Framework of Automated Beam Assembly and Disassembly System for Temporary Bridge Structures

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Abstract –

Temporary bridges play an important role in disaster relieving operations. However, available workers and limited time are precious resources during a disaster event. The requirement of not only human resource but also construction safety creates a barrier for completing the temporary bridge construction within expected time, which may result in the delayed subsequent rescue operation. To address these issues of worker safety and the worker shortage during a disaster event, an automated beam assembly approach for temporary bridge segment is proposed in this study. The approach includes a framework for temporary bridge construction to be automated assembled by a crane and a construction process based on the framework. The framework and the construction process are examined with both virtual and small-scale models.

Keywords –

Automated construction; Construction safety; Mobile crane control; Autonomous structural connector; Disaster relief

1 Introduction

Temporary bridge is recognized as being considered to be the approach of disaster relieving operation, when a bridge structurally loses its workability. Russell et. al. classified temporary bridges which were portable and rapidly-deployable into four types in 2013 [1]. Those bridges remain the span length and maximum load-carrying capacity of a bridge as a key issue. Therefore, Yeh et. al. in 2015 applied glass-fiber-reinforced-plastic (GFRP) material in a segmental temporary bridge design making it light-weight and reusable [2]. The live load capacity of the GFRP bridge was 5 tons, and the span was 20 meters. However, when taking actual working environment into consideration, the assembly of the GFRP bridge may be difficult. The reason is that not only the weather may not be suitable for construction but also it is hard to recruit sufficient workers on-site.

To clarify the main reason of these problems, we analyzed the video of the process of constructing the GFRP temporary bridge. The hoist and assembly process has been found to be so critical that it majorly controlled the construction progress and the worker safety of the bridge construction. This process put emphasis on the technique of beam assembly.

2 Background

Many attempts have been made with the purpose of automated steel beam assembly. A research team focused on automated construction of high-rise building with a construction factory covering at the top of the building [3, 4]. They developed robotic bolting and robotic transport of steel beam, and tested beam assembly in real construction site. This application created the constraint of architecture design because of the geometrical limitation caused by the working space of the construction factory. In 2016, a research developed an approach helping construction workers assemble steel beam with an automated wire control machine [5]. The research protected workers from assembling steel beams at height, although the pre-installation of the guiding ropes for automated assembly may be risky for workers. Another research tried to remotely achieve steel beam assembly by means of structural connector design and controllable rotation of crane hook [6]. The rotating hook would trigger the opposite rotation of the attached steel beam to finish beam assembly. However, object avoidance during the beam rotation was a challenge for the research.

To address worker safety and shortage during disaster event as well as comprehensive consideration of steel beam assembly using a crane, an automated beam assembly framework for segmental temporary bridges is proposed in the research.

3 Automated Beam Assembly Framework

The automated beam assembly framework identified critical elements for research development and proposed a construction process providing an automated approach utilizing a mobile crane to build up a temporary bridge.

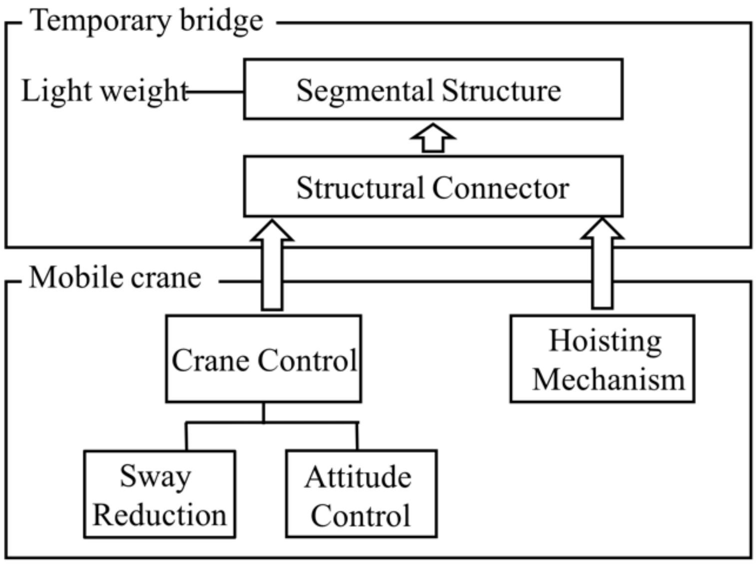

Figure 1. The framework of automated beam assembly

3.1 Elements of the Framework

The critical elements were categorized into two parts: structure and automated process. The structure part, also named Temporary bridge in Figure 1, including segmental structure, light weight, and structural connector, defines the requirement of the material and structural geometry to be used in a construction. The automated process part, also named Mobile crane in Figure 1, considers technical requirement on how a mobile crane finishes hoists and assembly tasks without any worker on site.

