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3D KNOWLEDGE EMBEDDED ENGINEERING ON PREFABRICATED BRIDGE SUBSTRUCTURES

Shim C. S.[1], Park S. J.[2] Song H. H.[3] and Lee S. Y.[4]

ABSTRACT

Prefabricated bridge construction enabling better productivity of design and construction by standardized members, and robotic construction becomes an important issue in construction industry. Modular structures needs accurate information delivery between design, fabrication and construction processes. BIM (Building Information Modeling) based parametric modeling was proposed for precast bridge substructures. Engineering experience and design specifications should be embedded in the information of the 3D model. Considering ranges of design parameters, fixed value, variables and relations were defined and these parametric models were applied to design, analysis and fabrication of precast bridge piers. Dimensions of precast members and connections are main knowledge from research development and applications. Prefabricated bridge columns satisfying current design requirements in terms of structural performance in static and seismic loadings were modeled as 3D information models. The models provide efficient and precise knowledge delivery through the lifecycle of precast members.

1 Professor, Department. of Civil Engineering, Chung-Ang University, Korea
2 Ph.D Student, Department of Civil Engineering, Chung-Ang University Seoul, Korea
3 Ph.D Student, Department of Civil Engineering, Chung-Ang University, Seoul, Korea
4 Master Student, Department of Civil Engineering, Chung-Ang University, Seoul, Korea

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ABSTRACT

Prefabricated bridge construction enabling better productivity of design and construction by standardized members, and robotic construction becomes an important issue in construction industry. Modular structures needs accurate information delivery between design, fabrication and construction processes. BIM (Building Information Modeling) based parametric modeling was proposed for precast bridge substructures. Engineering experience and design specifications should be embedded in the information of the 3D model. Considering ranges of design parameters, fixed value, variables and relations were defined and these parametric models were applied to design, analysis and fabrication of precast bridge piers. Dimensions of precast members and connections are main knowledge from research development and applications. Prefabricated bridge columns satisfying current design requirements in terms of structural performance in static and seismic loadings were modeled as 3D information models. The models provide efficient and precise knowledge delivery through the lifecycle of precast members.

Introduction

The productivity currently achieved by the manufacturing industry was made possible in part by the use of digital data models to automate manufacturing methods. Building information modeling (BIM) and digital fabrication has the potential to do the same for the construction industry. Digital fabrication for infrastructures is a new attempt in construction industry. BIM deals with product, process and resources [1].Even though an infrastructure is not manufactured in its entirety and then transported to the owner, many parts of the structure are manufactured remotely, then delivered to the construction site and assembled. Prefabrication of concrete and steel members for bridge structures is common practice in construction industry.

The use of 3D information models for precast concrete detailing and fabrication enables a fully-digital, design to assembly process. Reusing the design model in this fashion is more efficient and provides higher quality results in fabrication and construction. A digital design-to-fabrication workflow creates opportunities for improved collaboration among designers, fabricators and contractors. Using coordinated data within a fully informed 3D information model can improve the constructability, reduce the cost, and enable design innovations for creating unique and repetitive precast concrete members. 3D information models for bridge structures were suggested by Lee et al. [2] and Shim et al. [3]. Additionally, the information used in the design and fabrication can be accurate and coordinated data worth sharing for

1 Professor, Department. of Civil Engineering, Chung-Ang University, Korea
2 Ph.D Student, Department of Civil Engineering, Chung-Ang University Seoul, Korea
3 Ph.D Student, Department of Civil Engineering, Chung-Ang University, Seoul, Korea
4 Master Student, Department of Civil Engineering, Chung-Ang University, Seoul, Korea

operation and maintenance activities.
Prefabricated bridge components have wide range of objects with different design parameters and information delivery requirements. This variety limits the application of BIM technology to infrastructures while building industry actively adopt BIM and enhance its information flow through life-cycle of a structure. Precast members have standard sections for certain range of design parameters. Therefore, information delivery manual (IDM) and model view definition (MVD) were developed and proposed [4,5].
For fast bridge construction, there have been many attempts to develop prefabricated bridge elements [6-9]. Among the precast element, a modular bridge substructure was selected and 3D parametric modeling of the bridge pier was developed by Kim et al. [10]. Parametric model definitions for a modular bridge were developed and their MVD and level of detail (LOD) were proposed to enhance design productivity.
In this paper, a research program for the development of prefabricated bridge substructures is introduced. During the development process, engineers can obtain experience in terms of design contents, fabrication and erection errors and details. 3D information models can include the experience as geometry and metadata. 3D printing technology was utilized to enable irregular shaped columns without significant increase of fabrication cost. Durability of the precast joints was enhanced by developing a sheath coupler which was invented by 3D models. Long-term and durable digital information is stored in 3D printed QR codes and the codes are attached in the precast segments. These innovative approaches are summarized in this paper.

