An Analytical Study of the Transportation Optimization for Modular Bridge Blocks in Korea

Woo Young Jung[1], Chan-Hee Park[2], Kwang-Il Cho[3], and HoYoung Son[4]

***Abstract*—** In recent years, the modular bridges utilizing the hybrid system of concrete and steel structures as the conventional materials have been issued, due to standardized modular members and robotic construction in Korea. However, preliminary numerical studies reveled that the modular blocks can be exposed to the stress concentration at the supported area during the transportation routing and lifting conditions. Therefore, the primary goal of this study was to develop the transportation routing or lifting optimization for modular blocks, using 3D Finite Element (FE) models in ABAQUS. In addition, based on the results of the optimization, the verified transportation tools and guidelines would be provided as an ultimate vision of this study and the performance of the modular blocks was evaluated through simplified 3D FE analysis.

***Keywords*—**Modular bridge, Finite Element, Stress concentration, Lifting block.

I. Introduction

BASEED on the modular techniques from automotive and shipbuilding industry, modular blocks similar to Lego blocks have been applied in modular bridge systems. In recent years, modular system has been emerging area of construction, due to standardized modular members, economical efficiency, robotic construction, and easy maintenance plug-in mode. Furthermore, many researchers have addressed the performance evaluation of the modular bridges. Burgueno *et al.* studied the structural characterization of modular bridge components for the concrete filled carbon shell system [1]. Also, Ju *et al.* evaluated the flexural and fatigue behavior of link slab for continuous girder-type precast modular bridges [2] and Cheng *et al.* developed characterization of the modular bridge incorporating Fiber Reinforced Polymer (FRP) composite girders connected by stiffened FRP deck panels [3]. Therefore, this study focused on development of permanent modular superstructure and substructure of the bridge system in accordance with span length 20 *m* to 60 *m*. The primary objective of this research was to evaluate the performance of the superstructure modular blocks about 12 *m* during lifting of the system. Consequently, in order to develop the transportation optimization for modular blocks, linear elastic simplified 3D full scale Finite Element (FE) model was performed in ABAQUS [4].

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II. Finite Element Model of Modular Blocks

For the numerical analysis of the modular blocks, 3D full scale FE model using solid element for superstructures using ABAQUS was discretized. The 12 *m* span for the modular blocks was selected to evaluate the lifting performance in this study. The modular block was composed of four different parts: 1) concrete slab; 2) steel plate; 3) steel girder; 4) connector and Fig. 1 showed 3D full scale FE model of the block using solid element C3D8R in ABAQUS.

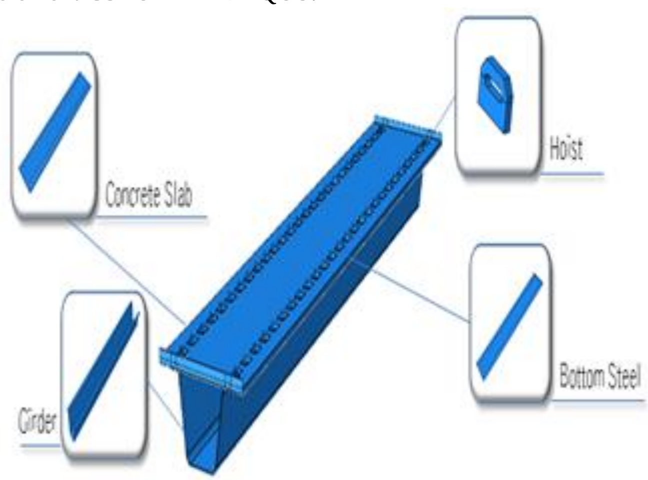

Fig. 1 3D full scale FE model of the modular block

A. Material Properties of the Modular Block

Table I listed various material properties considered in this paper for the numerical analysis and basic boundary conditions of the system using connectors (hoist) corresponding to lifting condition were described in Fig. 2. The hoist area was fixed to consider the real construction condition and the dead load was considered as only external loads, as shown in Fig. 3.

