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Effect of intermediate diaphragms on the load – carrying capacity of steel – concrete composite box girder bridges

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ABSTRACT

Intermediate diaphragms are used in box girders not only to prevent premature distortion under eccentric loading conditions but also to improve the distribution of live loads. This paper reports an investigation into the effect of intermediate diaphragms on the load - carrying capacity of a Steel – Concrete Composite Box (SCCB) girder bridge with open steel box section. In the current study, a three - dimensional finite element (FE) model of the SCCB girder is developed and analyzed using ABAQUS software. The nonlinear inelastic analysis is invoked in order to accurately capture the actual behavior of the girder. The numerical model is verified with experimental results to ensure the accuracy of the FE modeling method. A parametric analysis is implemented to study the effect of intermediate diaphragms on the load – carrying capacity of an SCCB girder with a 30–60 m span length. Based on parametric studies, the number of intermediate diaphragms (N) is recommended for practical design of the girder, which satisfies the requirement stated in the provisions of the AASHTO LRFD standard.

1. Introduction

Recently, the design and construction of the SCCB girders have become widely prevalent due to their high bending stiffness, torsional rigidity, and rapid construction. However, this type of girder still contains some intrinsic limitations. Under an eccentric loading condition, the shape of the cross section may distort and warp out of the longitudinal plane. Distortion of box girders may induce excessive distortional warping and lateral bending stresses when the lateral bending stiffness of the flanges and webs is not sufficient to retain the shape of the box section. Therefore, in order to prevent the aforesaid incurred lateral warping and stresses from happening, lateral distortion must be limited. For this reason, intermediate diaphragms are placed to maintain the box shape, reduce the transverse bending and longitudinal warping stresses, and to ensure the maximum load – carrying capacity of the box girder.

A number of studies affiliated with analyses of box girders have been carried out for several decades. Research on the distortional behavior of single-cell box girders originated with Dabrowski [1]. Based on the governing differential equation of Dabrowski [1], some studies have been performed regarding the intermediate diaphragms within steel box girders such as those by Sakai and Nagai [2] and Yoda et al. [3]. Furthermore, several design guidelines proposed the spacing of intermediate diaphragms in steel box girders based on the fixed values of the ratio of the distortional warping normal stress to the longitudinal bending normal stress. According to the Hanshin Expressway Public Corporation of Japan [4], this ratio is 5%, whereas a ratio of 10% is proposed in AASHTO LRFD [5] and by the Korean Ministry of Construction and Transportation [6]. In order to consider the various desired stress ratios, Park et al. [7–9] developed an analysis program using a box beam FE to investigate the effects of the axial, flexure, torsion, and distortion in box girders. On the basis of the box beam element, Park proposed tentative design graphs for the sufficient intermediate diaphragm spacing in steel boxes with a non-composite doubly symmetric cross-section for straight bridges taking into account the various desired stress ratios. Regarding diaphragms at supports, in order to determine the optimum design of the unstiffened/stiffened bearing diaphragms of box girders, Megson and Hallak [10–13] carried out experimental and analytical researches for this girder with several support conditions. More recently, several researches were conducted by Helwig et al. [14] and Helwig and Yura [15] to provide design guidelines for the end diaphragms of steel box girder bridges. Shervin Maleki et al. [16] used a nonlinear finite element analysis to study the behavior of the end diaphragms under seismic and gravity loads. Effect of the diaphragm components was evaluated for each loading. As a result, the most efficient diaphragm configuration was introduced for combined seismic and vertical loads.

However, all above-mentioned research results and design guidelines related to intermediate diaphragms spacing only concerned the closed steel box section, which may not be suitable for use in the open