Prefabricated Bridge Substructures

Bridge substructures include pier, pier cap, foundation and piles. Among the members, pier and pier cap can be chosen to be prefabricated elements. There have been many experiments to verify structural performance of precast bridge piers in terms of strength, serviceability and seismic behavior. Bonded or unbonded axial prestressing was introduced for the integrity of the column segments [11-16]. Fig. 1 presents design and construction issues for prefabricated bridge piers.
Main design issues of the precast bridge pier are prestress, crack control at joints, and transverse reinforcements for seismic performance. The amount of axial prestress force is determined to limit tensile stress at the joint between a footing and the first segment of the pier. For the effectiveness of prestressed concrete column design, partial prestressing concept was adopted. Limited tensile stress is allowed for service load conditions by using continuous reinforcing bars across the joints. Total compressive stress of the column needs to be limited around 20% considering deadweight of superstructures and the prestressing force.
Crack control at the first joint is commonly governed by wind load for high-rise bridge piers. Multiple prestressing steels need multiple anchorages at the top surface of the pier cap. There may have interference between the anchorages and bearings. In order to solve these difficulties, intermediate anchoring of the prestressing steel is considered for the high-rise bridge piers. The continuous reinforcing bars are connected by couplers at joints.
Currently there is no clear design provision on transverse reinforcements for prestressed precast concrete columns. Due to high strength axial steel and compression, it is necessary to assess the amount of the transverse reinforcements for obtaining required seismic performance. Complex details of the column include discontinuous and continuous axial reinforcing bars, sheaths for prestressing steel and transverse reinforcing bars. Bonded or unbonded prestressing steels influence on the seismic performance.
For the constructability of the precast bridge pier, there are several issues such as metal

formwork for irregular shaped columns, match casting, verticality and leveling of the precast segments. Aesthetic consideration for bridges in urban area requires irregular shapes resulting in difficulty of metal formworks. Reuse of the formwork is essential for economy of precast members. Axial prestressing requires accurate match of the precast segments. It takes time and additional cost to fabricate the segments by vertical match casting. During erection and assembly of the precast members, verticality and leveling of the bridge pier are main concerns. Erection equipments are determined by weight of the precast segments.