3.1.1 Segmental Structures (SS)

The temporary bridge for disaster relieving needs to be constructed within limited time. Therefore, segmental structure becomes an option to satisfy the requirement. Before a disaster occurs, each segment of the temporary bridge can be compactly stored in a container for shipping. The container can be placed near the potential damaged area.

3.1.2 Light Weight (LW)

To have a longer span of a temporary bridge, light weight is one of the important properties. According to the information from officers in Taiwan Directorate General of Highways, 30 meter at least is the common span of the bridge to be repaired after the bridge has been devastated by a disaster. Additionally, lighter weight of the bridge makes more convenient for shipping to the proximity to a valley or a river in a mountain where is often not easily accessible.

3.1.3 Structural Connector (SC)

A structural connector allows two segmental structures to be assembled with each other. The structural connector to realize automated bridge construction focuses on the beam design for autonomous assembly. The designed connector should also consider the construction feasibility when using a crane. In the research, we utilized the connector from our previous research for autonomous beam assembly [7]. The previous research demonstrated the feasibility of the hook-shaped structural connector for autonomous assembly. The design concept was to use a male connector and a female connector to lock themselves autonomously.

3.1.4 Crane Control– Sway Reduction (SR)

Sway reduction is necessary to reduce the magnitude of a sway of a payload. The payload such as a beam with designed connector should be stabilized to a suitable level to execute position control. Finally, the automated attachment of the male connector and the female connector can be executed afterwards.

3.1.5 Crane Control– Attitude Control (AC)

When a connector is at the targeted position, attitude control of the structural component may rotate the male connector to attach the female connector. Taking advantage of the sway reduction and the attitude control, the automated assembly of these two structural components becomes easier.

3.1.6 Hoisting Mechanism(HM)

Before the beam transportation using a crane, the beam should be firmly attached to the crane hook. After the transportation, the beam needs to be conveniently detached from the hook. Without human operation to attach and detach the beam, the automated mechanism of attaching and detaching is necessary.

3.2 Construction Process

The construction process defines each step of the beam assembly and disassembly.

3.2.1 Assembly process

- Step 1: Connect the crane hook to the beam.
- Step 2: Lift up the beam.
- Step 3: Transport the beam to the selected position for assembly.
- Step 4: Adjust the attitude of the male connector to attach the female connector on the bridge.
- Step 5: Release the beam for assembly triggered by gravity.
- Step 6: Lock the beam on the bridge structure.
- Step 7: Disconnect the beam from the crane hook.

3.2.2 Disassembly process

- Step 1: Connect the crane hook to the beam to be disassembled.
- Step 2: Unlock the beam.
- Step 3: Lift up the beam.
- Step 4: Detach the male connector from the female connector on the bridge structure.
- Step 5: Transport the beam to the storage area.
- Step 6: Release the beam.
- Step 7: Disconnect the beam from the crane hook.

4 Experiment & Result

The framework and the construction process were validated by the experiment described in this section. Three assumptions were made in the experiment. (1) If the assembly steps are feasible, the disassembly steps are also feasible. (2) Attitude control rotates the beam in the longitudinal direction. According to the research by Lee et. al. in 2012, the attitude control of a beam is probable to be implemented [8]. In the experiment, we rotated the beam by human operation. (3) Hoisting Mechanism was assumed that it connects to the end of a beam and can be remote controlled. The experiment was tested on-site and also in a virtual model using a commercial physics engine.

4.1 On-site experiment

The first four steps of the proposed assembly process were validated by an on-site experiment. The experiment measured the placement deviation from the targeted position of the hoisted structural component for assembly (Fig. 2). A crane with hydraulic retractable boom with the maximum load capacity of 3.4 tons was used in the experiment. The payload was an approximately 80kg and 1.45m beam. The crane operation was executed by a graduate student in the experiment. The student learnt crane operations from a professional crane operator, and practiced the required operation of the sway reduction before the experiment.

