Improvement Measures for Structure System Conversions Caused by Utilising SPMTs to Lift Trusses

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Abstract. Since the demand for accelerated construction is increasing these years, much attention has been paid to accelerated bridge construction (ABC) methods. The self-propelled modular transporters (SPMTs) are widely utilised in the ABC method as a versatile transport carrier. However, since the limitation of the SPMTs method, several structural system conversions will happen during truss installation, and tensile stress will potentially appear at the upper chord of the truss. Moreover, it is worth noticing the dynamic effects caused by utilising SPMTs to lift the truss can enlarge the impact of tensile stress. As one type of prestressing, beams prestressed with external tendons can effectively reduce the tensile stress. In order to reduce the impact of cracks caused by tensile stress, the feasibility of adopting temporary external pre-stressing tendons is discussed combined with the simulation results of MIDAS in this research.

Keywords: Spmts · Tensile stress · Accelerated bridge construction · Midas · External pre-stressing

1 Introduction

In recent years, the development of land in urban areas has increased rapidly with the development of the economy [1]. Consequently, the development of urban regions directly leads to an increase in commuter time. For example, the average commute time increased by 10.5% from 2000 to 2015 for the Seoul Metropolitan Area. Therefore, since the traffic pressure is increasing in cities at the present stage, the most significant problem has transformed into minimising the adverse impact of construction on urban traffic.

As a counterpart measure, the accelerated bridge construction (ABC) method has been developed to reduce traffic disruption [2]. ABC method is a novel method, which could reduce traffic and construction period, to expedite bridge construction by utilising new technologies and advanced management methods. In the US, the ABC method has

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been utilised as a powerful tool for reducing the social and economic costs of the possible closure to repair, rehabilitate and replace more than 150,000 bridges [3].

The self-propelled modular transporters (SPMTs) method is an important component of ABC methods. SPMTs is computer-controlled multiple platforms that can pivot, lift, and carry large, heavy loads of many types. Currently, SPMTs has already been applied in a series of bridge construction projects. In the past ten years, more than 100 bridges have been moved by SPMT in the US [4]. Furthermore, the State of Utah in the United States has listed the SPMT method as the recommended construction method and formulated relevant regulations with the SPMT as the core part [5].

However, as a lifting installation method, the SPMTs method also has some limitations. Previous studies proved that the trusses could not be lifted from beam-ends. It is not difficult to foresee that the structural system of the truss will convert several times during installation. Moreover, since SPMTs is one kind of crane, dynamic effects should also be considered. Thus, tensile stress is potentially appearing at the upper chord of the truss at this stage considering the compressive pre-stress is often applied at the web members and lower chord of the trusses in general designs. Due to the low tensile strength of concrete, cracks will appear on the surface of concrete structure even when the tensile force is not very large [6]. When the structure cracks, the concrete at the crack section will completely withdraw from the work. Also, suppose cracks are not properly sealed. In that case, it can increase the risk of corrosion because cracks will undermine bridge appearance, increase maintenance and repair costs, and decrease bridge riding quality and smoothness [7].

Researchers from Tongji University have pointed out that the use of external pre-stressing tendons can reduce the tensile stress of the upper flange of the beam and improve the crack resistance of the beam under a negative bending moment [8]. This research will utilise MIDAS to simulate the whole truss installation process to explore the impact of tensile stress. The feasibility and economic efficiency of adopting external pre-stressing tendons will also be discussed according to MIDAS results.

2 Methodology

2.1 Problem Description

Previous studies are utilising finite element simulation to analyse the internal force of bridge structures. In this research, the internal force of both truss and SPMTs will be analysed by using a similar approach. Simultaneously, the study will combine the dynamic effects with the internal force obtained from the analysis results of MIDAS to calculate the tensile stress caused by structure system conversions during installation.

In the research, a simply supported truss will be designed to simulate the whole process of installation. The design process of the truss will follow GB 50010–2010 Code and GB 50017–2017 Code. The length L of the truss will be 32 m, and the height H will be 4 m. The cross-section of the truss member is rectangular, and its area is bh, where b is width and h is height. Simultaneously, the study assumes that the support between the truss and SPMTs is point support, and the body of SPMTs will be regarded as a rigid body. The research will regard truss as a plane structure, and the following assumptions will be used during analysing: 1. All members are connected only at their ends by frictionless hinges; 2. The axis of each bar in the truss is straight, and the axis passes through the centre of the hinge; 3. The external load on the truss acts on the node and is located in the plane of the truss.

