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The energy efficient expansion remodeling construction method of bearing wall apartment buildings with pre-cast composite structural systems

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ABSTRACT

The remodeling construction method of wall type apartment buildings utilizing conventional Rahmen structural system has some drawback of compatibility of the beam depth between existing bearing wall apartment buildings and conventional Rahmen structural system. The pre-cast composite structural systems presented in this study are capable of providing the identical floor depth with conventional apartment buildings. Connecting steels between the existing structures and new frames are developed and presented. This paper also presents the energy efficiencies and related merits of the remodeling construction method of wall type apartment buildings. This work finally demonstrates that the use of pre-cast composite structural systems for the expansion of conventional wall type apartment buildings would reduce the overall amount of energy input compared to utilizing the wall structural system for remodeling.

The energy consumptions of remodeling construction method with pre-cast composite structural systems were reduced by approximately 45% in comparison with conventional wall type expansion, demonstrating opportunity for the healthy expansion of existing apartment spaces in environmentally friendly and sustainable ways.

1. Introduction

1.1. Research trend of construction method for horizontal expansion remodeling

Building remodeling is necessary to enhance the overall deterioration of a building in terms of its physical, functional, social, and economical aspects. Building remodeling refers to improving residential performance, building a pleasant environment, saving resources, and promoting the value enhancement of resources and the sustainable residential complex [1].

Kang et al. presented the research shear strength evaluation of slab joint for plan extended method of wall-type apartment structures; this research is to develop a detailing connection system for joint members which are designed for additional extension work of plan, providing modified resistance to earthquake [2].

The flexural strength and stiffness of hollow slabs was investigated by Chung et al. A new type of hollow slab making use of plastic air balls has been developed, which can effectively reduce the amount of concrete and self-weight of concrete structures. In this study, flexural and free vibration tests were carried out to investigate flexural behavior, including the flexural stiffness, cracking, strength, and ductility [3].

S.G. Hong et al. performed the research the remodeling techniques for apartment buildings by precast construction; this study was proposed to maximize the natural resources and to make ecology-environment and economic technical development for construction market. Dry-construction method of precast concrete structure for remodeling for old residential buildings in Korea became possible [4].

The dwelling space extension of remodeled apartments using composite structure was proposed by Kim et al. This research has developed extension method using RC Slab connected by hinged joints, precast concrete, and pre-stressed concrete [5].

In 2007, Hong and Jung suggested the shear-wall construction for the remodeling of shear-wall type apartment buildings This study was to provide structural design guidelines in additional shear-wall construction method for apartment remodeling with

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Table 1
The comparison of construction remodeling methods.

RC wall type systems	Steel frame systems	Precast composite structural systems
• Advantages	• Advantages	• Combine the advantages of Steel Frames and RC walls
1. Reduced floor height compared with steel frames	1. Simple joint connection of the existing walls and new columns	1. Simple joint connection with the existing walls with the steel joint
2. Fireproof not necessary	2. Modular construction	2. Modular construction
	3. Advantage in the construction period compared with RC wall type systems	3. Advantage in the construction period as steel frames
		4. Fireproof protection not required
• Disadvantages	• Disadvantages	5. Environmental friendly characteristics by the reduction of construction material quantities
1. Complexity of bonding process of the existing wall and new wall	1. Fireproof protection required	6. The same story height with the existing wall frames based on story depth reduction
2. Disadvantage in the construction period compared with steel frames	2. Increased floor height	
	3. Internal partition required	

understanding the effects of the position, length and thickness of the additional walls [6].

1.2. The significance of the research

Extensions utilizing reinforced concrete walls and steel frames were mainly considered as structural systems of remodeling extension for existing structures. Generally, steel frame systems are advantageous in the aspect of constructability including construction period for extensions. Construction methods using the conventional steel frame for the expansion of wall type apartment buildings have a disadvantage due to the excessive floor depth compatibility with wall type apartment buildings [7,8]. In RC wall type remodeling, there is complexity of bonding process of the existing wall and new one. To remodel RC wall type apartment buildings, the existing wall is drilled where the rebar is inserted for connection and expanded to a new wall. The remodeling method that uses a pre-cast composite structural system, however, enables the same floor depth as conventional wall type apartment buildings to be retained while being constructed at the same remodeling construction speed as steel structures [7–10]. The diverse research approach, however, is necessary for constructability and structural performance as well when apartment buildings with bearing walls are the most of remodeling demands.

Table 1 compares the advantages of three remodeling construction methods including precast composite structural systems. The precast composite structural systems present shallower structural depth and better constructability as well compared with the other two methods.

This paper develops a horizontal expansion remodeling method for conventional linear shaped bearing wall apartment buildings using pre-cast composite structural systems. Its energy efficiency is analyzed by comparing it to other conventional remodeling methods. The quantity of the main construction materials required for expansion with pre-cast composite structural systems is compared to the materials of the wall type remodeling method. The reduction in energy consumption is also analyzed in this study.

2. Methods

2.1. Concept of pre-cast composite structural systems

The Rahmen pre-cast composite structural systems consist of pre-cast composite beams and columns. The pre-cast composite beam consists of a reverse T-type steel, reinforcement steels, and pre-cast concrete. The pre-cast composite column consists of a combination of PC columns and steel sections inserted between the two PC columns above and below in order to provide a connection to the composite beams. The inserted steel section is mechanically attached to the PC columns above and below by headed stud connectors [9,10].

Pre-cast composite structural systems minimize the required volume of cast-in-place concrete except for slabs, thus minimizing the formwork. Minimizing the need for a formwork increases the constructability and reduces wasted construction quantities. Pre-cast composite structural systems which combine the advantage of steel with concrete can reduce construction quantities compared to RC Ramen structures.

The strain-compatibility analysis approach is used for the design of composite beams with diverse cross-sections, determining one correct location of the neutral axis [11].

For each assumed strain distribution, the equilibrium equation was solved for the neutral axis, from which stresses in the compressive concrete, reinforcing steel, and steel section were identified. The one assumed strain distribution at each limit state that was determined to be the same as the calculated strain distribution was verified as the correct one [12].

These procedures were repeated for a series of elastic and inelastic strain distributions, each corresponding to a particular location of the neutral axis and stress distribution until the true stress distribution was found [12].

In Maximum Load Limit State, the equilibrium field is assumed by Eq. (1) which assumed location of the neutral axis between steel flange and compressive reinforcement, indicating that not yield flange of structural tee and partially plastic tensile side of web. It was also assumed that the compressive reinforcement is not yield, and tensile reinforcement is yield [13,14].

$$M - CTF_{ny}TW_{pp}CR_{ny}TR_{y} \tag{1}$$

Fig. 1 shows that the assumed neutral axis location of cross-section at the maximum load limit state is verified by the calculated location.

Eqs. (2)–(3) show a quadratic equation for estimating of neutral axis according to the equilibrium equation based on Eq. (1).

$$\alpha f_c' bc + A_s' E_s \left(\frac{\varepsilon_c}{c}\right)(c - d'') + A_f' F_y \left(\frac{\varepsilon_c}{c}\right)(c - d''' - 0.5t_f) + 0.5A_w' E_s(c - d''' - t_f) = A_s f_y + A_{wp} F_y + 0.5A_{wny} E_s \varepsilon_{sy} \tag{2}$$

where, $A'_w = t_w(c - d''' - t_f)$, $A_{wp} = t_w\{d - (c + d' - (\varepsilon_{sy}/\varepsilon_c)c)\}$, $A_{wny} = t_w(\varepsilon_{sy}/\varepsilon_c)c$