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TABLE I
MATERIAL PROPERTIES OF THE MODULAR BLOCK

	Girder	Bottom Steel Plate	Concrete Slab	Hoist
Density (t/mm3)	7.8e-009	7.85e-009	2.5e-009	7.8e-009
Elastic Modulus (MPa)	205,000	205,000	30,891	205,000
Poisson's Ratio	0.3	0.3	0.17	0.3
Design Strength (MPa)			40	

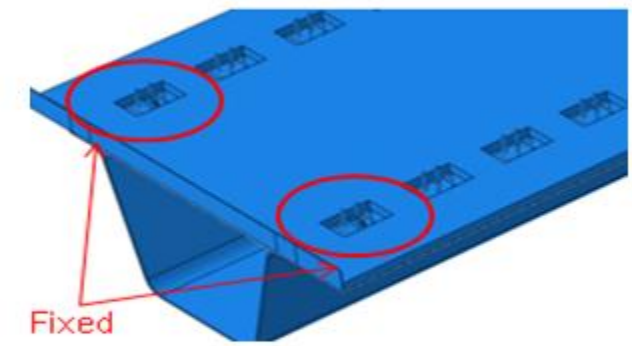

Fig. 2 The boundary condition of the modular block

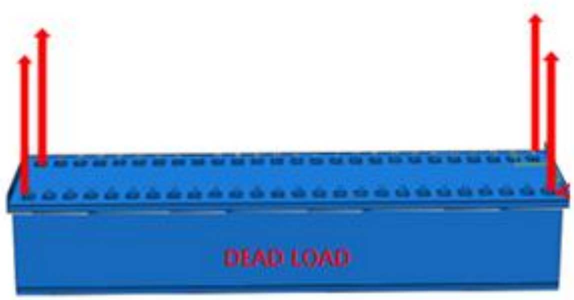

Fig. 3 Lifting condition for the system

B. Numerical Analysis Conditions for the Modular Block

In order to transport the modular blocks, various lifting approaches were considered in the study, as described in Fig. 4. This study used 4-point lifting method at the connectors and the gravity load of the block system was applied during the lifting. In addition, lifting method was applied to the cases of moving gradually inward from both ends.

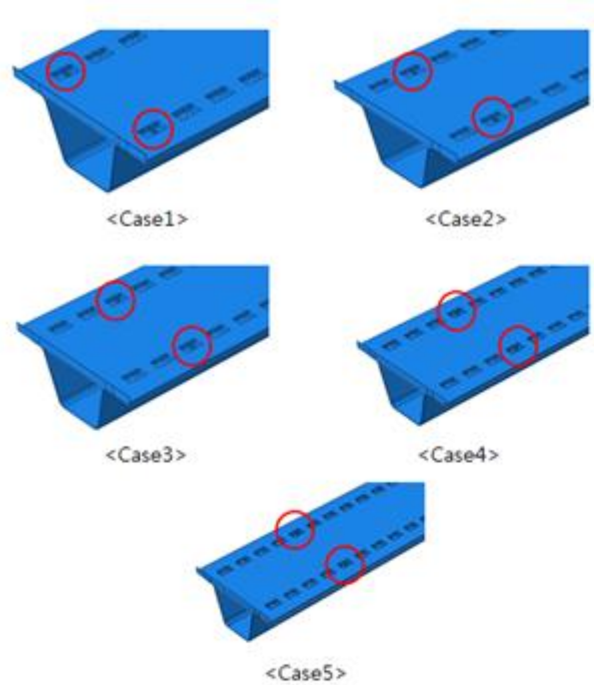

Fig. 4 Lifting methods for the modular blocks

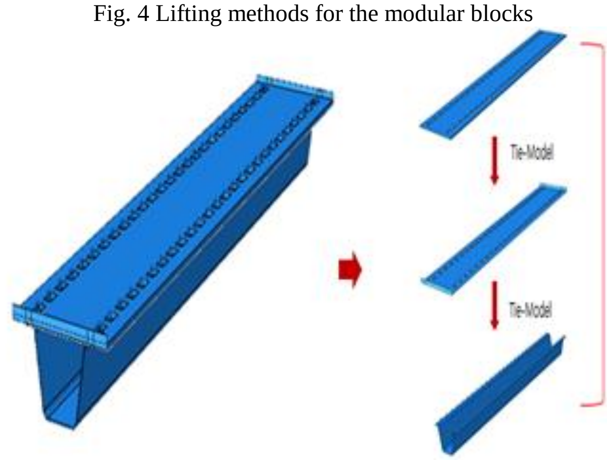

Fig. 5 Tided Connection of the FE model

For the simplified linear elastic 3D FE model, the interface between girder and steel plate, and also the area between steel plate and concrete slab were modeled as a perfect bond using tied option. It should be noted that the performance evaluation obtained from this study would be more conservative than the FE model considering sliding effect, due to the perfectly bonded interface. Further, the results based on the numerical analysis will be discussed in next section.

