Automation in Construction 86 (2018) 81–98

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Optimal placement of precast bridge deck slabs with respect to precast girders using 3D laser scanning

Seongheum Yoon[a], Qian Wang[b], Hoon Sohn[a,*]

[a] Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea
[b] Department of Building, School of Design and Environment, National University of Singapore, Singapore

ARTICLE INFO

Keywords:
3D laser scanning
Precast girder
Precast bridge deck slab
Shear connector
Shear pocket
Optimal placement

ABSTRACT

Because precast components offer faster production, lower cost, and more efficient construction, more and more bridges are constructed using precast components rather than conventional on-site construction. For example, precast bridge deck slabs are placed on precast girders, and they are connected by shear pockets on deck slabs and shear connectors on girders. For the coupling of deck slabs and girders, it is important to ensure proper connections between shear pockets and shear connectors. However, shear pockets and shear connectors often do not match properly at construction sites because of dimensional errors and misalignments. Furthermore, precast girders deform over time due to their heavy weights, time dependent creep and shrinkage, pre- or post-tensioning, etc., once they are placed on sites. To match these components at construction sites, workers often need to trim and cut some components, delaying construction processes. To shorten such delay, this study proposes a laser scanning and signal processing technique that can automatically identify the optimal placement of precast bridge deck slabs with respect to precast girders by minimizing mismatches between shear pockets and shear connectors. First, scan data from precast bridge deck slabs and precast girders are acquired using a 3D laser scanner, and their dimensions are estimated including the locations and dimensions of shear pockets using DBSCAN and mixed pixel filtering algorithms. Next, locations of the shear connectors are extracted from the scan data of the precast girders using RANSAC and K-means clustering algorithms. Finally, the optimal placement of the deck slabs with respect to the girders is determined by solving a nonlinear minimization problem considering the locations and sizes of the extracted precast components. To validate the performance of the proposed technique, experiments were conducted on small-scale test specimens and at an actual construction field. The experimental results demonstrated that the proposed technique could effectively estimate the optimal placement of precast bridge deck slabs with respect to precast girders.

1. Introduction

Precast components have been widely used in bridge construction since they provide reduced construction time, lower cost, and improved quality control compared to conventional on-site construction [1,38]. Precast structures are constructed by connecting precast components at construction sites. Connections between precast components are, however, often vulnerable to high stress concentration and become the weakest link within the entire structural system [23,25]. It is, therefore, important to perform quality control at the connections. For coupled behavior of precast bridge deck slabs and precast girders, the shear pockets on the deck slabs and the shear connectors on the girders must be properly connected [11]. However, the following three issues may lead to mismatches between the shear pockets and the shear connectors: (1) dimensional errors of precast bridge deck slabs and precast girders occurred in the fabrication stage, (2) deformation of precast girders, as shown in Fig. 1, due to their weight, time dependent creep and shrinkage, and pre- or post-tensioning [5], and (3) incorrect orientation and location of shear connectors, as shown in Fig. 2. It is of great significance to identify the optimal placement of precast bridge deck slabs with respect to precast girders to minimize the mismatches between shear pockets and shear connectors considering these three issues.

Currently, precast components are manually inspected by certified inspectors using traditional tools such as measuring tapes. The manual inspection follows guidelines from industry associations such as the International Organization for Standardization (ISO) [30] and the Precast Concrete Institute (PCI) [18]. However, manual inspections are time-consuming, expensive, and subjective [21]. Moreover, workers often need to trim and cut some of the components at construction sites

* Corresponding author.
E-mail address: hoonsohn@kaist.ac.kr (H. Sohn).

https://doi.org/10.1016/j.autcon.2017.11.004
Received 17 April 2017; Received in revised form 1 November 2017; Accepted 3 November 2017

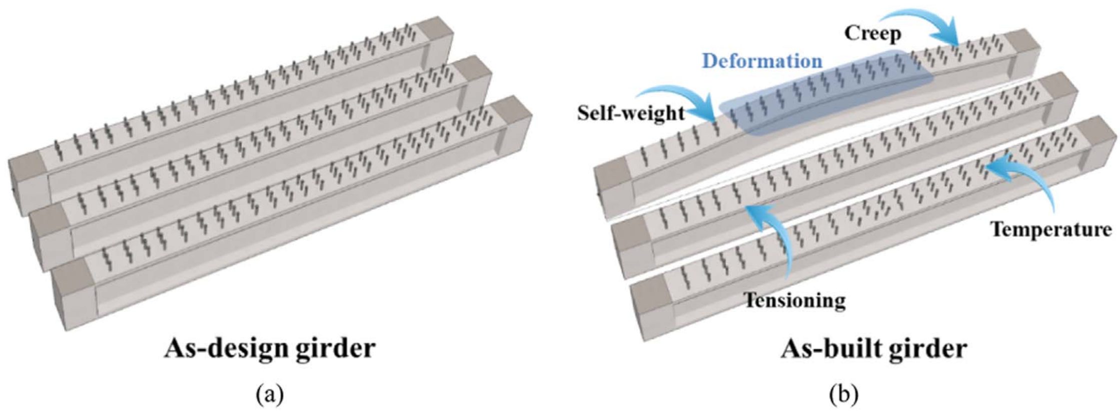

Fig. 1. Discrepancy between (a) as-design girder and (b) as-built girder deformed by self-weight, creep, post-tensioning, etc.