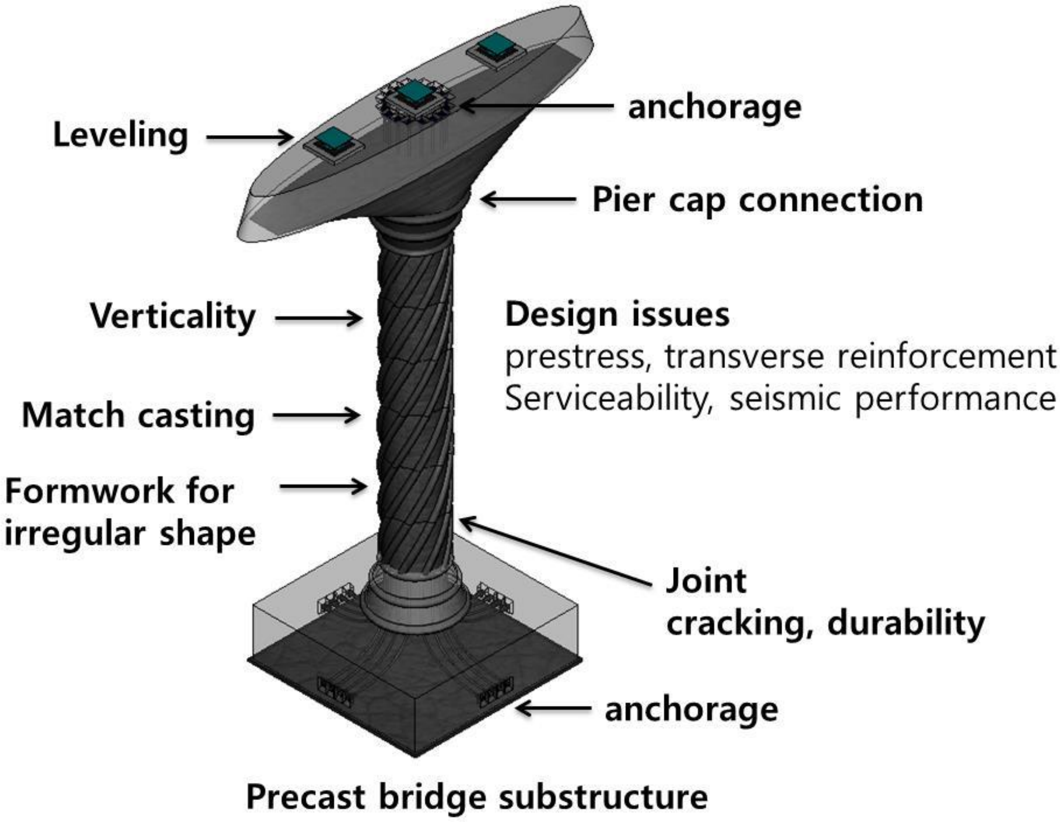


Figure 1. Design and construction issues of a precast bridge pier

3D Digital Models for Precast Bridge Piers

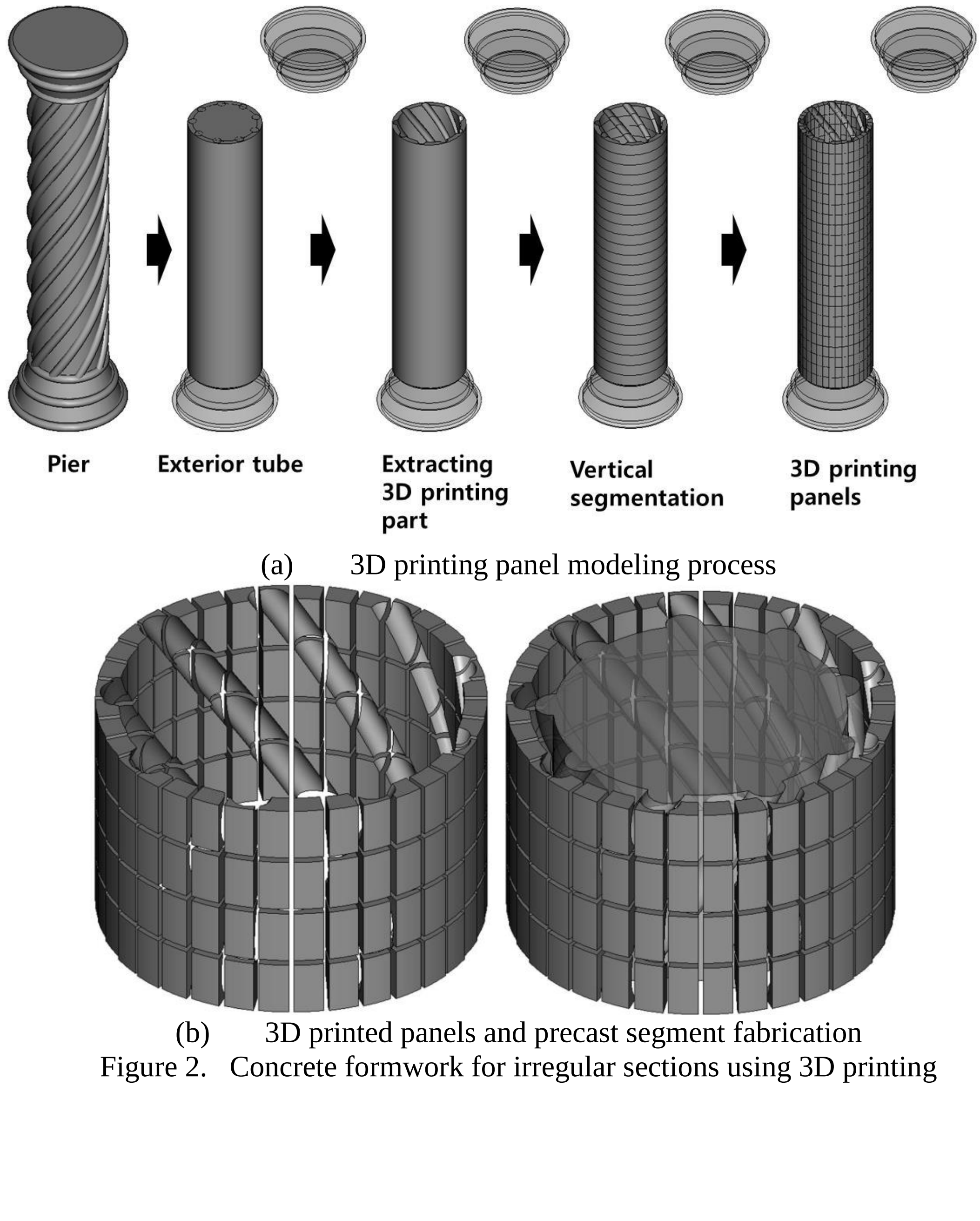
During development process, engineers or designers obtain valuable experience in terms of details and guideline for designers, fabricators and contractors. Currently the knowledge is transferred to the other engineers by drawings. 3D digital models including essential information can improve communication between participants in a construction projects from planning to maintenance.

