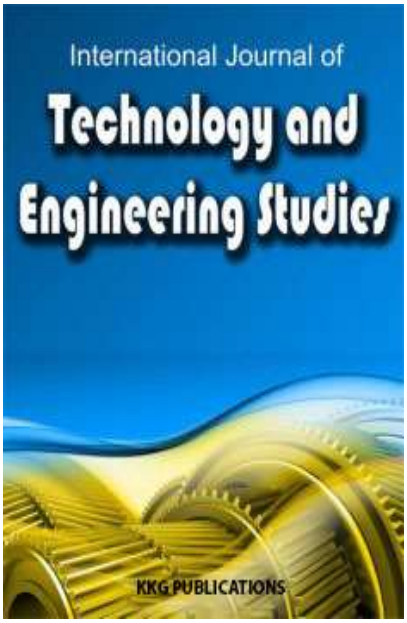

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Published online: 21 June 2015

To cite this article: W. H. Cho, C. Lim, S. Kim, S. Go, "Development of an innovative formwork system for casting reinforced concrete beams," *International Journal of Technology and Engineering Studies*, vol. 1, no. 1, pp. 14-18, 2015.
DOI: https://dx.doi.org/10.20469/ijtes.40003

To link to this article: http://kkgpublications.com/wp-content/uploads/2015/12/IJTES-40003.pdf

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International Journal of Technology and Engineering Studies

IJTES

vol. 1, no. 1, pp. 14-18, 2015

DEVELOPMENT OF AN INNOVATIVE FORMWORK SYSTEM FOR CASTING REINFORCED CONCRETE BEAMS

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Index Terms
Formwork
System Form
Beam
Column-Beam Structure
Work Process

Received: 4 March 2015
Accepted: 18 May 2015
Published: 21 June 2015

Abstract. This study aims to propose a formwork system for beams that can improve constructability and economic feasibility. There are several problems related to the structure, quality, duration, and cost of construction. In this regard, the study proposes the Formwork System for the Beams to improve the existing formwork problems and conduct it with more accuracy and shorter duration. However, no analysis on productivity as the system is applied on site is made for this study. The existing formwork requires a lot of time and effort when installing the joist and purlin. Moreover, a gap in load support arising from removing the joist and purlin may lead to cracks in concrete beams or declined compressive strength. Forms are produced according to the dimensions of beams on-site, so the quality and use of forms decrease. Therefore, further studies on analyzing the productivity resulting from the actual application of the Formwork System should be conducted.

INTRODUCTION

Formwork for construction of buildings or structures is a key process that has a great influence on the project duration, cost, safety and quality. Formwork largely accounts for approximately 30~40% of the frame work cost [1], [2]. However, the economic-feasibility of formwork declined owing to a lack of skilled labor in construction industry and increased labor cost, and completion of the work is delayed and relevant cost is increased caused by no standard design system and reluctance to use new construction methods [3]. As shown in Fig. 1, unlike the forms for columns and slabs, the forms for beams are difficult to be installed and dismantled, and they relatively require more manpower [4], [5]. In addition, the wooden forms for beams cannot be disassembled until a certain degree of strength is achieved after concrete pouring, so they are less likely to be reused [5].

To solve the problems of wooden forms, modularized forms is used instead for improving productivity and material use [5]. However, the steel-framed plywood forms and aluminum forms that are mainly used are heavy and they require a lot of manpower for installation and removal. Despite the weaknesses of existing forms, the construction industry is not actively developing new methods, and as the industry is reluctant to use the newly developed, it is continuously using the conventional methods. In this regard, the study proposes the Formwork System for the Beams to improve the existing problems of formwork and to conduct it with more accuracy and shorter duration.

Fig. 1. Conventional form for beam.

The study procedure is as described herein. First, the problems of existing formwork are identified and the requirements for improvements are analyzed. Second, an alternative to meet the requirements, the Formwork System for the Beams, is proposed. Third, the process of installing and removing the proposed Formwork System for the Beams is explained.

