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Flexible double-cage hoist for high operational efficiency in tall building construction

Taehoon Kim[a], Ung-Kyun Lee[b,*], Seung Woo Kim[c], Hyunsu Lim[d], Chang-Won Kim[e], Hunhee Cho[f], Kyung-In Kang[f]

[a] *Research Institute for Mega Construction, Korea Univ., 145, Anam-ro, Seongbuk-Gu, Seoul 02841, Republic of Korea*
[b] *Dept. of Architectural Engineering, Catholic Kwandong Univ., 24, Beomil-ro 579 beon-gil, Gangneung-Si, Gangwon-Do 25601, Republic of Korea*
[c] *Liftec Corp., 45, Sincheoksandan 5-ro, Deoksan-myeon, Jincheon-gun, Chungcheongbuk-do 27850, Republic of Korea*
[d] *Department of Architecture, Soonchunhyang Univ., 22, Soonchunhyang-ro, Sinchang-myeon, Asan-si, Chungcheongnam-do 31538, Republic of Korea*
[e] *Korea Institute of Procurement, 319, Eonju-ro, Gangnam-gu, Seoul 06226, Republic of Korea*
[f] *School of Civil, Environmental and Architectural Engineering, Korea Univ., 145, Anam-ro, Seongbuk-Gu, Seoul 02841, Republic of Korea*

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ABSTRACT

High operational efficiency in the use of hoists is crucial for the successful completion of high-rise building projects. Simply increasing the number of hoists may not be possible because of insufficient space or budget limits. However, adopting the "double-deck" concept can be an effective approach to improving the operational efficiency of hoists in projects with such constraints. This study proposes a flexible double-cage hoist for use in such projects. In a case study, we found that combining the proposed hoist with existing single-cage hoists enabled a smaller number of hoists to achieve significantly higher efficiency at lower cost than a group of single-cage hoists. The optimal combination showed a 16.6% decrease in total operational costs and a 7.9% increase in operational efficiency. Using the proposed hoist could therefore enable the successful completion of high-rise building projects at lower cost.

1. Introduction

The operational efficiency of hoists is one of the key factors that affect the successful completion of high-rise building projects [1]. "Operational efficiency" is defined either as the number of passengers that a hoist can transport within a certain time or the time required to transport a certain number of passengers. The recent trend toward increased height for high-rise buildings requires an even higher operational efficiency for hoists [2] and simply increasing the number of hoists may not be possible because of insufficient space or budget limits for equipment installation at a site [3,4]. Several studies have investigated improving the operational efficiency of hoists by controlling the range of service floors for a hoist. Such approaches include zoning, sky-lobby lifting systems, and intelligent controls [3–5]. However, these studies have focused on managing the operation of existing hoists, rather than developing new types of hoist, which could reduce the number of hoists required at a site.

Adopting the "double-deck" concept can be an effective approach to improving the operational efficiency of hoists in projects with space or budgetary limitations on the installation of hoists. This concept involves joining an upper cage and a lower cage together as a single entity, which not only increases the payload but also serves two adjacent floors at each stop, thereby increasing the operational efficiency and reducing the number of hoistways. The double-deck concept has been widely used for elevators in high-rise buildings since the 1970s, offering increased operational efficiency for an elevator where there is minimal installation space [6–9].

However, existing double-deck elevators have limitations. In particular, they cannot respond to variable traffic types such as occur at peak and nonpeak times because the two cages of the double-deck elevator are permanently joined [8,9]. The double-deck concept would be most useful at peak times when there are many passengers and the probability that departure or arrival floors are adjacent is high. It would offer less operational efficiency at nonpeak times, when there are few passengers and their departure and arrival floors are widely distributed. In this case, the double-deck elevator would be less energy efficient than a single-cage elevator. Being able to attach and detach the two cages according to traffic type would address this issue. Another

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* Corresponding author.
E-mail addresses: kimth0930@korea.ac.kr (T. Kim), uklee@cku.ac.kr (U.-K. Lee), ksw@liftec.co.kr (S.W. Kim), hslim@sch.ac.kr (H. Lim), cwkim@kip.re.kr (C.-W. Kim), hhcho@korea.ac.kr (H. Cho), kikang@korea.ac.kr (K.-I. Kang).

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limitation of existing double-deck elevators is that they require a 5–10% wider installation space than single-deck elevators, because of the outer frame connecting and enclosing the two cages. For the hoists used in high-rise building construction, there is a need to minimize the hoist width because of the constraints on space for hoist installation.

Therefore, this study aims to develop a flexible hoist for high-rise building construction that will achieve a high operational efficiency in a limited space by adopting the double-deck concept. Section 2 reviews conventional hoist and double-deck elevators to derive the design requirements. In Section 3, based on these requirements for practical use in construction sites, we describe the development of a prototype hoist, including a mock-up test to check that the prototype could meet the design requirements. Section 4 describes simulation experiments that estimated the performance of the proposed hoist in terms of its operational efficiency and cost. In Section 5, we present our conclusions, notably that using the proposed hoist could enable the successful completion of high-rise building projects at lower cost.

2. Hoists and elevators for high-rise buildings

2.1. Hoists for high-rise building construction

A typical hoist comprises a cage frame, a driving unit, a hoistway, a counterweight, power supply equipment, a control panel, and safety devices (Fig. 1).

