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The flexural behavior of horizontally curved steel I-girder bridge systems and single-girders

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ABSTRACT

The structural system of a horizontally curved steel I-girder bridge consists of a number of curved girders that are laterally braced by interconnected cross-frames. The modeling and nonlinear analysis procedures of large and complex systems of curved bridges are time consuming and demand a high computational cost. In order to facilitate the preliminary design procedures, it is suggested that the complicated bridge system might be replaced by simple single curved I-girders. In this paper, the applicability of single-girder models in determining the flexural response, elastic stiffness and the ultimate strength of curved bridge girders is examined. In addition, a series of finite element parametric studies is conducted to consider the effect of curvature on the accuracy of single-girder models. It is observed that the spread of plasticity, flexural strength and failure mechanism of bridge girders can be well predicted by the use of equivalent single-girder models. Yet, single-girder models cannot accurately predict the elastic stiffness and vertical and lateral and deflections of horizontally curved steel bridge girders.

1. Introduction

Horizontally curved bridges are widely used to construct traffic interchanges or gangways in places with restricted site space and pier locations. When curved bridge superstructures were first introduced, they were generally composed of a series of straight girder chords. Over time, with the advent of new construction technologies of curved girders, these systems have steadily been replaced by structures containing curved sections in any range of curvatures [1]. Horizontally curved girder steel bridges offer esthetic, economic and environmental benefits over more traditional chorded structures.

The inherent rotation characteristics of horizontally curved I-girders cause the cross-frames, diaphragms and bracings to be amongst the main load-carrying components of curved bridges, playing a major role in providing the stability of girders, especially during construction. Constructability is one of the main concerns in the design of bridges according to the AASHTO regulations [2]. In recent years, the AASHTO LRFD specifications provide more organized and explicit guidance of design for constructability than ever before [3]. Constructability issues should include consideration of deflections, strength of materials and stability during critical stages of construction [2]. Before the hardening of the concrete deck, discretely braced flanges should be investigated for positive flexure according to the AASHTO requirements, expressed in terms of combined vertical bending and flange lateral bending of the non-composite steel section. This way, it is ensured that lateral-torsional and flange local buckling, flange yielding, and web bend-buckling do not occur during construction.

The present study is confined to consider the flexural behavior of non-composite horizontally curved steel bridge I-girders. In general, a linear elastic analysis method is implemented to determine deflections and force effects in bridge structures. This procedure produces an obvious inconsistency since the AASHTO flexural resistance equations are derived based on the inelastic material behavior for the strength limit states. Thus, the cross-sectional resistance is not limited to the linear range. On the other hand, the AASHTO LRFD loads and load factors are determined via analyses based on linear material models. Therefore, the analytical procedures based on material nonlinearities are not permitted in the AASHTO specifications, except in limited explicitly outlined cases [2]. However, it is recommended to use fully nonlinear methods of analysis to obtain a better understanding of the structural behavior of high priority structures.

A high computational effort is required for refined FE methods of analysis being applied to study the structural behavior of complex systems of horizontally curved bridges. In the present study, the flexural response of curved multi-girder bridge systems is compared against their equivalent simple single-girder models. Consequently, the applicability of single-girder models in determining the elastic deflections and the ultimate flexural strength of curved bridge girders is assessed.

In the literature, Culver and McManus [4] studied the inelastic behavior of horizontally curved girders and provided some design recommendations. However, it was later demonstrated that the curvature induced flange lateral bending stress in the McManus-Culver predictor equation was double counted [5].