LITERATURE REVIEW

Problems of the Existing Form for Beams

When producing beams, usually the plywood form, steel-framed plywood form, and aluminum form is used. Plywood form is conventionally used in sites, so it is familiar to workers and relevant parties. However, unlike columns and slabs, beams have a variety of sections, so plywood should be cut in accordance with the dimensions of beams for use on site [2]. When plywood is

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processed on site, the use and quality of forms will not only decline, but lots of construction wastes will be generated. To supplement the weaknesses of plywood form, steel-framed plywood forms and aluminum forms are used [6]. The steel-framed plywood form is an assembly of modularized forms, developed to improve the material use and productivity. Yet, when compared to the plywood form, it is heavy and requires a lot of manpower for installation and removal. Also, the form cannot be used permanently, making it difficult to obtain precise beams. The aluminum form is used for precise beam production and the quality of beams can be uniform. However, it requires longer hours for manufacturing and installing the form. Also, it is fairly noisy and generates condensation.

Beam is a member that delivers the load of slabs to columns, and since its shape is complicated, it is difficult to build forms and requires a lot of manpower. For concrete pouring in beams, a plywood form and multiple joists, purlins and supports should be installed in the bottom side of the beam as shown in Fig. 1. Installation of the form is time-consuming and requires a lot of materials [7]. When the concrete curing time is over, the form should be removed for reuse. When removing the form, the support in the bottom side of the beam was removed along with the form, and then the support shall be reinstalled in the bottom side of the beam to keep the removal time of support. However, when reinstalling the support after its removal, there is a gap in load support. This will cause undesirable structural problems, like cracks or decreased compressive strength. Also, the conventional formwork is conducted mainly based on manpower, not on materials and machines like other work types. The manpower-based formwork requires a lot of skilled labor in all processes of form manufacturing, assembling, installing and removing. Yet, it is short of the skilled labor in recent construction industry, and the dependence on non-skilled labor caused by such shortage has been increasing materials [7]. Thus, such problems need to be solved.

Related Studies

The following studies were conducted to improve the problems of existing formwork previously mentioned. Related studies are largely divided into development of forms and improvement of existing methods.

Firstly, the studies related to development of formwork systems are as described herein. [8] proposed a duration-reducing formwork system that enables simultaneous pouring by pre-assembling the floor slabs with the vertical structure, bearing wall on ground during the formwork of a bearing wall type building. Moreover, [9] developed a form that can be assembled in order to respond to the changes in wall height. However, such studies were on development of forms for slabs and walls, which are different from this study and study subject. [5] developed a monolithic form, in which the form for beams and slabs is assembled with the horizontal steel frame and wall's full-length form. However, just like the existing forms, his study used joist and purlin to connect with walls and floor slabs, making the installation and removal complicated. [10] modularized the joist, purlin and support in the bottom side of a form for beams to propose a formwork system that can ensure high constructability. Yet, the formwork system is related to the joist, purlin and support in the bottom side of a form for beams, where a gap in load support occurs just like the existing forms.

Secondly, the studies that suggest some improvements of the existing forms are described as follows. [1] proposed some improvements through a questionnaire study after the factors of selecting formworks were drawn. [11] and [6] ways for improvements by comparing and analyzing the existing forms with the system forms. However, they were conceptual improvements, lacking concrete solutions for forms.

As stated above, the previous studies were not able to solve the labor-intensive formwork, and the gap in load support. In this regard, the study proposes the formwork system for beams that can improve constructability and economic-feasibility.

Development of Formwork System for Beams

Requirements Analysis

Installation and removal of the plywood form generally used for concrete pouring in beams are not only complicated, but also they are time-consuming and effortful. Moreover, there are several problems related to the structural stability, quality, duration and cost. To solve these problems of forms for beams, the Formwork System for the Beams that meets the following requirements needs to be developed.

First, structural stability should be secured. When removing the form, the support in the lower part of the beam was removed along with the form, and then the support was reinstalled in the bottom side of the beam to keep the removal time of support. Here, when reinstalling the support after its removal, there is a gap in load support, which will cause undesirable structural problems, like cracks or decreased compressive strength. So, a form that ensures structural stability should be developed.

