

## A COMPOSITE FRAME CONCEPT FOR THE LONG LIFE OF APARTMENT BUILDINGS

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**ABSTRACT:** Consumers demand an increasing variety of requirements for the residential space as the quality of life improves. However, many apartment buildings with the bearing wall structure cannot meet such demands in Korea. A lot of construction resources are squandered and wastes are created as this type of residential buildings is reconstructed. The life of apartment buildings needs to be extended on the basis of easy remodeling of internal space in order to overcome the limits of the bearing wall structure. This research project aims to propose the Rahmen composite frame concept for the long life of apartment buildings. The Rahmen composite frame is expected to have better structural performance, constructability and economic feasibility than the bearing wall structure.

*Keywords:* Composite Frame, Extended Life, Green Frame

### 1. INTRODUCTION

As the quality of life improves and family composition changes, consumers are presenting an increasing variety of requirements for their housing units. However, apartment buildings with bearing wall structure that limits freedom of spatial remodeling account for a majority of housing units in Korea. Such a structural design is bound to have difficulties with remodeling, given the limitations of floor layout modification and the shorter service life of facilities than structural members [1]. Therefore, it is essential to reconstruct apartment buildings to meet ever-increasing needs of occupants and rearrange floor layout over their life-cycle. If the cycle of building and rebuilding apartment buildings with bearing wall structure at 30 year-interval, reconstruction projects will account for 70% of construction wastes in 2020 [2].

Hence, demands are rising for a new structural concept that enables easy remodeling of interior space to overcome the limitations of apartment buildings with bearing wall structure. The Korean government has enforced an incentive system that eases the restriction on floor area ratio and building height by up to 20% in exchange for remodeling-friendly Rahmen structure design adoption as a solution for the issues in the above [3].

Accordingly, people are showing increasing interest in Rahmen structure design. However, transition from bearing wall to Rahmen structure entails a lot of challenges. Flat plate structure is difficult to enable long-span structure construction and ensure constructability and quality. Reinforced Rahmen structure is compatible with long-span structure design and advantageous in ensuring constructability and quality while it results in

increased ceiling height and construction cost. A lot of researchers are now working on potential solutions to ensure the long life of composite frame structure and Green Frame technology has already found application in several high-profile apartment complex projects, an indication of its viability.

Green Frame system is a Rahmen structure system that combines the advantages of steel frames and reinforced concrete to save construction time, quantity and costs [2]. It can reduce ceiling height by about 10% in comparison with steel skeleton structure and ensure environment-friendliness [2].

Apartment buildings with conventional Rahmen structure and flat plate structure also have individual weaknesses such as increase in ceiling height, restriction of freedom in floor layout modification from internal columns and rise in construction quantity. Green Frame also needs to tackle the challenge of inefficient structural steel beam layout and connection between structural members. Therefore, it is necessary to develop a new structural system that can address the shortcomings of conventional ones [3]. If such new system can increase remodeling projects and reduce reconstruction projects, it will contribute to resolving such issues as environmental pollution, energy shortage and resource crunch.

Against the backdrop, this paper proposes a composite frame improvement solution that addresses the weaknesses of Green Frame as a Rahmen Composite Frame Concept to lengthen the service life of apartment buildings. The solution is expected to ensure better structural integrity, constructability and economic viability than conventional ones.

Rahmen Composite Frame structure is applicable to all types of building structures and its application to

apartment buildings that account for the lion's share of construction industry in Korea is studied in this paper.

Firstly, the concept of PC hybrid and the background of Rahmen Composite Frame development are explained. Secondly, Green Frame which is available now in Korea is described and Rahmen Composite Frame developed to improve the weaknesses of Green Frame is presented

## 2. COMPOSITE FRAME

Hybrid method refers to the combination of conventional and PC construction methods to reduce on-site labor requirement. Generally speaking, hybrid method combines half PC concrete, re-bar pre-fabrication and large formwork, etc. with conventional rebar, formwork and concrete to reduce construction schedule and improve construction quality. Hybrid method can minimize wastes, facilitates site management and ensure the advantage in schedule reduction by pre-fabricating structural members and reducing the use of temporary materials in turn. It can also improve structural integrity, ensure gain in labor productivity by minimizing site labor requirement and prevent safety incident [5].

### 2.1 Composite Frame Concept

Composite Frame must have the following features to ensure long life of apartment building. First, it needs to ensure freedom of floor plan adjustment which is not available in conventional bearing wall or flat plate structure, supporting long-span structure with excellent adjustability. In addition, it must adopt flat plate structure to ensure constructability and quality to reduce ceiling height and support excellent constructability and economic viability. Table 1 summarizes such requirements.