The result of X deviation was 3.03cm in average, and the result of Y deviation was 1.37cm. Figure 3a-1 shows the environment of the experiment. We placed a short beam which is around the center of the picture as the targeted position for beam assembly. The overview of the crane we used and the test environment is represented in Figure 3a-2. Figure b recorded the first four steps of the assembly process. In the experiment, we connected the end of the beam to the crane hook using steel cables (Figure 3b-1). The beam was lift up with an approximate distance of 50cm from the ground (Figure 3b-2). The crane operator transported the beam only by slewing the crane (Figure 3b-3). Figure 3b-4 is the state that the beam was already at the targeted position, the crane operator reduced the sway by manual crane operation, and the operator manually rotated the beam in the longitudinal direction for the attitude control. After the position and the attitude of the beam were stable, the crane operator placed the beam on the ground to measure the placement deviation (Figure 3b-5).

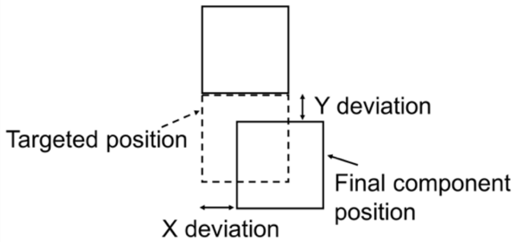

Figure 2. Measurement of structural component deviation from selected target.

Table 1 Placement deviation from selected target

Test	X deviation [cm]	Y deviation [cm]
1	4.0	2.9
2	1.9	0
3	3.2	1.2

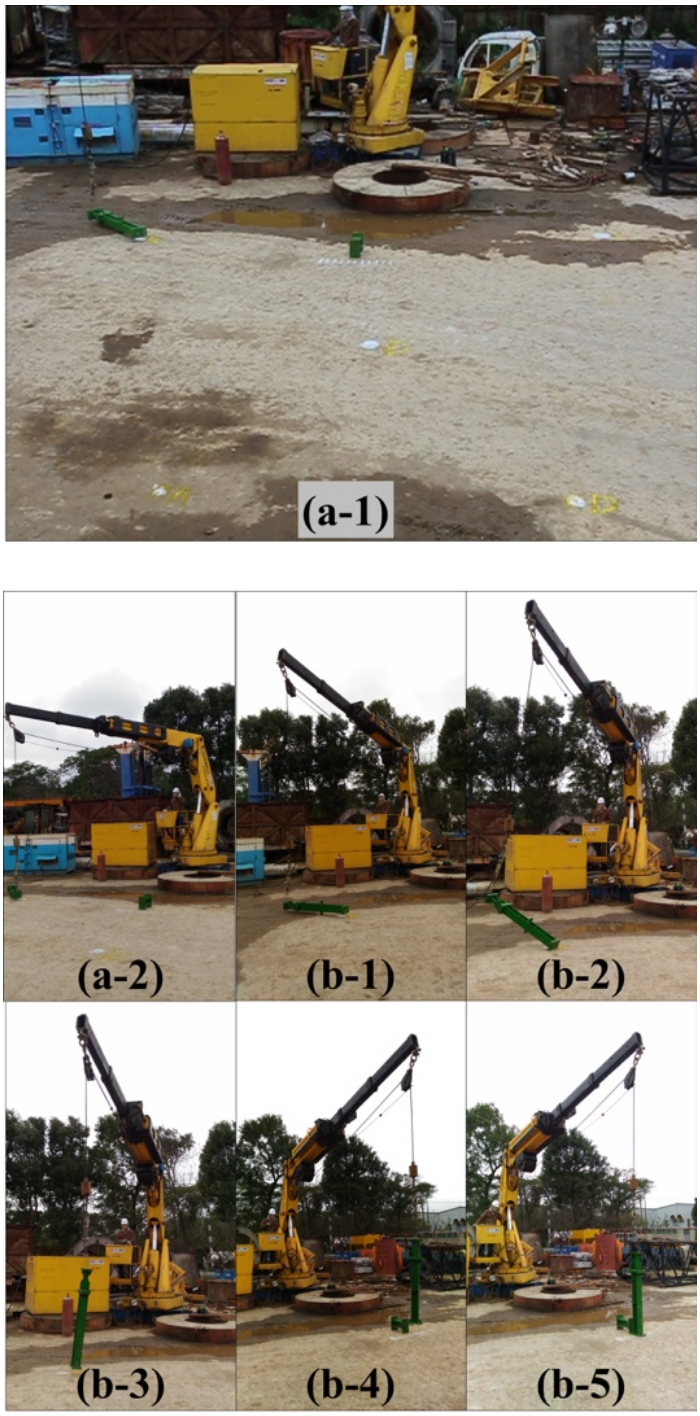

Figure 3. (a) On-site experiment environment. (b) The results of the automated process.