Second, the reuse of forms and constructability should be improved. All construction projects have different floor plan compositions. Since such difference exists, the length, width and depth of structural members (columns, beams and slabs) will vary. In case of existing forms, they are cut and processed on site in accordance with the characteristics of structural members, which will result in decreased constructability and quality. In addition, the reuse of forms has an effect on the frame work duration and cost. Thus, a form that can maximize use and constructability is needed.

Third, the quality and productivity of skilled labor work should be ensured. The existing labor-centered formwork requires skilled labor upon installation and removal. However, currently the construction industry are lack of skilled labor, which led to an increase in labor cost and decrease in economic-feasibility. So, to solve such shortage of the skilled labor, a form that ensures the quality and productivity of skilled labor with only a simple training of non-skilled labor and simple installation/removal methods needs to be developed.

Composition & Functions of the Formwork System for the Beams

The Formwork System for the Beams proposed in the study is composed as shown in Fig. 2 and 3. Bottom and side panels are the form members that consist the bottom and side of beams. Bottom filler panel remains with the support for filler, not removed even after the concrete curing time is over, so as to solve the structural problems that may be generated between the support removal and its reinstallation. Side filler panel is removed with the side panel for reuse. Bottom corner frame is a member that fixes the bottom panel with the side panel, and wedge pins are used to fix them and it becomes monolithic. It also acts as a chamfer strip. Upper corner form is a member installed in the upper side panel, which is to standardize the side panel, fix the form for slabs and ensure erection. The height of upper corner frame shall be calculated by equation 1 as shown in the Fig.4.

HU = DB(①) - tS(②) - HS(③) - hE(④) (1)

Where, HU: Height of upper corner frame

DS: Depth of beam

tS: Thickness of slab

HS: Height of side panel

hE: edge height of bottom corner frame

For example, as shown in the Fig.4, the height of upper corner frame shall be calculated as 105mm if the depth of beam(①) is 600mm, thickness of slab(②) is 18mm, height of side panel(③) is 300mm, edge height of bottom corner frame(④) is 15mm. Bottom and side end fillers face the columns and retaining walls. In case of the existing forms, the gap between the lower form and the side form is not filled in, which may lead to a leakage of concrete. However, the bottom corner frame seals the "gap between the bottom panel and the side panel", as well as the "gap between the bottom filler panel and the side filler panel", preventing concrete from leaking.