For optimisation measures, the research will start from preventing tensile stress to determine the details of the measures and relevant costs. Then, the economic efficiency of the measures will be discussed.

2.2 Design Variables

Table 1. Description of truss members.

Parameter	Value
Length of truss	$L = 32$ m
Height of truss	$H = 4$ m
Cross-section width of the truss members	$b = 400$ mm
Cross-section height of the truss members	$h = 600$ mm
Area of truss members cross-section	$A = 240000$ mm^2
Area of longitudinal tension steel reinforcement	$A_s = 2454$ mm^2
Area of shear reinforcement within spacing s	$A_v = 314$ mm^2

Table 2. Description of design parameters.

Parameter	Value	Rationale
The elasticity modulus of steel	$E_s = 2.06 \times 10^5$ MPa	GB 50017–2017 Code
The elasticity modulus of concrete	$E_c = 3.45 \times 10^4$ MPa	GB50010–2010 Code
The specific mass of steel	$\rho_s = 7850$ kg/m^3	The study of Yeo and Gabbai
The specific mass of concrete	$\rho_c = 2400$ kg/m^3	
Poisson's ratio of steel	$\mu_s = 0.3$	GB 50017–2017 Code
Poisson's ratio of concrete	$\mu_c = 0.2$	GB 50010–2010 Code
Concrete cover (includes a radius of longitudinal tension reinforcement)	$d' = 65$ mm	The study of Yeo and Gabbai
Longitudinal spacing of shear reinforcement	$s = 150$ mm	
External pre-stressing tendons tensile strength	$f_t = 1860$ MPa	JTG 3362–2018 Code

Table 1 lists the description and value of the truss member. In this study, the size of the web member and chord member is consistent. Thus, width b and height h are two fixed parameters. Since MIDAS will be utilised to analyse the internal force of structure system conversions during installation, the parameters of steel and concrete in Table 2 will be regarded as design parameters [9]. Also, the research will not consider the discrete case, where the steel reinforcement positions and the selection of steel and concrete are invariant.

2.3 Methods for Improvement

The external pre-stressing tendons will be adopted to decrease the tensile stress caused by structure system conversions. Preventing from producing tensile stress in truss members will be taken as design principles of external pre-stressing tendons. In this study, the 1 × 7 steel strands whose tensile strength f_t is 1860 MPa will be utilised as temporary external pre-stressing tendons during installation, as shown in Table 2. It will calculate the area of external pre-stressing tendons combined with the analysis results of MIDAS.

$$\sigma_t = \frac{F_t}{A} \quad (1)$$

Equation (1) represents the tensile stress during installation and the required area of external pre-stressing tendons. σ_t is the tensile stress in truss members, and F_t is the maximum tensile force obtained by MIDAS simulation considering dynamic effects. Furthermore, dynamic effects will also be considered in this study. According to GB 3811–2008-T Code, the dynamic effects are taken as the dynamic coefficient multiplying the tensile stress caused by self-weight effect of the concrete structure, as shown in Eq. (2). σ_{dt} is the tensile stress of the upper chord of the truss considering dynamic effects, and φ_1 is a dynamic coefficient that can be taken as 1.5 for hoisting and transportation.

$$\sigma_{dt} = \sigma_t \times \varphi_1 \quad (2)$$

$$A_p = \frac{\sigma_{dt}}{f_t} \quad (3)$$

Finally, the required area of external pre-stressing tendons can be obtained from Eq. (3), in which A_p is the required area of external pre-stressing tendons. And the expected cost of the improvement measures can be considered by Eq. (4). P is the total cost of the improvement measures, m_p is the required weight of steel strands, is the unit price of steel strands, and P_c is the unit price of strand cable pre-stressed anchor.

$$P = m_p \times P_p + 2 \times P_c \quad (4)$$

3 Results

According to Table 1 and Table 2, the study simulates the whole truss installation process by utilising SPMTs. Figure 1 (a), (b) and (c) show the results of internal force analysed by MIDAS. It can be obtained that the structural system has been converted two times during the whole installation. It is worth noting that the maximum tensile force, 294.4

kN, appears at the upper chord of the truss during lifting when the structure is a cantilever truss. Thus, combined with Eq. (1), it can obtain that σ_t is 1.23 MPa.

