# Nonlinear Analysis of A Horizontally Curved Composite Box-Girder Model

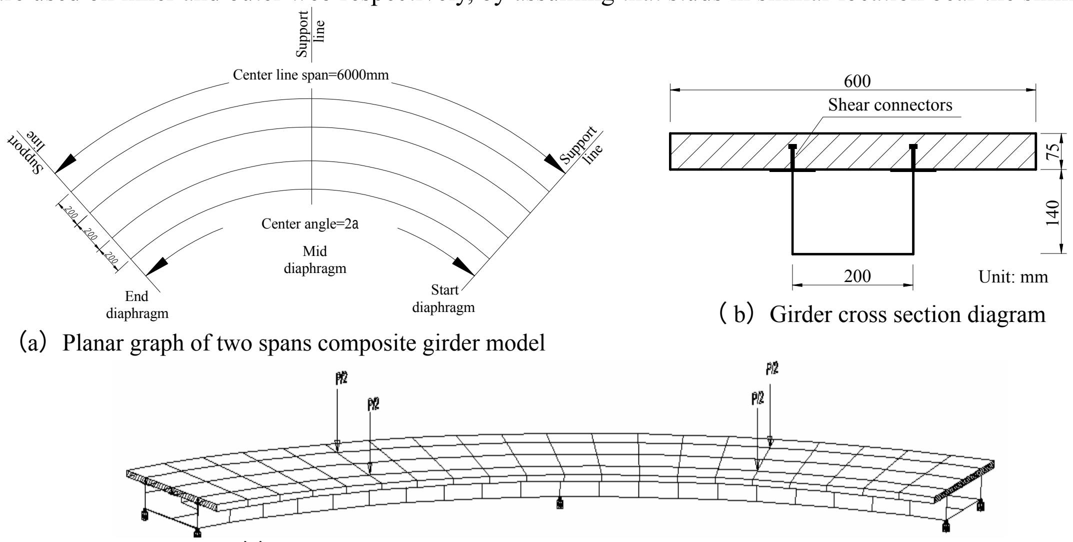
Waseda University, Department of Civil and Environmental Engineering Student Member ○ Weiwei Lin
Waseda University, Department of Civil and Environmental Engineering Fellow Teruhiko Yoda

## 1. Introduction

In recent years, steel-concrete composite girders have been widely used for the construction of curved bridges and flyovers for economic and aesthetic reasons. However, curvature of the superstructure leads to combined bending and torsion in the girders, so there is considerable additional complexity associated with the analysis, design and construction compared to that for typical straight bridges. Especially, there is still much room for improvement in research of ultimate strength of such kind of bridges. As Hall (1999) have already stated, the behavior of curved composite bridges at ultimate strength has not been investigated enough, and the behavior of curved bridges near ultimate load is unknown since only a limited number of publications are available on this important design aspect[1]. Thus, the failure mechanism of a curved bridge needs to be defined and the failure tests of full-scale bridges are necessary. Similar studies have been conducted in recent years, such as Thevendran et al[2], Shanmugam et al[3], Jung et al[4)~5)]. This study aims to provide a comprehensive investigation to clarify the ultimate behavior of curved composite girders by using finite element method.

## 2. Description of Girder Model

With a view to the literature[6], a curved composite girder model is designed as the research object. The model has two spans of (3000+3000) mm measured along the centerline of the bridge model. Dimensions are shown in **Fig.1.** In order to predigest complicated calculation, two groups of studs: 31 inner studs and 31 outer studs with the diameter of 24mm are used on inner and outer web respectively, by assuming that studs in similar location bear the similar forces.




(a) Planar graph of two spans composite girder model
(b) Girder cross section diagram
(c) Three-dimensional model of two spans curved composite girder
**Fig.1 Detailed Geometry of Girder Model**

## 3. Model Building

The modeling of the girder prototype is carried out in three dimensions using the finite-element method and the ANSYS software. Solid elements, shell elements, spring elements are used to simulate the concrete deck, steel girder and shear connectors respectively. Also, in order to account for the slip between concrete deck and steel girder, contact elements are used in this model. The widely-used uniaxial stress-strain relationship for concrete proposed by Hognestad[7], C50 concrete properties specified in Chinese code[8], and shear force-slip behavior of studs suggested by Ollgaard[9] are adopted in this study. BKIN model is chosen to simulate the non-linear behavior of the steel, in which, elastic modulus: E=2.1×$10^5$MPa, Poisson's ratio: ρ=0.245, Yield strength is 235MPa.

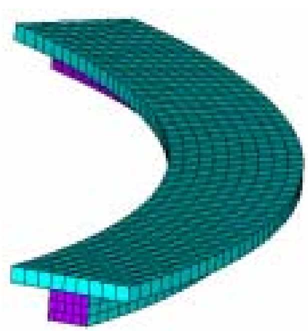


**Fig.2 FEM model**

## 4. Results and Discussion

### 4.1 Load-deflection curve

Nonlinear analysis of this model is performed, then the load-displacement curve is obtained and shown as **Fig.3.** [1]The results indicate that: during the initial loading stage, the girder is under elastic state and the deflexion shows a linear growth as the load increases. When the load exceeds 210kN, the girder displacement increases rapidly, showing

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Address: 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555 Japan. Tel: 03-5286-3399. E-mail: linweiwei@akane.waseda.jp

remarkable nonlinear behavior; when the load increases to 273kN, the girder achieves its maximum deformation and loses its bearing capacity. The calculation stops as convergence cannot be attained.