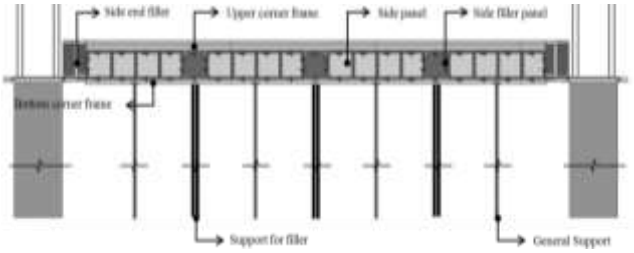

Fig. 2. Side view of formwork system

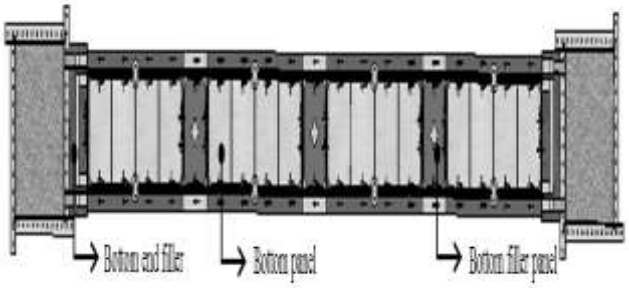

Fig. 3. Bottom view of formwork system

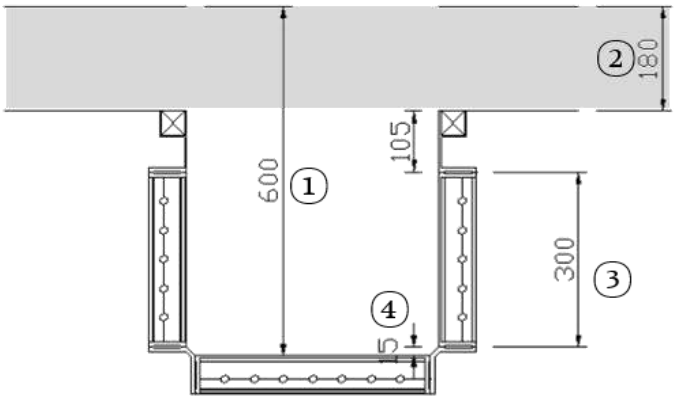

Fig. 4. Calculation example of edge height of bottom corner

Installation and Removal Process

Installation process of the Formwork System for the Beams can be divided into assembly and installation. Above all, concrete pouring in columns is performed before installing the system, and a frame is installed along the outer side of upper columns.

When the frame is completely installed, the Formwork System is assembled. Assembly process is as illustrated in Fig. 5-a~f. As shown in Fig. 5-a, the bottom panel and bottom filler panel are assembled on ground.

Then, the bottom corner frame is assembled with the bottom panel as shown in Fig. 5-b. Here, the bottom corner frame should be longer than the assembled bottom panel-bottom filler panel. So, the bottom corner frame supports the bottom panel and bottom filler panel to be fixed. The bottom corner frame is assembled with the bottom end filler as shown in Fig. 5-c. Then, a form for the bottom side will be ready.

Place a square wood bar under the form for the floor and flip it over. Then, assemble with the side panel as shown in Fig. 5-d. Assemble the side panel and side filler panel with the upper part of bottom corner frame. The side panel and side filler panel are the same in length with the bottom panel and bottom filler panel. The upper corner frame is assembled with the upper side panel as shown in Fig. 5-e. The length of upper corner frame and that of bottom corner frame are the same.

When the upper corner frame is completely assembled, the side end filler is assembled with both form ends as shown in Fig. 5-f. Here, the Formwork System for the Beams is completely assembled.

Then, the installation begins. As demonstrated in Fig. 5-g, the completed Formwork System for the Beams is safely mounted on the column frame by lifting it with a tower crane. Until a support to support the form for beams is ready, fix the form for beams with a tower crane. As shown in Fig. 5-h, the support is installed from the exterior part of the form.

The support of Formwork System for the Beams is composed of a support for filler and a general support. When installing the support, all general supports must be installed, and then the tower crane is removed and the support for filler is installed. In accordance with the process of assembly and installation, the Formwork System for the Beams in other location is installed. After installing all the forms for beams needed, forms are installed in the column corners. This will complete the installation process.

After concrete pouring and curing for a specific time, forms are removed as shown in Fig. 6. First, the support is removed as illustrated in Fig. 6-a. Here, only the general supports are removed, while the support for filler remains.

When the supports are removed, the members are removed in the following order: bottom corner frame, bottom and side end filler, side panel & side filler panel, upper conner frame and bottom panel. However, the bottom filler panel and support for filler are not removed while the support remains.

In case of the existing formwork, all supports and forms were removed and then the support reinstalled to conform to the support remaining period. This caused several problems like cracks or decreased compressive strength owing to the gap between the removal and reinstallation of support.

