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Authors: Taehoon Kim, Chosun University
Sang-Dae Kim, Korea University

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Comparative Analysis of Lifting Loads of Tower Cranes by Core Structure Construction Methods

Yong Seok Choi[1], Taehoon Kim[2], and Sangdae Kim[3]

[1]LOTTE Engineering & Construction, Republic of Korea
[2]Department of Architectural Engineering, Chosun University, Republic of Korea
[3]School of Civil, Environmental & Architectural Engineering, Korea University, Republic of Korea

Abstract

In tall building construction, the appropriate control of lifting loads on tower cranes is critical in terms of the construction duration of structural works. The adoption of efficient construction methods can be the most effective way of minimizing the inputs of tower cranes and making a lifting plan and management easier. Based on actual data from a tall building project, this study comparatively analyzes lifting loads of tower cranes by the core structure preceding construction method (CSPCM) and the core structure succeeding construction method (CSSCM). The results revealed that the CSSCM could reduce up to about 56.3% of lifting loads for core works and significantly enhance lifting efficiency compared with the CSPCM. Consequently, this enabled a substantial reduction in the construction duration of structural works. This study provides a practical reference to assist engineers and managers in applying efficient construction methods and lifting equipment operation in tall building projects.

Keywords: Tower crane, Lifting load, Core structure succeeding construction method, Core structure preceding construction method, Tall building construction

1. Introduction

Tall building projects generally require reduced construction duration to secure the profit of a project. Because the construction duration of tall buildings is longer than that of low- and medium-height buildings, clients require a reduction in total construction duration to lower their financial expenses (Cho et al. 2004). In particular, structural works play a crucial role in total duration reduction because they account for the largest portion of the total construction duration and directly affect subsequent operations.

Appropriate control of lifting loads is one of the critical factors in reducing the construction duration of structural works in tall building construction. As buildings are becoming increasingly taller, much larger amounts and longer distances of vertical transportation of resources are needed. Thus, the effective control of lifting loads has become more important to enhance the lifting efficiency and complete tall building projects on time (Zhang et al. 2018). In particular, the appropriate control of lifting loads of tower cranes (T/Cs), which are essential for the vertical transportation of materials in structural works, significantly affects the duration reduction of structural works in tall building construction.

To control lifting loads of T/Cs properly, applying construction methods to reduce lifting loads can be an effective solution. Several methods are used to control lifting loads properly, such as increasing the number of T/Cs, improving the operation rates of installed T/Cs through a proper lifting plan, and adopting construction methods that can reduce total lifting loads. Of those measures, the last is the most effective for minimizing the T/C inputs and making a lifting plan and management easier and more efficient.

This study analyzes lifting loads of T/Cs by core structure construction methods for tall buildings with steel-reinforced concrete (SRC) structures, and compares the results of lifting loads from the application of the core structure preceding construction method (CSPCM) and the core structure succeeding construction method (CSSCM) to an actual tall building project in Korea. The results of this study can provide a useful reference to help engineers and managers apply efficient construction methods and lifting equipment operation in tall building projects.

2. Core structure construction methods

2.1. Core Structure Preceding Construction Method (CSPCM)

The CSPCM involves constructing the core structure several floors ahead of other structural elements on the

†Corresponding author: Kim, Taehoon
Tel: +82-62-230-7145, Fax: +82-62-230-7155
E-mail: thoonkim@chosun.ac.kr