4.2 Virtual model experiment

To validate the step 5, "Release the beam for assembly triggered by gravity", of the assembly process, we created a virtual structural component and used a virtual mobile crane to simulate the rotation of the structural connector. The virtual model was created on a commercial physics engine, Unity3D. The virtual model successfully demonstrated the step 5 (Fig. 4).

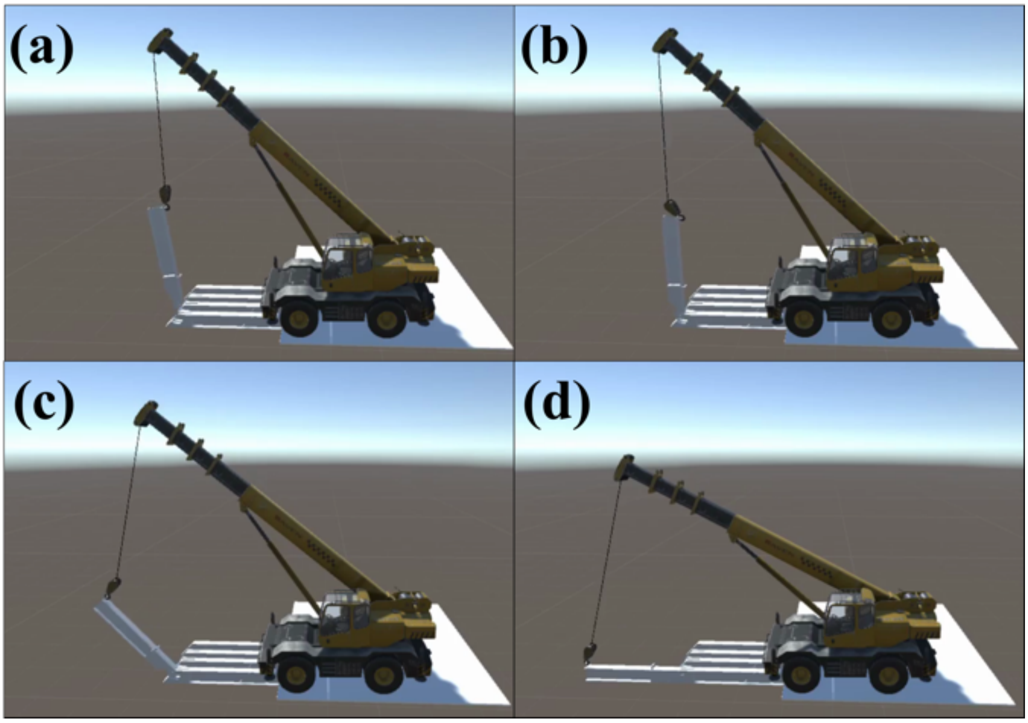

Figure 4. The results of virtual beam assembly by a mobile crane.

4.3 Discussion

The placement deviation from selected target showed the sway reduction made by the student crane operator an unstable performance. The unstable slewing torque generated by the hydraulic system of the crane was the main reason. The hydraulic control system could not keep the same angular velocity of slewing during the transportation of the beam, even the control stick of slewing remained the same inclination level. Another crane control issue was the control limitation of degree of freedom. Only one degree of freedom could be controlled at one time, indicating that the hoisted beam could not move as smoothly as we expected. To minimize the sudden change of the transportation path, we only applied slewing rotation in the experiment.

5 Conclusion

This research tried to clarify the construction process of automated beam assembly and identify key elements for the automated assembly for temporary bridge by a crane. The key elements including structure part and automated process part form a framework presented in the article. We conducted an on-site experiment and a virtual simulation to validate the construction process. The beam placement deviation from the targeted position was found, which can be the reference for autonomous structural connector design. The results showed the feasibility of the proposed framework and the construction process which may contribute to the development of automated beam assembly approach using crane operations. Future research can be focused on crane control including sway reduction and attitude control. It is suggested that the sway reduction for crane operation can be executed after the hoisted beam arrives the expected position. Since it is difficult for the crane hydraulic system to apply stable output force on the hoisted beam, it is easier to apply the sway reduction by controlling the crane boom to follow the motion of the beam. To control the beam attitude for connection, the benefit of controlling two crane hoist lines may be taken into consideration.

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