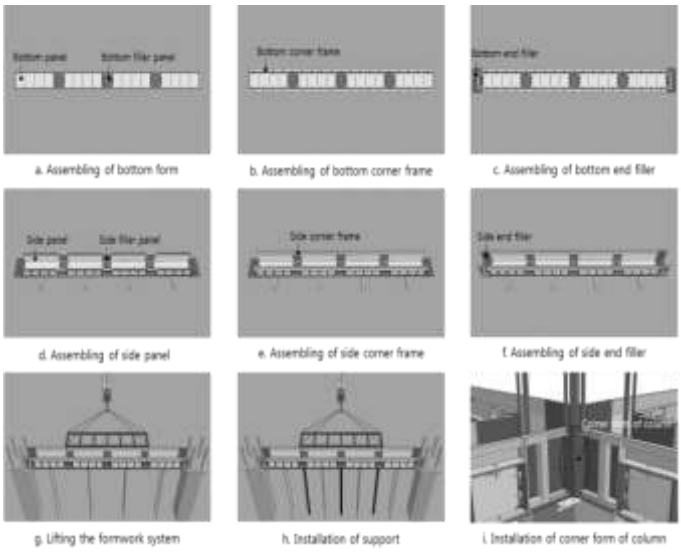

Fig. 5. Installation process of formwork.

The Formwork System for the Beams proposed in the study does not remove the bottom filler panel and support for filler while the support remains, to solve the structural problems of the existing formwork. Furthermore, the Formwork System for the Beams starts removing the parts neighboring columns, making it easy to remove the forms in the center with the self-load of beams.

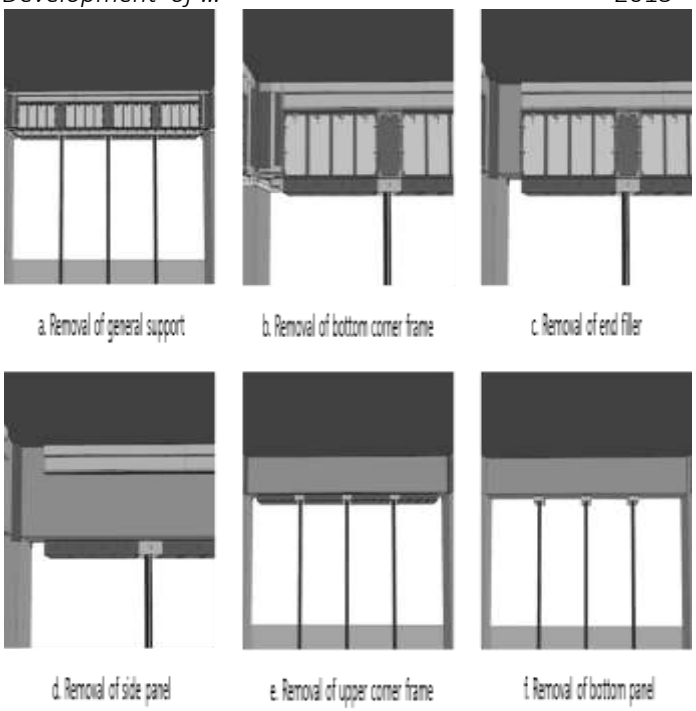

Fig. 6. Removal process of formwork system

CONCLUSION AND RECOMMENDATIONS

The existing formwork requires a lot of time and effort when installing the joist and purlin. Moreover, a gap in load support arising from the removal of joist and purlin may lead to cracks in concrete beams or declined compressive strength. Forms are produced according to the dimensions of beams on site, so the quality and use of forms decrease. Such problems cause delays in completion of framework, increased cost and decreased productivity. To solve these problems, the Formwork System for the Beams is developed. The characteristics of Formwork System for the Beams are as described below.

First, a form for beams is modularized by unit, and produced on ground and installed by lifting it with a crane. Any laborers can do so with a simple training, which will ensure the quality and productivity of the skilled labor. Second, only the general support is removed after the concrete curing period, so that the support can remain without a gap in load support, with the bottom filler panel and the support for filler.

Third, the parts neighboring the columns are removed first, which will make it easier and faster to remove the central part with the self-load. Fourth, an edge is formed in the part that connects the upper and bottom corner frame to ensure the quality of concrete finishing after the forms are removed.

The study proposed the Formwork System for the Beams to solve the problems of existing forms. However, no analyses on productivity were conducted for the system proposed in the study. Thus, further studies should be conducted to actually apply the Formwork System for the Beams and to analyze its productivity.

Declaration of Conflicting Interests

This study has no conflicts of interest.

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