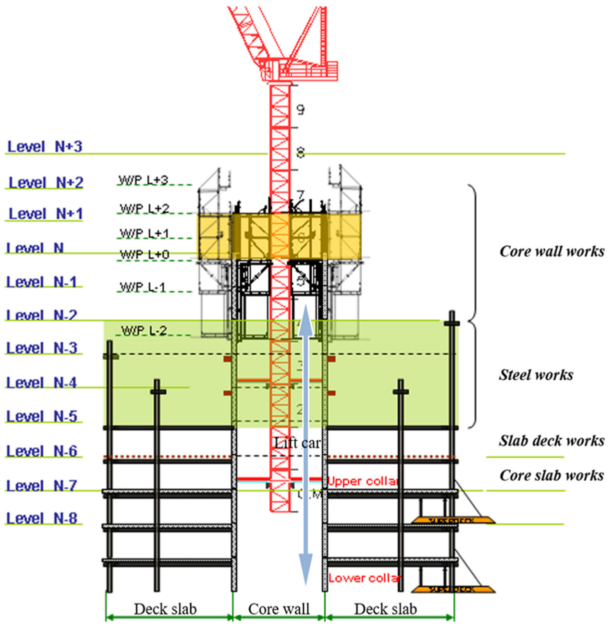
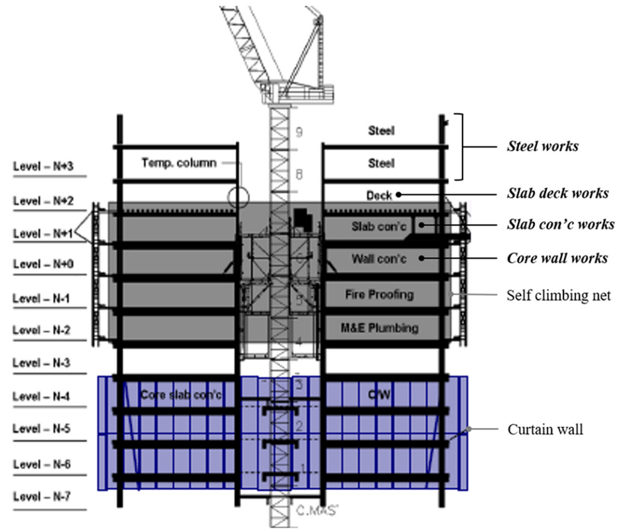


Figure 1. Schematic diagram of the CSPCM.



* Note: Temp. (Temporary), Con'c (Concrete), CW (Curtain wall), M&E (Mechanical and electrical)

Figure 2. Schematic diagram of the CSSCM.

perimeter zone. That is, in tall buildings with SRC structures, the core structures are generally constructed five to six floors above the floor where the steel erection works in the perimeter zone progress. The slab decks and concrete are then placed after the steel erection works (see Figure 1).

In general, the construction of the core structure becomes the critical path in structural works because it has a greater workload in a smaller workspace compared with the construction of other structural elements. Therefore, the application of the CSPCM enables easier control of subsequent activities by separating complex works of the core structure, and facilitates a reduced workload by adopting system forms, such as auto climbing systems (ACSs), to the core wall structure (Ahn 2004). For this reason, the CSPCM has been applied to many tall building construction sites in Korea. However, observations from the adoption of the CSPCM show that this method can lead to several management issues, including 1) limited workspace and interference between activities for core construction, 2) difficulties in joint construction between core walls and steel members, and 3) heavy reliance on T/Cs to transport materials and equipment for core construction, such as prefabricated rebars and portable urinals.

2.2. Core Structure Succeeding Construction Method (CSSCM)

The CSCCM, which is an alternative method to overcome the issues related to the CSPCM, has recently been introduced in several tall building projects. The CSCCM has a reverse construction process compared with the CSPCM, that is, steel erection on the perimeter zone is first conducted with the support of erection columns and girders. Slab decks and concrete are then placed two to three floors below the floor where the steel erection works progress. The core construction, including rebar, formwork, and concrete works, is conducted four to five floors later than steel works (see Figure 2). Unlike in the CSPCM, hand-set forms such as aluminum forms are adopted instead of ACSs on the external walls of the core structure.