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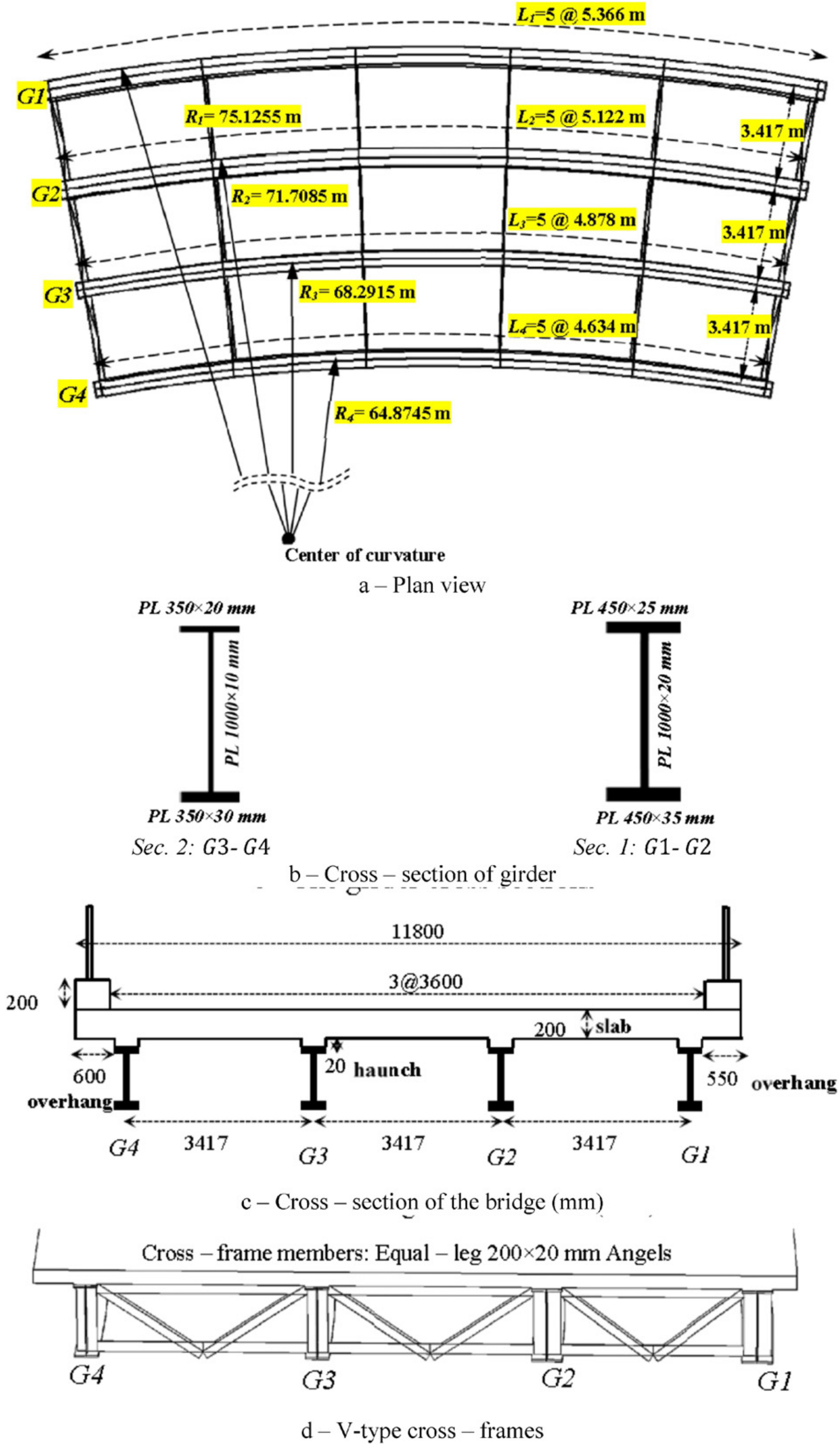

Fig. 1. Base bridge model geometry. a — Plan view. b — Cross-section of girder. c — Cross-section of the bridge (mm). d — V-type cross-frames.

Mozer and Culver [6] conducted seven tests to study the flange local buckling of scaled, doubly symmetric, welded plate girders under static loads. ASTM A36 and AISI 1008 steels were used in flange and web plates, respectively. It was concluded that in the case of cut curved flanges, the straight girder compression flange slenderness limitations can be conservatively applied to horizontally curved girder design.

Table 1
Design limit states.

Limit state	Load combination
Strength I	$1.25DC + 1.75(LL + CE) \times (1 + IM)$
Strength IV	$1.50DC + 0.00(LL + CE)\times(1 + IM)$
Service II	$1.00DC + 1.30(LL + CE)\times(1 + IM)$