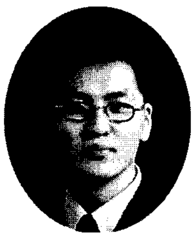
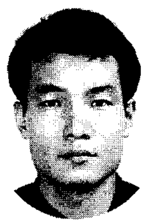
Prestressed Concrete Girder Bridges Strengthened by External Post-tensioning Method





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ABSTRACT

This paper deals with the analysis of both unstrengthened and strengthened prestressed concrete girder bridges. Finite element method is utilized to perform the analysis of superstructures. Based on the grillage method of analysis, emphasis is placed on the modeling techniques for structures. The conventional grillage method of analysis is modified so that the interaction between the slab and girder behaviors can be taken into account in the analysis. A prototype of simply supported prestressed I-type girder bridge is selected for the analysis. The results of numerical analyses are compared with those of load test. The results of analysis indicate that the proposed method of analysis gives more realistic response of bridges than the conventional grillage method.

Keywords : prestressed concrete, bridge, finite element method, loading test, girder bridge

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1. Introduction

Due to heavy vehicles and environmental attacks, bridges are continuously deteriorated as the year of service is increased. To ensure the public safety, deteriorated bridges should be repaired or strengthened to meet the function as originally designed.

In Korea, among 15,270 bridges, prestressed concrete (PSC) I-type girder bridges take 10 percent of entire bridge inventory. Although many different types of strengthening methods are available to date, the external post-tensioning method is widely used as a strengthening method for PSC girder bridges and proven to be an effective strengthening method.

In the design of bridge strengthening, load carrying capacity of the superstructure must be determined. One method for determining the load carrying capacity of bridge is the load test. Since the load test is expensive and requires time consuming process, load rating based on the structural analysis is generally used in practice. With the availability of powerful analysis tools such as finite element analysis softwares, realistic analysis of structural behavior is no longer difficult.

In the finite element analysis, the superstructure of bridges can be modeled in several different ways. One popular method of modeling may be a grillage method, in which slab, girders, and cross-beams within the superstructure are idealized as a set of planar grids. Although, grillage method of analysis is very simple in concept and easy to use, a realistic behavior of superstructure cannot be analyzed with this method. This is because, in the method, slab-and-girder deck is modeled in the same plane, interaction between the slab and girder behaviors cannot be taken into account in the analysis.

This paper deals with the analysis of both unstrengthened and strengthened PSC I-type girder bridges. Finite element method is used to perform the analysis of superstructures. Based on the grillage method of analysis, emphasis is placed on the modeling technique of structures.

The conventional grillage method of analysis is modified to take into account the interaction between the slab and girder behaviors. In the proposed method, slab-and-girder deck is discretized by a number of frame finite elements and rigid links are used to connect the elements that represent the longitudinal and transverse stiffnesses of the deck.

The effect of strengthening by external post-tensioning method is included in the analysis. A prototype of simply supported prestressed I-type girder bridge is selected for the analysis. The results of numerical analyses are compared with those of load test.

2. Method of Analysis

2.1 Planar Grillage Method of Analysis

In the conventional grillage method[1,2] of analysis, slab-and-girder deck shown in Fig. 1(a) is generally idealized by an equivalent grillage of beams as shown in Fig. 1(b).

If the grillage mesh is sufficiently fine, the bending as well as twisting actions of the deck can be approximated by this method of analysis. Although the results of grillage analysis may sufficiently accurate for the design purpose, one of shortcomings of this analysis can be summarized as follow.