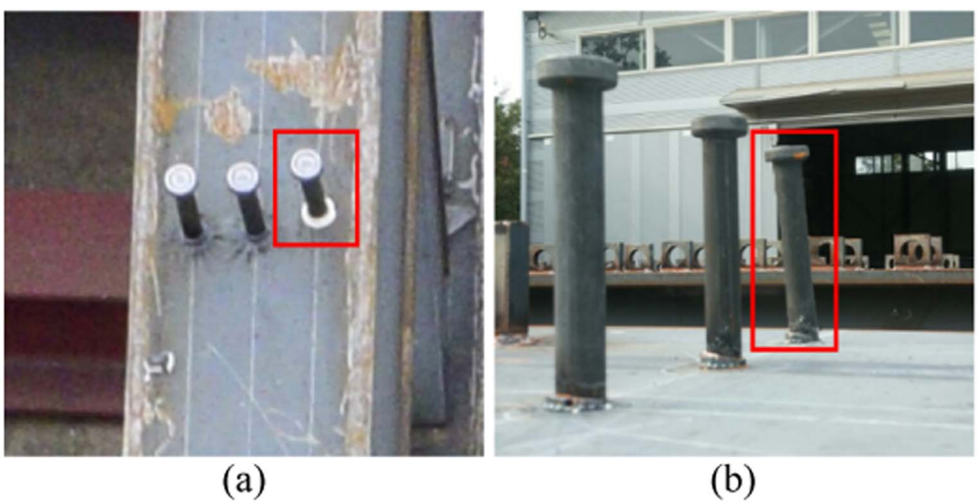

Fig. 2. Discrepancy between as-built and as-designed shear connectors: (a) misaligned shear connector and (b) inclined shear connector.

to properly match these components [26]. According to Construction Industry Institution (CII), cost of rework caused by poor quality or dimensional defects of precast components is estimated to be around 5% of the total construction cost [29]. A previous study also shows that the costs associated with defects account for 4% of a new construction contraction value [17]. In this light, it is necessary to develop techniques that can automatically and accurately assess the dimensional quality of precast components to reduce additional cost and construction time.

Over the past few years, several sensing technologies have been deployed for quality assessment of structural components. Among them, 3D laser scanners have recently gained attentions because of their capability to rapidly and accurately acquire range information of large structures [7,33]. Due to these advantages, the laser scanners have been used for measurement of structural deformations [9,19], detection of concrete surface damage [13,20,32], assessment of surface flatness [31,35], etc. Although 3D laser scanners have been used to assess the dimensional quality of precast concrete components [4,12,14,34,37], these studies mainly focus on precast bridge deck slabs. Little study has been conducted to assess the quality of precast girders.

When it comes to optimal placement of precast components, Ergen et al. [6] proposed a technique for optimally locating precast components in a storage yard by utilizing radio frequency identification technology and GPS. Shewchuk and Guo [28] suggested an automated approach to prefabricated panel stacking, panel sequencing, and stack locating. However, the majority of the previous studies rely on as-design data such as CAD or BIM data. Rausch et al. [24] proposed an optimal assembly technique for modular construction components utilizing their as-built data.

This study proposes an automated optimal placement estimation technique for precast bridge deck slabs with respect to precast girders using 3D laser scanning. After obtaining scan data using a 3D laser scanner, the proposed technique first removes noise components using a DBSCAN-based algorithm and a mixed pixel filtering technique. Next, a RANSAC-based plane detection algorithm is used to extract scan data associated with shear connectors. Third, a two-class classification algorithm is applied to extract scan data corresponding to shear connector heads, and the orientation and location of each shear connector are estimated. Finally, the optimal placement of precast bridge deck slabs is estimated by solving a nonlinear minimization problem based on the previously estimated orientation and location of the shear connectors and the shear pocket location obtained in a previous study [12]. The uniqueness of the present study includes (1) the development of an automated dimensional quality assessment technique for precast girders, particularly focusing on the orientation and location of shear connectors, and (2) the development of an optimal placement estimation technique by solving a nonlinear minimization problem. This paper is organized as follows. Section 2 provides the research background on precast bridge connections and 3D laser scanning. A dimensional quality assessment technique for precast girders and an optimal placement estimation technique for precast bridge deck slabs are developed in Section 3. In Sections 4 and 5, the effectiveness of the proposed techniques is validated using laboratory tests and a field experiment, respectively. Finally, Section 6 provides a summary and conclusions of this study.