**Table 1.** Performance Requirements Applicable to Composite Frame

	Performance Requirements
Floor plan	<input type="checkbox"/> Freedom of floor planning
Ceiling height	<input type="checkbox"/> Flat plate structure to keep ceiling height low
Span	<input type="checkbox"/> Highly adjustable long-span structure
Misc.	<input type="checkbox"/> Ease of installation and excellent constructability <input type="checkbox"/> Better economic viability than conventional structure design

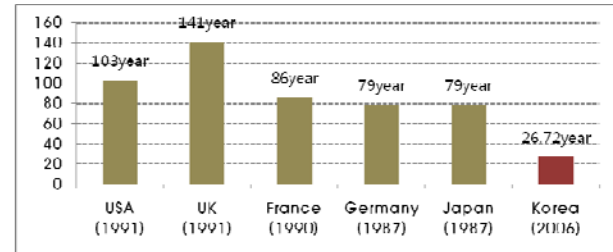
## 2.2 Green Frame Method

### 2.2.1 Background of Green Frame Development

Most apartment buildings in Korea are bearing wall structures and have limitation in terms of the adjustability of floor plan to change in the life style of occupants, which results in severe resource waste and environmental pollution. Fig 1 shows that the service life of most

apartment buildings in Korea is about 27 years, just 1/3 of other developed countries. [6]

The government decided to grant incentives on floor area ratio as a part of remodeling-friendly apartment building standards in order to stimulate the industry to have more interest in long-life housing buildings.



**Fig. 1.** Life of Apt. Bd. By Country

The government encouraged a transition from bearing wall structure to column type structure to ensure sustainability, high quality and floor plan adjustability of apartment buildings. To that end, technologies intended to ensure significantly longer life of apartment building were studied. Table 2 describes the features of each structural design. Bearing wall structure consists of concrete wall and slab, reduces ceiling height and its structural integrity and constructability has been proven in a variety of construction projects. However, it has weaknesses in that it entails significant floor impact sound issue, difficulties with floor plan modification, which leads to less than full utilization of its potential service life. Flat plate structure consists of column and slab, reduces ceiling height and ensures freedom of floor plan adjustment better than conventional bearing wall structure. However, as apartment buildings have become taller recently, slab thickness need to be increased and more rebar use required to reinforce resistance against punching shear around columns. Rahmen structure consists of beams and columns, ensures freedom of floor plan design by facilitating adjustment of column spacing and reduces floor impact sound. It is also advantageous in terms of constructability and quality control. However, as slab is to be placed over column and girder, ceiling height needs to be increased. Composite frame development efforts to increase the service life of apartment building have progressed to the development of Green Frame structure that compliments the weaknesses of Rahmen structure and combines the advantageous of other structural system designs.

### 2.2.2 Green Frame Configuration & Features

Green Frame that addresses the weaknesses of Rahmen structure is a composite PC structure that utilizes the strengths of steel members and reinforced concrete. Green Frame consists of Green Beam and Green Column. As Table3 shows, Green Beam removes top flange contributing less to bending resistance on the basis of preceding study on H-beam adoption, ensuring efficiency of structural member. It is highly advantageous in terms of reduction of construction cost and CO2 footprint. It can also reduce ceiling height above ground and soil

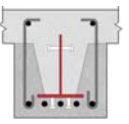
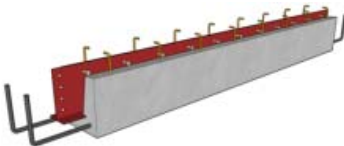
excavation quantity underground. Green Beam is also applicable not only to Green Column but also steel frame, **Table 2.** Character of Structure Type

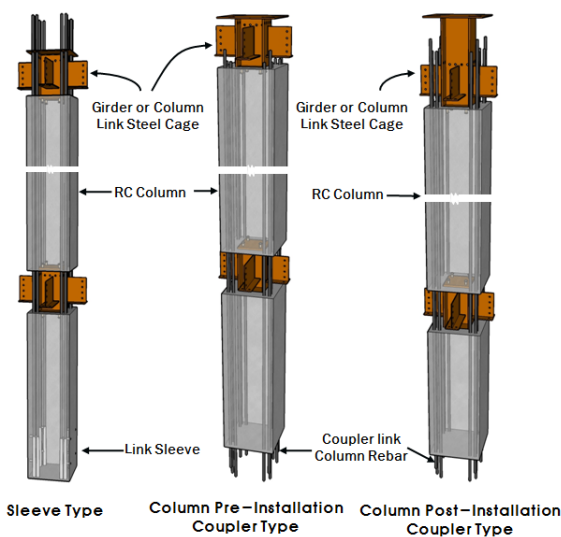
reinforced concrete or steel-reinforced concrete column.