Based on this procedure, the workers for operations of the core structure can use wide spaces constructed on the perimeter zone. In addition, the application of the CSSCM does not require plate or rebar embedment installation to connect steel girders or slab rebars to the perimeter zone, and lifting loads of T/Cs can be reduced because a large amount of the materials can be transported by temporary lift cars installed to the perimeter zone. Choi et al. (2016) showed that using the CSSCM can lead to a substantial reduction in terms of both construction duration and cost compared with the CSPCM. This study focuses on the comparison of lifting loads of T/Cs through the application of the CSPCM and CSSCM to an actual tall building project.

3. Case study

3.1. Case Description

The case used in this study is a supertall building project with an SRC structure and a height of 555 m (123 floors above ground and six floors underground) located in Sincheon-Dong, Seoul. Typical floors have a square-shaped core structure and eight mega columns, and are designed to carry gravity loads of 60% on the core and 40% on the mega columns (Kim and Lee 2016). As shown in Figure 3, lateral forces are resisted by the core structure and the outrigger and/or belt trusses located on the 39th–44th, 72nd–76th, and 104th–107th floors.

This case project adopted two different core construction methods, the CSPCM and the CSSCM. First, the CSPCM

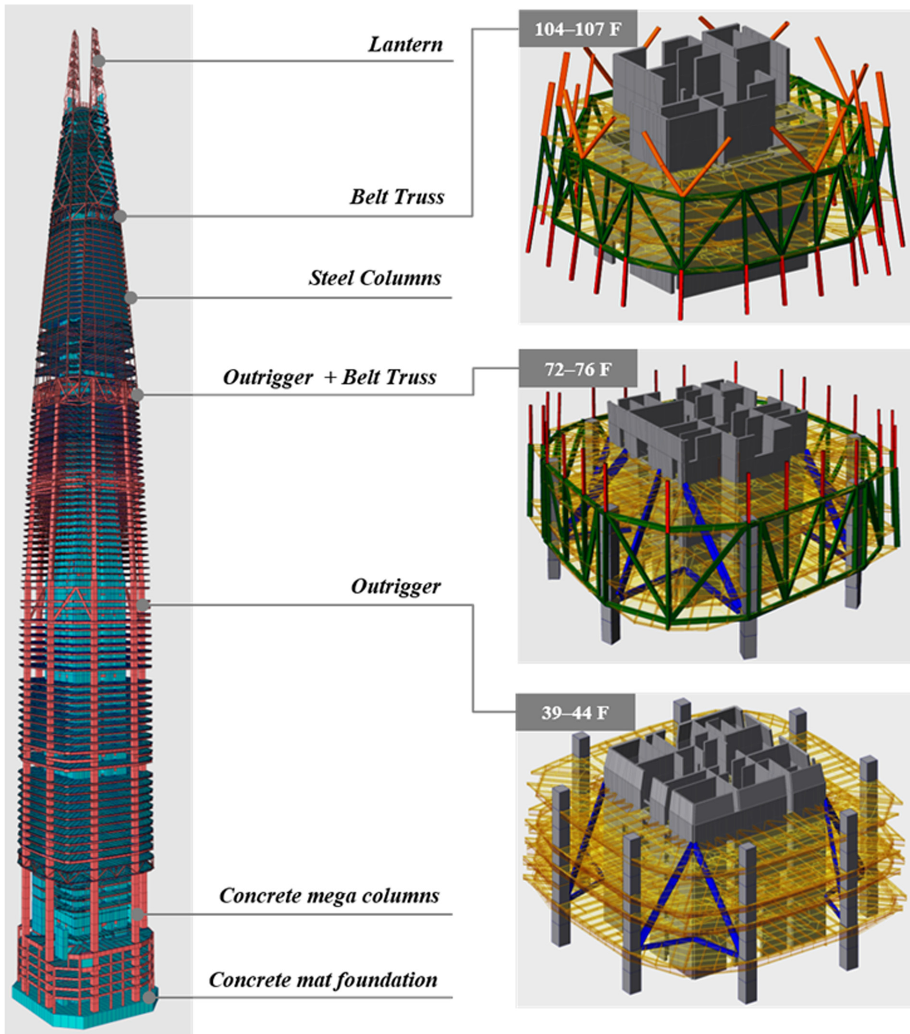


Figure 3. Structural systems applied in the case project.