### 4.2 Cracking of the concrete deck

**Fig.4** shows the cracking development process of concrete deck, which reveals that with the load increase, concrete in negative moment and along arrangement path of shear studs subjects to large tensile stress, causing the cracking of concrete flange slab. Similar to straight composite girders, cracking of curved composite continuous box-girders in the negative moment area limits its application for longer spans.

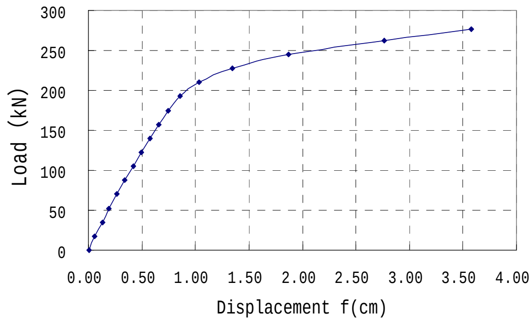



**Fig3 Load-displacement curve**

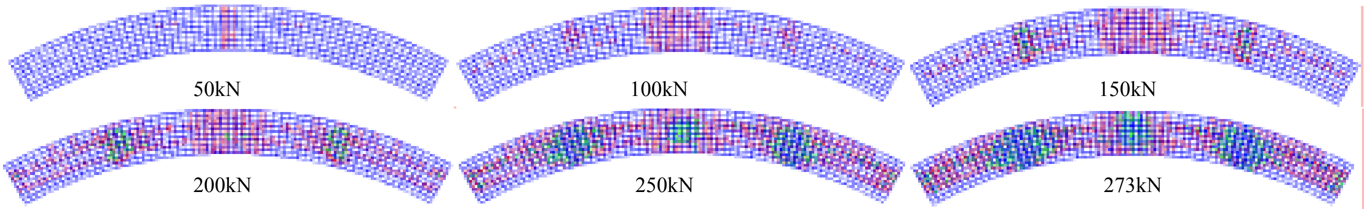
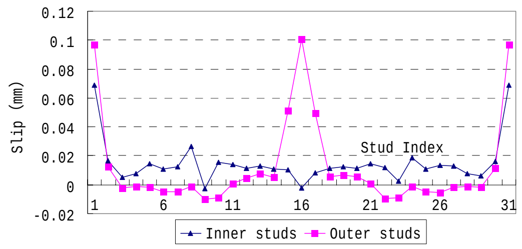


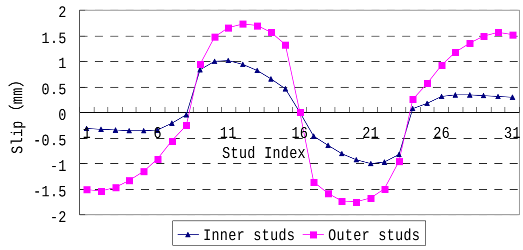

**Fig.4 Cracking development process of concrete deck**

### 4.3 Slip distribution of shear connectors

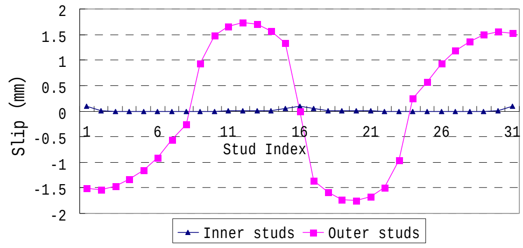
**Fig.5** shows the slip distribution of shear studs in curved composite bridges in ultimate limit state, three points need to be pointed out are：(1) Unlike straight girders, there is transverse slip of shear studs in curved composite girders, which means the shear studs need to bear transverse forces. (2) According to the studied model, longitudinal slip distribution of shear studs in curved composite bridges is similar to that of straight girders, but the longitudinal slip of outer studs is larger than that of inner ones. In ultimate state, shear forces beared by different studs are redistributed. (3) The amount of transverse slip of shear studs is quite small compared with its longitudinal slip.




(a) Transverse slip distribution of studs




(b) Longitudinal slip distribution of studs




(c) Comparison of transverse and longitudinal Slip

**Fig.5 Slip distribution of studs under ultimate state**

## 5. Conclusions

On the basis of the results obtained from this study and within the designed model studied, conclusions can be drawn as follows: (1)During the whole destructive process, the curved composite bridge structures could make the most of material properties of steel and concrete; (2) Cracking of the concrete flange slab will properly occur in negative moment area along the arrangement path of shear connector. Similar to the straight composite bridges, serious cracks in the negative moment area deserve special attention. (3) Different from straight composite beams, there are longitudinal and transverse slip coexist in shear connectors. The shear slip of outer studs is larger than that of inner ones. The amount of transverse slip is very small compared to that of the longitudinal slip.

## 6. References

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