Items		Structure System		
		Bearing Wall Structure	Flat Plate Structure	Rahmen Structure
Composition		Bearing Wall, Slab	Column, Slab	Column, Slab
Feature	Dash	<input type="checkbox"/> Excellent constructability <input type="checkbox"/> Low ceiling height <input type="checkbox"/> Low construction cost	<input type="checkbox"/> Lower ceiling height (than steel frame structure) <input type="checkbox"/> Floor plan adjustable to some extent	<input type="checkbox"/> Freedom of floor planning <input type="checkbox"/> Good floor impact sound attenuation <input type="checkbox"/> Reduction of frame quantity
	Dot	<input type="checkbox"/> Floor plan not adjustable <input type="checkbox"/> Disadvantage in floor impact sound <input type="checkbox"/> High CO <sub>2</sub> footprint	<input type="checkbox"/> Increase in slab thickness due to rise in stories <input type="checkbox"/> Increase in rebar quantity <input type="checkbox"/> Difficult to ensure constructability and quality	<input type="checkbox"/> Disadvantageous in terms of ceiling height

As Fig.2 shows, Green Column is a composite PC structure that links reinforced concrete columns of 3 stories with steel frame member. Columns are linked by sleeve or coupler. In terms of linkage by sleeve, rebar strands exposed on the top of slab are inserted into the sleeve of upper column and non-shrink mortar is infiltrated into the sleeve at high pressure and cured. As for a linkage by coupler, rebar strands of upper column are joined with coupler fixed in the lower column via steel plate on the top. It again divides into Column Pre-installation type and Column Post-installation type.

**Table 3.** Green Beam Configuration

	Profile	Shape
Green Beam		



**Fig. 2.** Green Column Configuration

When Green Column is linked with Green Beam, upper rebar penetrates into Green Column and links with RC Frame and lower rebar links with Steel Frame with bolts or by welding. Therefore, using Green Beam in combination with Green Column can ensure structural integrity, improve constructability and reduce construction schedule. In addition, Green Frame can keep ceiling height at the same level as bearing wall structure to address the issue of ceiling height issue typical in Rahmen structure. Table 4 summarizes the features of Green Frame.

**Table 4.** Features of Green Frame

	Features
Green Beam	<input type="checkbox"/> Less CO <sub>2</sub> footprint by decreasing steel quantity by 10% or more from steel structure <input type="checkbox"/> Environment-friendliness as RC serves as fire-resistant covering <input type="checkbox"/> Slab and beam integration reduces ceiling height above ground and soil excavation underground <input type="checkbox"/> Applicable to SS, RC or SRC structures
	<input type="checkbox"/> Reduce construction schedule by building 3 stories in a single cut <input type="checkbox"/> Use of Sleeve or Coupler linkage ensures constructability

### 2.2.3 Room for Further Improvement in Green Frame

In spite of all its advantages ensuring longer life of apartment buildings, Green Frame still has room for further improvement. Green Beam lays reverse-T beam along its entire length, depending on the conditions present at the end where maximum moment occurs. Such layout is not optimum in terms of load bearing

mechanism, resulting in unnecessary T beam consumption.

In addition, upper rebar strands of Green Beam penetrate into steel beam at column linkage. The hole in the steel frame at column linkage to admit the upper rebar strands must be about 5mm wider than rebar diameter in consideration of the rib in deformed rebar. If the hole is not wide enough, rebar might be jammed, hampering installation. Therefore, the trouble of using penetration inducing tool may be required. Table 5 summarizes such room for further improvement.