was applied up to the core structure located on the 101st floor. As shown in Figure 4(a), a total of four T/Cs (two with 64 tons and two with 32 tons of loading capacity) were installed inside and outside of the core structure, respectively. By contrast, the CSSCM was applied from the 102nd to the top floor to reduce lifting loads. Only two T/Cs installed inside the core were used because it is expected to occur interferences among T/Cs by reduced floor area (see Figure 4(b)). The following section compares the lifting efficiency of T/Cs in the CSPCM and CSSCM based on actual data from the case study.

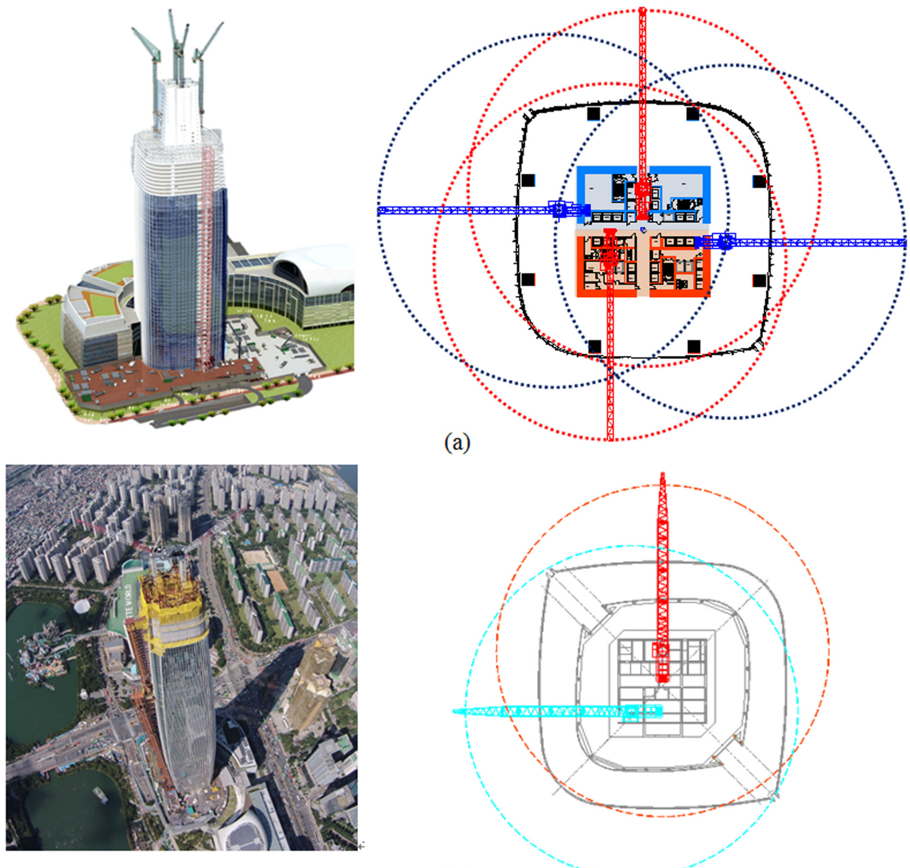
3.2. Conditions for Comparison

This study compares the lifting loads of T/Cs, focusing on core structure construction, on nine floors constructed using the CSPCM (93rd–101st floors) and CSSCM (102nd–110th floors). Figure 5 shows the core floor plans for each work area in the CSPCM and CSSCM. The area of the core zone in the CSSCM (525 m^2) accounts for about 85% of that in the CSPCM (25.35 m long and 24.2 m wide, 619 m^2). The average lifting heights are 401.2 m for the CSPCM zone and 432.9 m for the CSSCM zone, showing a difference of about 31.7 m in lifting distance and about 1 minute in lifting time per lift.