Design parameters for design changes are height and width of the bridge substructure. According to these main variables, dimensions of precast segments should be changed. Therefore, relationship constraints between these design parameters need to be defined properly. Minimum gaps of the joints can be knowledge embedded parameters in the 3D models. Upper and lower bound of the gap or spacing between components can be included in the model definitions. Parametric modeling techniques are useful for this definition. The 3D models have hierarchical structure, fixed variables and relationship constraints.

Level of detail (LOD) of the 3D models can be defined according to two different approaches such as database and model capability. LOD identifies the specific content requirements for each model element at each phase of a project. There are five progressively detailed levels of completeness. Each subsequent level builds on the previous level [17].

- LOD 100: Overall structure massing indicative of area, volume, location and orientation
- LOD 200: Model elements are modeled as generalized systems or assemblies with approximate quantities, size, shape, location and orientation.
- LOD 300: Model elements are modeled as specific assemblies accurate in terms of quantity, size, shape, location and orientation.
- LOD 400: Model elements are modeled as specific assemblies that are accurate in terms of size, shape, location, quantity and orientation with complete fabrication, assembly and detailing information.
- LOD 500: Model elements are modeled as constructed assemblies that are actual and accurate in terms of size, shape location, quantity and orientation.

Design models are used to create formwork models. As shown in Fig. 2, 3D printer was utilized to realize irregular shaped column models without significant increase of formwork cost. Optimized 3D printed panels are created from the design models as presented in Fig. 2 (a). Due to the limitation of printing dimensions, the 3D panels should be extracted to have minimum thickness. These panels are fixed at the metal formwork.



(a) 3D printing panel modeling process

(b) 3D printed panels and precast segment fabrication

Figure 2. Concrete formwork for irregular sections using 3D printing

Design information is essential for operation and maintenance (O&M) process. It should be stored for the service life of infrastructures such as 100 years. Currently, digitalized design data are stored in digital devices. Frequently, owners find out missing design data during O&M process. 3D printed QR codes are suggested to be attached to the precast segments. The codes have basic metadata for the identification of the segment, material properties, major dimensions and important details. The 3D codes are partially embedded in precast concrete and have durable material to maintain the data for the service life of the structure. The codes are also very helpful for field engineers to inspect structures. Mobile devices can be efficiently utilized to access information of the structures.