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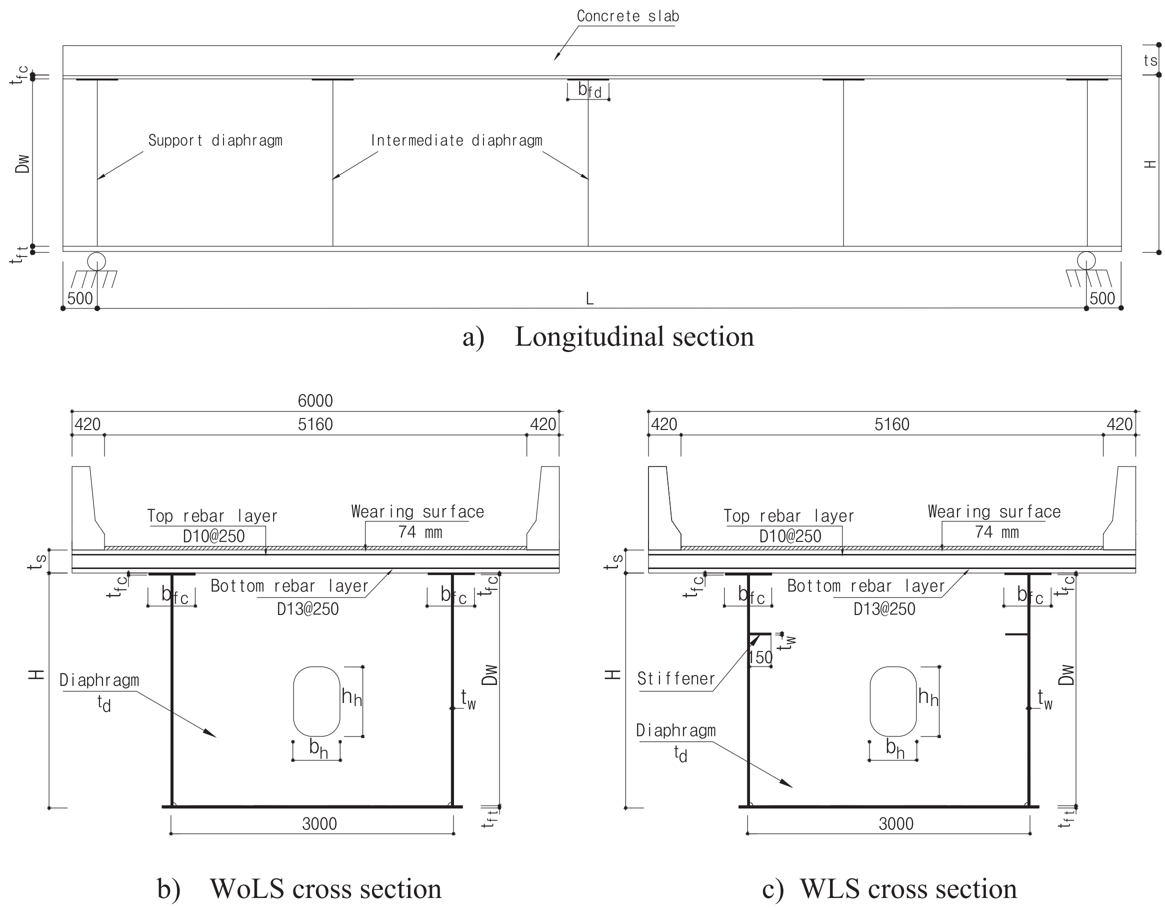

Fig. 1. Section of the SCCB girder.

Table 1
Material properties of steel and concrete in parametric study.

No	Type of steel	Thickness Diameter (mm)	Yield strength Fy (MPa)	Ultimate strength Fu (MPa)	Modulus of Elasticity Es (GPa)
1	Web plate	t_w	406.9	503.1	193
2	Bottom/Flange plate	t_f	314.1	418.5	192
3	Diaphragm plate	t_d	303.3	413.3	191
4	Longitudinal reinforcement	D13	258.6	445.6	188
5	Transverse reinforcement	D13	258.6	445.6	188
6	Longitudinal Stiffener	t_w	406.9	503.1	193
	Specimen	**Cube strength fcu (MPa)**	**Compressive strength f'c (MPa)**	**Modulus of elasticity Ec (GPa)**	**Age at testing (days)**
7	Concrete slab	67.19	53.08	38.3	60

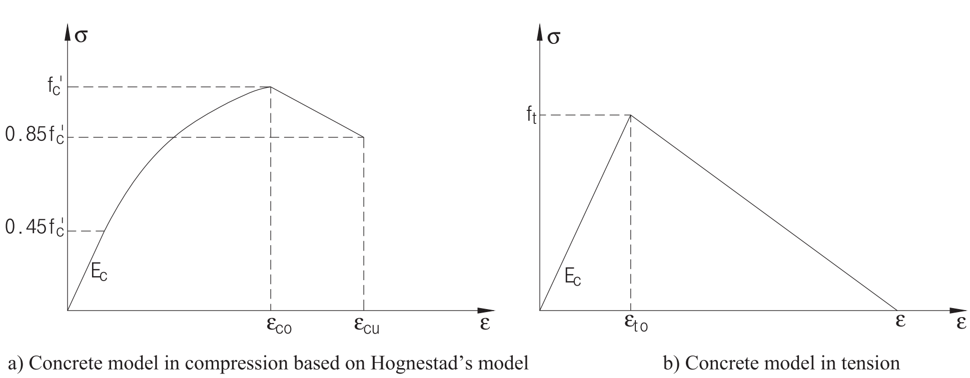

Fig. 2. Stress – strain relationships of concrete model 1.