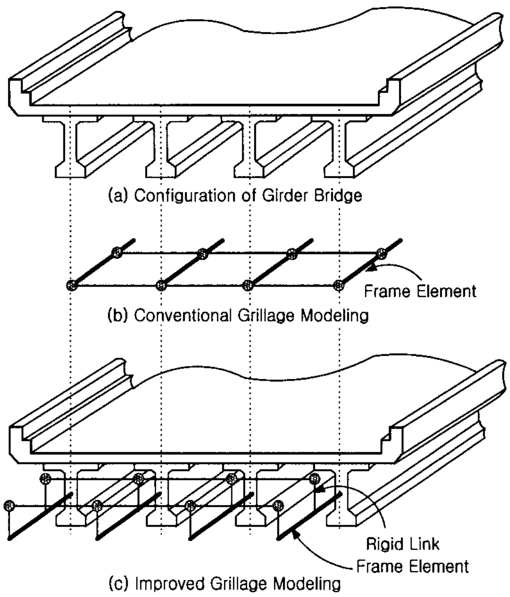


Fig. 1 Grillage methods of analysis

For PSC I-type girder bridges, the neutral axes of interior and exterior girders may be different in the longitudinal direction. Furthermore, in the transverse direction, the neutral axes for the composite section of decks may be quite different than those of cross-beams and slab. However, in the grillage method, the grid elements in the longitudinal as well as transverse directions are modeled in the same plane. Therefore, using the conventional grillage method, realistic bending and twisting behaviors and in-plane shear actions of the deck, especially due to non-uniform loading, cannot be taken into account.

2.2 Proposed Method of Analysis

In the proposed method[3,4] of analysis, slab-and-girder deck shown in Fig. 1(a) is idealized by an equivalent grillage of beams as shown in Fig. 1(c).

The proposed modeling technique is similar to the conventional method, but rigid links are imposed to take into account the interaction between the slab and girders. Grid elements to represent longitudinal and transverse stiffnesses of slab-and-girder deck are connected at the neutral axis of each bridge component with the rigid link elements.

Since displacements and reactions of grid element are transferred through the rigid links, the actual behavior of slab-and-girder deck is more exactly approximated than that with the conventional grillage method of analysis.

Since the finite element method is utilized in this study, a frame finite element can be used to discretize slab-and-girder deck. The frame element consists of two nodes and three degrees of freedom per node: axial, rotational, and vertical displacement components.

In this study, the rigid link is idealized by a frame element having high bending and torsional stiffnesses.

3. Illustrative Example

A prototype bridge in service is analyzed to verify the proposed method of analysis. The bridge selected herein is a simply supported PSC bridge[5] having five I-type girders. The bridge deck is 8 m wide and 30 m long, and the design live load is DB-18.

Load test and bridge analysis with the proposed modeling technique are performed for the bridge before and after the strengthening. Material properties of concrete, reinforcing steels, and PS strands are summarized in Table. 1

Table 1 Material properties of concrete, rebar, and ps strands

		Properties(kg/cm²)
Concrete	σ_{ck}	340
	E_c	276,586
Rebar	σ_y	4,000
	E_s	2,040,000
PS Strand	$\sigma_{py} / \sigma_{pu}$	13,500/15,500
	E_{ps}	2,000,000
	P_j	458.16(t)

Fig. 2 shows the plan view and configuration of the girder before and after the strengthening. As shown in Fig. 2(b), the girder is strengthened by external post-tesioning method. A saddle is installed at a point of 11 m away from the bearing and post-tesioning force of 128 ton is introduced during the strengthening.

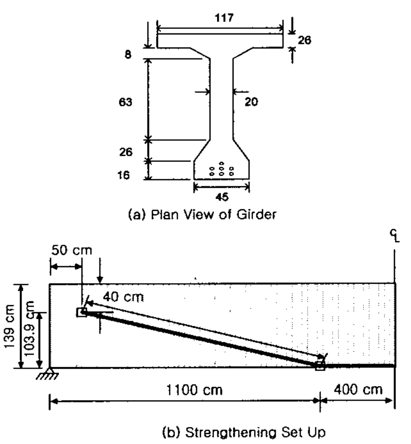


Fig. 2 Plan view and external post-tensioning set up

3.1 Load Test

In the load test, six loading cases shown in Fig. 3 are considered. A right rear wheel of the truck is loaded at positions 1 m away from a curb in 1/4, 2/4, and 3/4 of the span of the girder to be measured, and these correspond to LC1, LC2, and LC3 in the figure, respectively. On the other hand, a right rear wheel of the truck is loaded at positions 2.575 m away from a curb so that the truck may pass the centroid of bridge, and these correspond to LC4, LC5, and LC6 in the figure, respectively. It should be noted that the load test is not done in the course of this study, but the procedure and results of load test are well summarized in the reference by Han (1997).