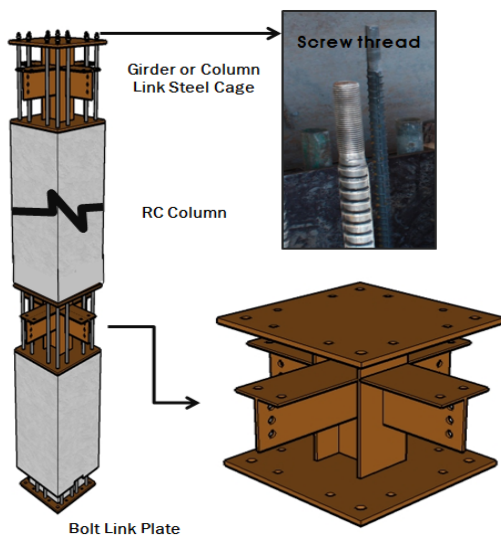
**Table 5.** Room for Improvement in Green Frame

	Room for Improvement
Economic viability	<input type="checkbox"/> Steel frame layout not optimum for load-bearing mechanism
Constructability	<input type="checkbox"/> Difficulties with linking column and beam <input type="checkbox"/> Difficulties with fabrication and installation and beam rebar penetrates column
Environment-friendliness	<input type="checkbox"/> Increase in CO <sub>2</sub> footprint from overuse of steel beam

### 3. IMPROVED COMPOSITE FRAME

#### 3.1 Configuration & Features of Improved Composite Frame

Composite Frame improved in consideration of the freedom of floor planning, long-span, low ceiling height, excellent constructability and economic viability consists of column, steel linkage and beam. Improved Composite Frame Column is as illustrated in Fig.3.



**Fig. 3.** Improved Composite Frame Column

Column is 3 stories and 1 cut, reducing construction schedule. It consists of steel linkages at the top, the bottom and in the center and RC. As for the linkage, steel linkage is buried lengthwise at the same height as the girder. As it is installed in the same manner as generic steel frame structure, it can be linked fast, reducing construction schedule. Screw threads are machined onto main rebar strands of lower column to provide linkage between columns. Rebar is bent at bolt hole location and section beam is superimposed to deliver moment from the end of column, which can ensure structural integrity and ease of construction with bolt-only approach. In addition, girder and slab are integrated to reduce ceiling height and Steel Frame Reinforced Concrete Structure is used as a girder to support longer span. All these features ensure freedom of floor planning by reducing the number of internal columns.

Improved Composite Frame Beam is as shown in Table 6. End of girder is where columns are linked and maintained by T beam. Linkage is designed to be steel frame linkage. To ensure optimization to load-bearing mechanism, T beam is laid in the negative moment section of beam end and T beam is removed in the center of beam while lower rebar and concrete suppresses unnecessary quantity increase for positive moment.

**Table 6.** Improved Composite Frame Beam

	Profile	Shape
Composite Frame Beam		

**Table 7.** Features of Improved Composite Frame

Classification	Features
Economic viability	<input type="checkbox"/> Reduce construction schedule <input type="checkbox"/> Increase floor area ratio by reducing ceiling height
Constructability	<input type="checkbox"/> Ease of construction by using the same construction method (bolt linkage) as generic steel frame structure
Environment-friendliness	<input type="checkbox"/> CO <sub>2</sub> footprint reduction by minimizing the use of steel frame
Misc.	<input type="checkbox"/> Reduce use of welding <input type="checkbox"/> Pre-fabrication enhances quality control

As linkage is installed in the same manner as steel frame linkage, ease of construction is ensured and



quality is improved via reduction in welded linkage and standardization. As is the case with Green Frame, it can secure additional sellable space by reducing ceiling height and, in case of Composite Frame, it is entitled to a variety of government incentives in terms of floor area ratio and number of stories in accordance with applicable laws providing for such incentives for remodeling-friendly Rahmen structure apartment buildings. Lastly, structural construction quantity is optimized to reduce material quantity along with CO<sub>2</sub> and environmental pollutants. Table 7 summarizes such features.

### 3.2 Improved Composite Frame Construction Sequence

Fig.4 shows the construction sequence of improved composite frame members.

- ① Lay the rebar strands of lower column through the base plate of the steel linkage, with screw threads on the rebar strands to enable bolt linkage with upper column.
- ② Lift and place girder at location with lifting equipment such as Tower Crane and link the bracket using CT beam and the other beam buried in the girder with high tensile-bolt.
- ③ Link lower rebar strands of the girder by welding, Coupler, lap joint and link upper rebar strands with the same method.
- ④ Install linkage formwork and slab and cast in concrete.
- ⑤ Lift and place upper column at location with lifting equipment such as Tower Crane Tower Crane and install it.