The items for calculating the lifting time of T/Cs include are as follows: 1) steel members and accessories for steel erection work, 2) forms and scaffoldings, rebars, machinery, and other accessories for reinforced concrete (RC) work in the core and perimeter zones, 3) deck plates, 4) curtain walls, 5) lift cars, 6) concrete placing booms (CPBs), and 7) other miscellaneous items. The following causes are considered for calculating the waiting time of T/Cs: 1) weather conditions, 2) working standby, 3) maintenance and climbing of T/Cs, and 4) mealtime.

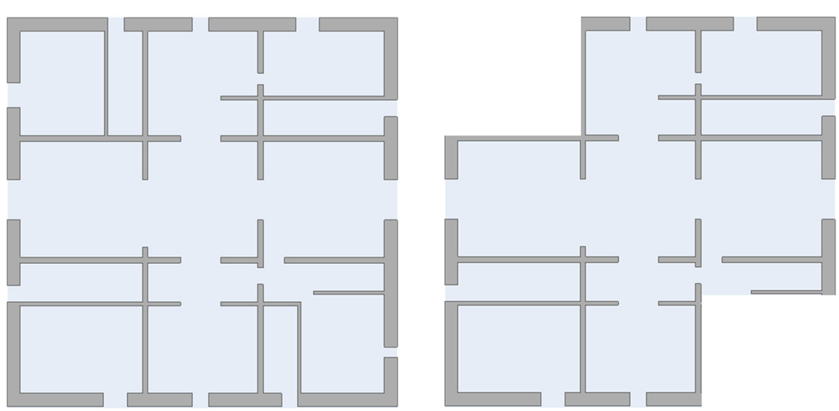
3.3 Comparison of Lifting Efficiency by Core Construction Methods

Table 1 shows the lifting items of T/Cs by applying the CSPCM and CSSCM. As shown in Table 1, the CSPCM depends on T/Cs for the lifting of most materials and the machinery required for structural works, while T/Cs in the CSSCM mainly lift only rebar bundles and steel



(a) (b)

Figure 4. Perspective and layout of T/Cs in (a) the CSPCM and (b) CSSCM zones.



(a) (b)

Figure 5. Core floor plan in (a) the CSPCM and (b) CSSCM zones.

columns and girders. This is because temporary lift cars to access the core zone in the CSPCM have low speed and small-sized cages and cannot reach to the top of the core working places because of interference between the main frame of ACSs and the cage of the temporary lift cars. Therefore, most lifting items in the CSPCM should be loaded on the platforms attached to the ACSs by T/Cs, and the lifting load per T/C lift is generally restricted at about 4-5 tons, considering the loading capacity (10 tons) of a shoe anchor for supporting the ACS. This causes frequent waiting times as well as a careful operating plan of T/Cs. In contrast to the CSPCM, most lifting items for the core works are transported by temporary lift cars with high speed and large-sized cages installed on the perimeter zone, instead of T/Cs. In addition, T/Cs in the CSSCM transport over 10 tons per lift because lifted items can be

Table 1. Comparison of lifting items of T/Cs by applying the CSPCM and CSSCM

Method	Work type	Lifting items
CSPCM	Form work	ACS main materials, form-cutting debris and accessories, scaffoldings, box openings for doors and MEP, and consumables
	Concrete work	CPB pipes, initial mortar debris, and flexible hoses
	Rebar work	Prefabricated rebar cage, connection hoop and dowel bars, Halfen box, and bar-bending machines
	Steel work	Steel columns, steel link beams, embedded plates, and welding machines
	Other works	Temporary lighting, firefighting pipes and extinguishers, E/V-embedded plates and mechanical sleeves, toilets and urinals, safety materials, and debris
CSSCM	Rebar work	Rebar bundles, connection hoop, and bars
	Steel work	Erection columns and girders

*Note: MEP, mechanical, electrical, and plumbing; E/V, elevator.

loaded on the prebuilt core slabs, such as elevator hall slabs. Therefore, the total number of transportations and the lifting time by T/Cs can be substantially reduced.