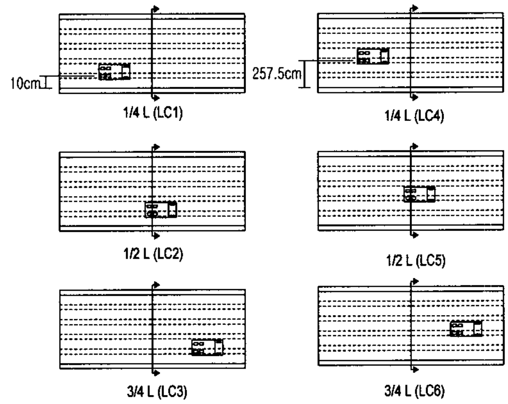


Fig. 3 Loading cases used in load test

3.2 Finite Element Analysis

Using the conventional and proposed grillage methods of analysis, the bridge is analyzed in accordance with the loading cases shown in Fig. 3. The finite element analysis software SAP2000[6] is used in generating nodes, elements, and meshes. A number of rigid links are used to connect the longitudinal and transverse elements at their neutral axes.

The effect of strengthening by means of external post-tensioning on the girder behavior is included in the analysis by imposing additional nodal loads corresponding to the post-tensioning forces.

Based on the magnitude of post-tensioning force and configuration of external post-tensioning set up for the girder, equivalent nodal loads are computed.

In the analysis, the effective moment of inertia for the deteriorated girder is computed by

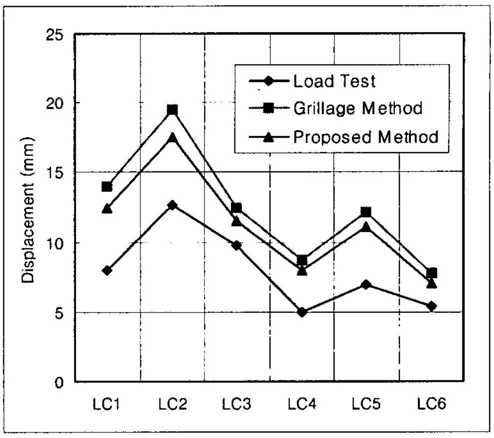
$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \quad (1)$$

in which M_{cr} is the cracking moment, M_a[7] the maximum moment due to live load, I_g the moment of inertia of the gross concrete section, and I_{cr} the moment of inertia of the fully cracked transformed concrete section.

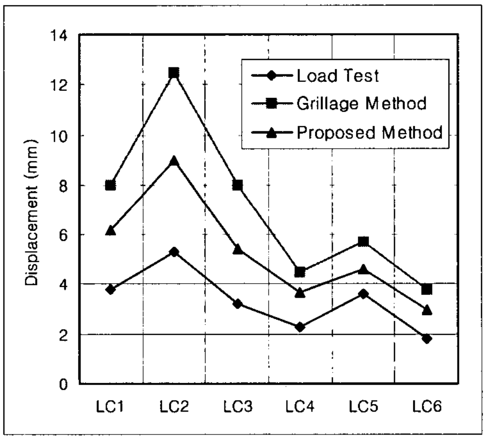
3.3 Results of Analysis

In Fig. 4, the results of finite element analysis are summarized and these are compared with the results of load test. Fig. 4(a) shows the maximum vertical displace-ments of the exterior girder in the bridge before the strengthening. The results indicate that the proposed method gives more realistic response of the bridge than the conventional method of analysis.

In Fig. 4(b), for the strengthened bridge, the maximum vertical displace-ments obtained by the finite element analysis are compared with that of load test. Although the discrepancy between the results by using the proposed method and the results of load test is apparent, it clears that the proposed method gives more realistic response of the bridge than the conventional method of analysis.



(a) Unstrengthened bridge



(b) Strengthened bridge

Fig. 4 Result of analysis

4. Conclusions

This paper proposes an improved grillage method for the analysis of both unstrengthened and steregthened PSC girder bridges. The results of analysis with the conventional and proposed methods of analysis are compared with the results of load test. The results of present study can be summarized as follows:

(1) The results of analysis indicate that the

proposed method of analysis gives more realistic response of PSC girder bridges than the conventional grillage method. This may be due to the fact that bending, twisting, and in-plane actions of the slab-and-girder deck are more accurately approximated in the proposed method of analysis.

(2) Within the scope of present investigation, the proposed method can be used to calculate the load carrying capacity of PSC girder bridges. However, it should be noted that the results of load test are generally conservative and the maximum discrepancy of two sets of results is about 30%.

References

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