Since SPMTs is one kind of crane, the dynamic effects need to be considered during lifting. According to Eq. (2), the maximum tensile stress of the upper chord can be regarded as 1.85 MPa. Considering the design value of axial tensile strength of concrete f_{td} is 1.83 MPa in China GB 50017–2017, it is reasonable to believe the crack can appear during lifting and can decrease the effective cross-sectional area.

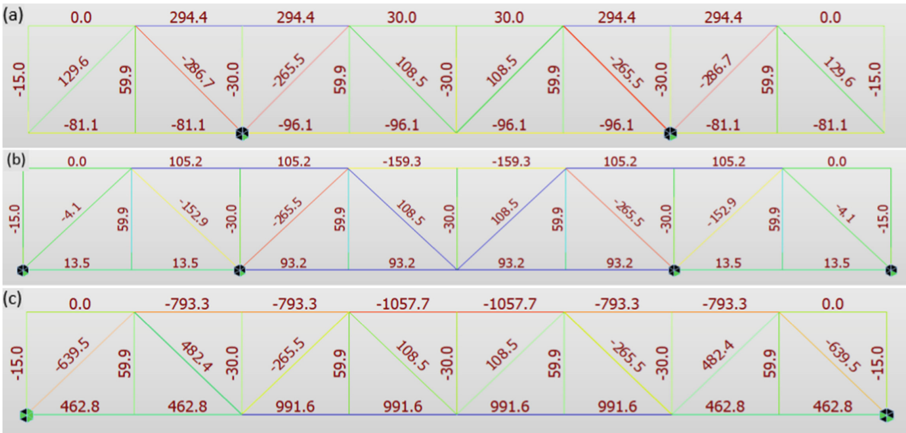

Fig. 1. Internal force of the truss: (a) lifting; (b) installing; (c) completion (kN, negative value represents compression).

In order to reduce the impact, it is necessary to adopt external pre-stressing tendons. Combined with Eq. (3), one 1×7 steel strand is required if it considers that no tensile stress appears at the upper chord of the truss. Moreover, if it ignores the labour cost, according to the current market price, the total cost P can be obtained as 26.46 dollars per truss by Eq. (4).

4 Conclusions

Since the limitation of the SPMTs method, the trusses cannot be lifted from beam-ends. Therefore, two structural system conversions will happen during installation. In this study, a new improvement measure for lifting simply supported trusses by utilising SPMTs is explored.

Combined with Table 1 and Table 2, the research simulates the whole process of installation of a simply supported truss by utilising MIDAS. The simulation results in Fig. 1 illustrate that tensile stress is easy to appear at the upper chord of the trusses during lifting. Furthermore, the calculation shows that the maximum tensile stress of the upper chord is 1.85 MPa considering the dynamic effects. It exceeds the design value of axial tensile strength of concrete, which is 1.83 MPa, in GB 50010–2010 Code. The upper chord of the truss is relatively fragile, considering the compressive pre-stress is often applied at the web members and lower chord of the trusses in general designs. Thus, adopting one 1 × 7 steel strand as a temporary external pre-stressing tendon is reasonable to reduce tensile stress. Moreover, the materials cost of this improvement measure can be obtained as 26.46 dollars per truss by Eq. (4). Due to the potential damage and maintenance cost caused by cracks, it will be helpful to reduce tensile stress by adopting temporary external pre-stressing tendons in practice.

Nowadays, ABC is becoming more popular, and SPMTs are utilised more often in construction. This research shows the rough idea of the improvement measure during lifting trusses by using SPMTs. It can obtain from the research that the dynamic effects have a considerable impact on the internal force of the structures. For further study, it can consider exploring the impacts of different lifting velocities on dynamic effects. It can also research the influence of offering additional constraints, which potentially could reduce accelerations, on dynamic effects. Furthermore, improving the structure of SPMTs would be another interesting future research direction. It can be considered to add a detachable component to the SPMTs to improve the internal force distribution of the trusses during installation.

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