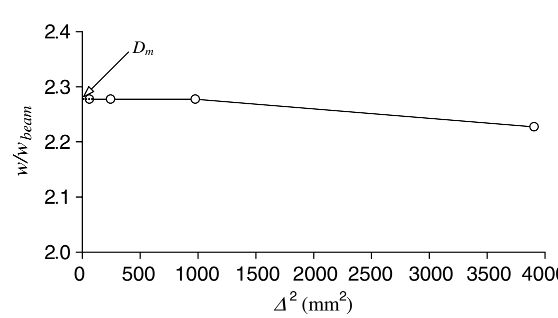

Fig. 5. Variation of deflection with respect to representative element size.