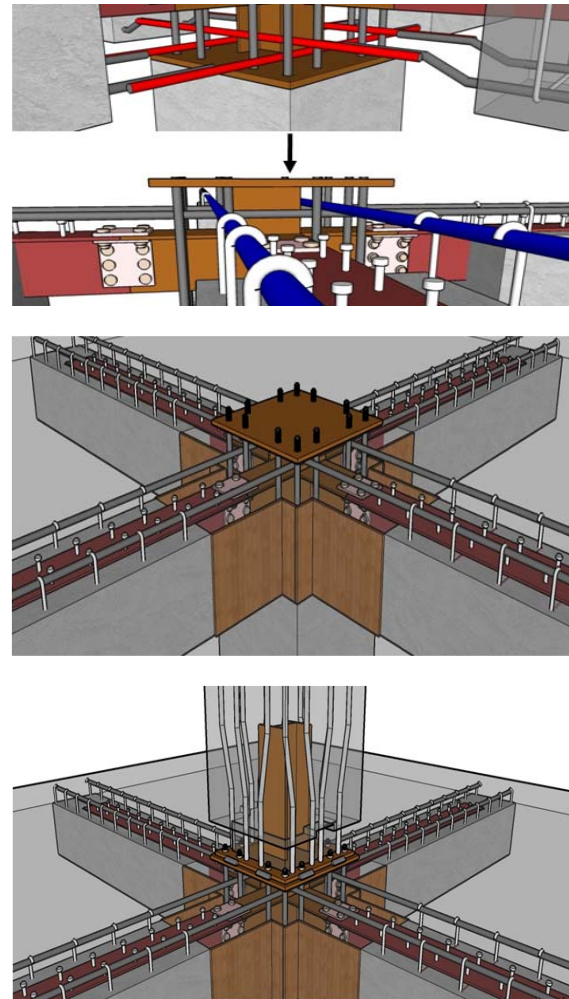
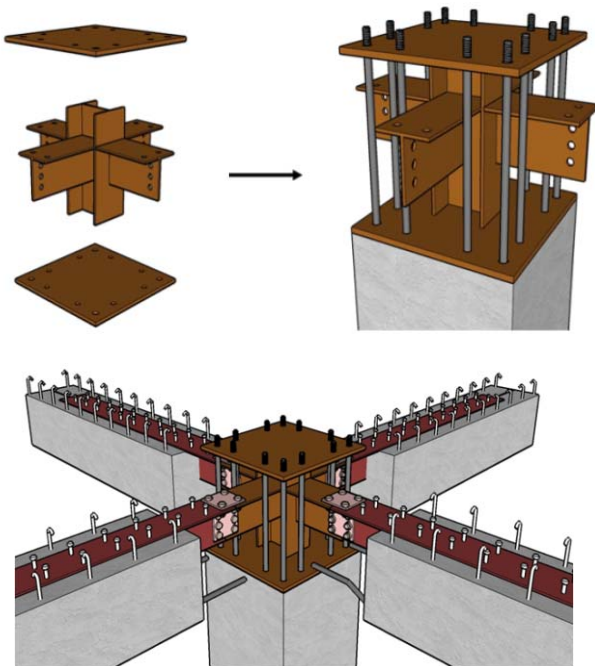


Fig. 4. Improved composite frame construction sequence

## 4. CONCLUSIONS

This research aims to propose improvement solution for Green Frame that is a Rahmen Composite Frame utilizing the advantages of steel frame and reinforced concrete to lengthen the life of apartment buildings. Bearing wall structure and conventional flat plate structure do not fulfill the basic requirements of long-life apartment building such as adjustability of floor plan or ease of facility replacement. Green Frame which is the best-known Rahmen composite structure in Korea involves excessive use of members due to inefficient layout and size of steel beam and reduction of constructability due to difficulties with end linkage installation. Improved composite frame concept intended as a solution provides the following features:

- ① Utilizes the advantages of steel frame and reinforced concrete to support long-span structure and freedom of floor planning.
- ② Integrate girder and slab to reduce ceiling height and increase sellable space.
- ③ Improve ease of construction and reduce construction schedule with the same construction method (bolt linkage) as generic steel frame

structure.

- ④ Optimize the use of steel frame member to load-bearing mechanism, reducing CO<sub>2</sub> emission
- ⑤ Pre-fabrication ensures quality and economic viability.

In addition, technical features of improved Composite Frame are as follows:

- ① Optimization of reinforcing member layout in conformity to load flow ensures structural integrity, reduces self structural weight and secures excellent earthquake resistance.
- ② Column and girder linkage uses the same method as steel frame linkage and column uses only bolt mounting, ensuring excellent constructability.
- ③ Environment-friendly by reducing CO<sub>2</sub> footprint and industrial waste from minimization of material in use.

Accordingly, the improved composite frame concept presented herein will extend the service life of apartment buildings in Korea, with additional benefits of reduction of construction schedule and gain in productivity. More studies on further improvement will need to follow this study subsequently.

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