In this paper, the term “hoist” refers to all these components except for the hoistway. The driving unit is usually composed of two electric motors and brakes, and determines the maximum speed and payload of the hoist and the required power capacity. The governor is the main safety device that prevents the hoist from a sudden fall, and its capacity is determined by the maximum speed and payload of the hoist. In addition, limit switches are used to prevent the hoist from moving outside the hoistway. The hoistway is composed of mast segments, which are installed vertically from the ground floor to the top of the building. It is fixed to the building wall by wall ties. The counterweight has the role of reducing the load burden on the motors. A power cable conducts electricity from a power box on the ground floor to the hoist. The thickness and weight of the cable are related to the capacity of the power supply and the height of the building. The first section of the cable is fixed to a point approximately halfway up the hoistway and the remaining section hangs from the cage frame. A cable trolley moves under the hoist along the hoistway to ensure the safe movement of the flexible section of the cable. This prevents the cable from twisting or disconnecting from the power supply because of wind and vibration [10]. Because each component of the hoist is closely related to other components and capacities, we needed to consider these relationships when developing the proposed hoist.

2.2. The double-deck elevator

The double-deck elevator is widely used to enhance operational efficiency in high-rise buildings with limited shaft space. Some examples are the Sears Tower in the USA (442 m, 110 F, 1970), the Shanghai World Finance Center in China (492 m, 101 F, 2008), the Burj Khalifa in the United Arab Emirates (868 m, 168 F, 2010), and the Lotte Jamsil World Tower in Korea (555 m, 123 F, 2017). Use of a double-deck elevator can reduce the installation area by 25–40% compared with a single-deck elevator of the same operational efficiency [6]. It also has the advantage of improving the operational efficiency of each shaft by 50–100% [7].

A typical double-deck elevator comprises two elevator cages, an adapter, a driving unit, a control panel, and safety equipment. The upper and lower cages are enclosed by an outer frame and connected by the adapter. A traction machine installed in the machine room on the top floor serves as the driving unit and it allows the double-deck elevator to move along its guide rail by means of a winding rope. A

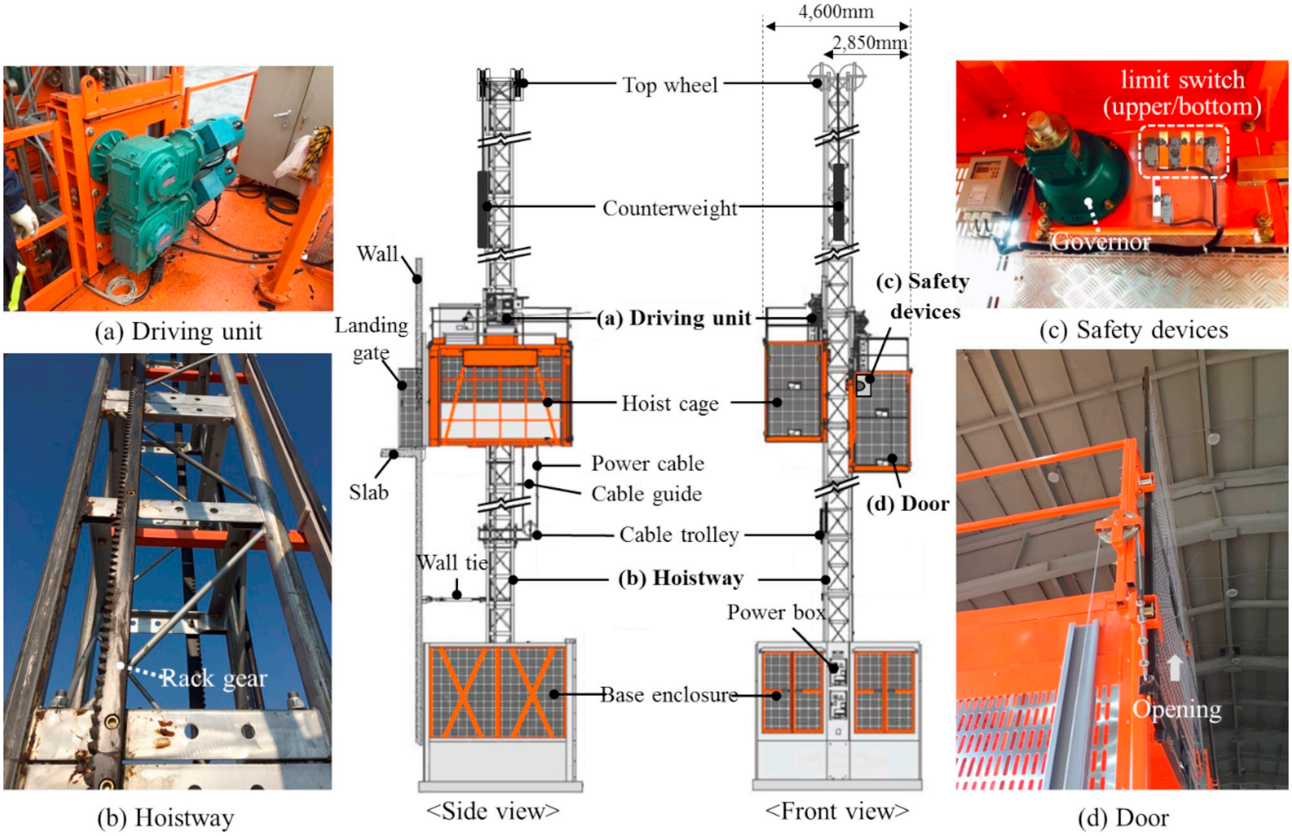

Fig. 1. Configuration of a typical hoist.