III. NUMERICAL ANALYSIS OF MODULAR BLOCKS

In this section, we conducted the numerical analysis of 12 *m* span modular block for lifting condition using ABAQUS. This study compared the results such as the maximum deformation and flexural stresses with allowable stresses for the structural safety. The limit state for the structural safety of the assembled modular block was given in Table II.

TABLE II
LIMIT STATES OF THE MODULAR BLOCK

	Steel	Concrete
Allowable Stress (MPa)	230	-
Yield Stress (MPa)	380	-
Allowable Flexural Tensile Stress (MPa)	-	3.93
Tensile Fracture Stress (MPa)	-	0.82

The maximum displacement at center area of the modular block was decreased with moving gradually inward from the ends shown in Fig. 6, but the values due to the dead load of the modular block were not significantly affected to the system.

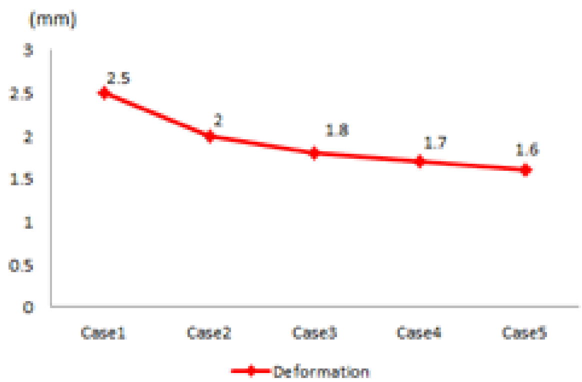

Fig. 6 Maximum displacements of the modular block at the center area (unit: mm)

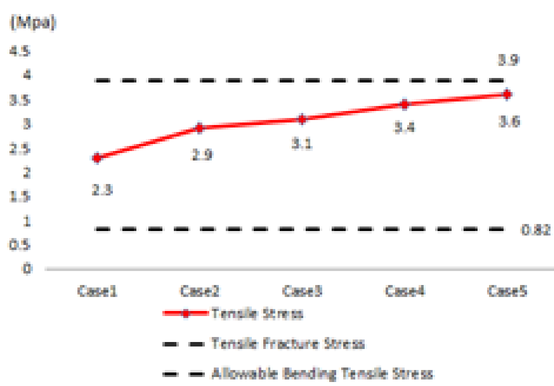

Fig. 7 maximum principal stresses of the concrete slab

In the case of stress distribution, the maximum value (flexural stress) at the center area linearly increased with moving to the center line of the modular block, as illustrated in Fig. 7. The stresses obtained from the analyses were placed within the allowable value.

Fig. 8 and Fig. 9 showed the stress distribution of the concrete slab and steel girder, respectively. In particular, the stress of the concrete slab was dependent on the mesh for the solid element at the area, due to local stress and stress concentration.

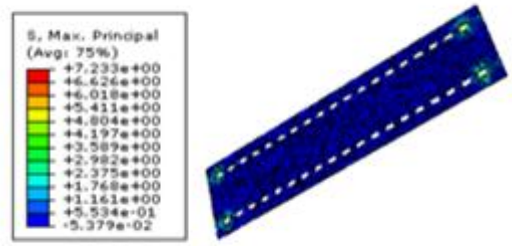

Fig. 8 stress distribution of the concrete slab

Fig. 9 stress distribution of the steel girder

IV. CONCLUSION

This paper presents the safety evaluation of the modular blocks using a 3D full scale FE model in ABAQUS, during lifting time. For the conservative analysis, especially, the 3D FE model used perfectly bonded interfaces between the steel plate and concrete slab. Consequently, the result showed that the deformation of the block was significantly small and the stress concentration phenomenon was not critical issue to the modular block during the lifting condition. Further, in order to evaluate the performance of the blocks for the modular bridge, 3D nonlinear FE model must be developed and various conditions such as span length and connecting method of the system must be considered.

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