Table 2 compares the lifting loads of T/Cs by each method for the case project. In the CSPCM, lifting loads for RC works account for 43.3% of the total lifting time, while T/Cs in the CSSCM are mainly used for steel erection works (68.2% of the total lifting time). This was caused by the difference in the number of steel members. In the CSPCM zone, only 550 steel members (about 61 members per floor) had to be lifted by T/Cs. By contrast, 1741 steel members in the CSSCM zone had to be lifted because of belt trusses (104th-107th floors) and a circular tube-type diagrid installed from the 107th floor, although the floor areas were gradually reduced. However, the lifting efficiency for steel works at least doubled. That is, the lifting time per steel member in the CSPCM took about 2.6 hours (1404/550) on average, but about 1.2 hours (2113/1741) in the CSSCM. This remarkable difference in lifting efficiency may be explained by the following reasons: 1) steel girders in the CSPCM should be connected to the steel plates embedded in the RC core wall, making steel erection and adjustment difficult, and 2) erection columns and girders, which are more slender than the steel members in the perimeter zone, are easy to erect and make steel erection and adjustment on the perimeter zone much easier.

In addition, the lifting loads of T/Cs for RC works in the core zone were substantially reduced by applying the CSSCM compared with the CSPCM. As shown in Table 2, the lifting times for RC work in the core zone by the CSPCM and CSSCM were 1217 and 451 hours, respectively. Considering the area ratio of the core zone, the lifting loads in the CSSCM zone were reduced by about 56.3% (451 h / (525 m^2 / 619 m^2) / 1217 h 100 = 43.7%) compared with that in the CSPCM zone because of the following factors: 1) most items in the CSSCM could be transported by lift cars instead of T/Cs, and 2) the lifting capacity per

Table 2. Comparison of lifting loads by applying the CSPCM and CSSCM

Category			Core construction method	
			CSPCM	CSCCM
Lifting time (h) (Ratio (%))	Steel works		1404 (24.9)	2113 (68.2)
	RC works	Core	1217 (21.6)	451 (14.6)
		Perimeter slabs	1221 (21.7)	136 (4.4)
	Deck plates		180 (3.2)	152 (4.9)
	Curtain walls		251 (4.5)	85 (2.7)
	Lift cars		16 (0.3)	7 (0.2)
	CPBs		17 (0.3)	2 (0.1)
	Others		1327 (23.6)	150 (4.8)
	Subtotal [A]		5633 (100.0)	3096 (100.0)
Waiting time (h) [B]			728	575
Total operating time (h) [C = A + B]			6361	3671
Nonworking time (h) [D]			4535	1934
Total (h) [C + D]			10,896	5605

T/C lift was improved with the support of the rigid structure, leading to a reduced total number of transportation. Lastly, the total construction duration on nine floors by applying the CSSCM was 123 days, which was 52 days (calendar days) less than where the CSPCM was applied. Even though the total floor areas in the CSSCM zone were decreased compared with those in the CSPCM zone, the overall level of difficulty in structural works increased because of the installation of belt trusses and diagrids. The lifting distance was also increased, while the number of used T/Cs was reduced. Therefore, the change in the core structure construction method substantially decreased the construction duration by increasing the lifting efficiency.

4. Conclusions

This paper compared lifting loads of T/Cs by core structure construction methods based on data from an actual supertall building project. The results revealed that the CSSCM can substantially reduce the total lifting loads of T/Cs and enhance lifting efficiency compared with the CSPCM. These findings could be expected to contribute to considerable savings in the construction duration of structural works. As a useful reference, the results of this study can assist engineers and managers in the appropriate application of core structure construction methods in tall building projects that require an efficient lifting plan and control.

Acknowledgments

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