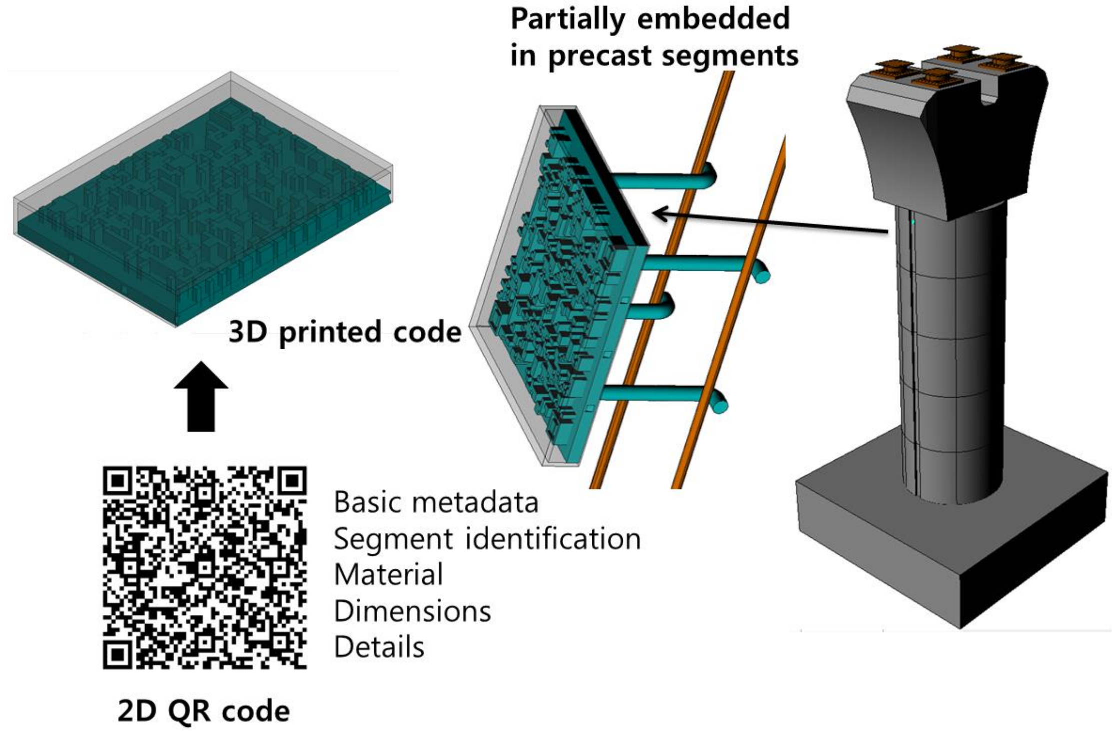


Figure 3. 3D printed QR codes

One of the main issues for precast bridge substructures is durability problem. Even though precast concrete provides more durable property than cast-in-place concrete, joints between segments are crucial parts for corrosion of prestressing steels. Especially when a bridge is located in severe conditions such as sea crossing, the precast bridge piers with prestressing should have adequate consideration for durability of the joint. Currently, sheaths for prestressing steel cannot be connected at the joint. Rubber strip is commonly used to protect any infiltration of epoxy or water to the sheaths. In this research program, it was suggested to use sheath coupler as shown in Fig. 4. A cone-shaped insert is connected to the end of a sheath. After a lower segment is placed, the coupler is connected to the insert. The coupler has a corrugated part in the middle and is compressed by the weight of an upper segment during assembly process. Mechanically connected sheath provides much better protection for corrosion of prestressing steels. Prototype of the coupler was produced by a 3D printer and used for experiments.

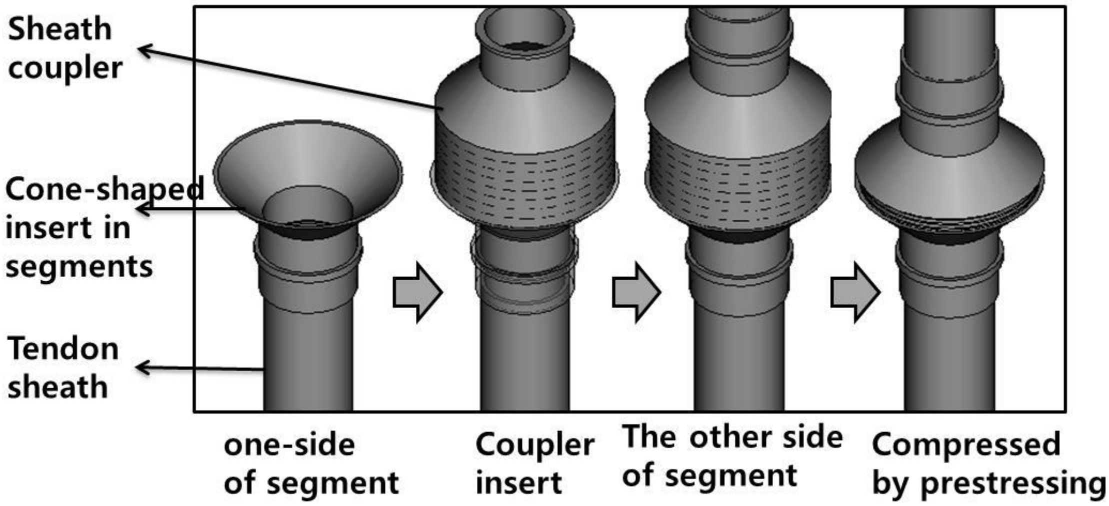


Figure 4. Sheath coupler

A research project to develop prefabricated bridge substructures utilizes information and communication technologies along with digital manufacturing technologies. Based on the proposed ideas, digital mock-up was finished. Experiments are prepared to realize the proposed technologies and to investigate structural performance of precast bridge piers.

Conclusions

For the productivity enhancement of construction industry, digital manufacturing concepts are actively adopted. Precast concrete elements and their assembled structural systems are excellent objects to utilize 3D information models and digital design and manufacturing. The models provide efficient and precise knowledge delivery through the lifecycle of precast members.

This paper presents design and construction issues for prefabricated bridge substructures and some solutions to solve the issues. 3D information models are utilized for knowledge transfer between participants in a construction projects. The models are reused to design formworks by adopting 3D printer. Essential design data is stored 3D printed codes which are attached to the precast segments. Durability of the prestressing steel for precast bridge piers is improved by the suggested sheath couplers.

Acknowledgments

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