

# Mechanical Analysis of Adding External Elevators by The Different Placement to The Existing Buildings

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**Abstract:** Elevators are vital for accessibility in buildings, where they serve as lifelines for individuals with disabilities and contribute to the overall enhancement of modern living standards. Despite their significance, the absence of elevator infrastructure in older buildings presents formidable challenges, limiting accessibility and hindering the full utilization of these structures. Furthermore, in today's environmentally conscious society, green retrofitting initiatives are paramount for reducing energy consumption and emissions, particularly in the realm of residential buildings. Retrofitting existing structures with elevators has become increasingly imperative, given the continued use of numerous buildings over the past decades. As a response to these challenges, external elevator integration has emerged as a critical research area, addressing both accessibility issues and the imperative for green retrofitting in existing buildings. External elevator integration is a critical research area addressing accessibility and green retrofitting, and seismic design measures are necessary to mitigate earthquake risks. This research specifically focuses on assessing the seismic effects of the external elevator into the specific existing RC structure at Kyungpook National University using RSA (Response Spectrum Analysis). The findings of this research are anticipated to serve as a valuable reference for external elevator design in existing buildings and provide assistance in the reconstruction and retrofitting of aging structures, ultimately contributing to the safety and resilience of urban infrastructure.

**Keywords:** External Elevator, Existing Building, RC structure, RSA (Response Spectrum Analysis).

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## 1. Introduction

In contemporary society, the pivotal role of green retrofitting initiatives in mitigating global energy consumption and greenhouse gas emissions within the context of residential buildings. Over decades, numerous research endeavors have delved into this subject, exemplified by *Yongtao Tan et al.* [1] on rejuvenating aged residential structures, and *Sui Pheng Low et al.* [2] into enhancing the sustainability of buildings in Singapore. Across these studies, a recurring theme emerges the critical role of external elevators in retrofitting existing buildings to align with modern environmental and societal standards.

In the urban landscape of Hong Kong, researchers emphasize the efficacy of external elevators as a viable renovation strategy for aging residential complexes. Similarly, in Singapore, studies underscore the importance of accommodating the needs of diverse demographics, particularly focusing on the elderly, young children, and individuals with disabilities. This emphasis leads to initiatives like the LUP (Lift Upgrading Programme), which aims to revamp pre-1990s buildings lacking comprehensive elevator access. By doing so, these retrofitting efforts not only promote environmental sustainability but also enhance social inclusivity by providing more efficient and accessible living spaces for all residents.

Particularly notable within mainland China, the installation of elevators in existing residential structures has transitioned from a mere initiative to a necessity, spurred by the rapid progression of an aging society [3-5]. As demographic shifts continue to unfold, the imperative to enhance accessibility and convenience within residential spaces has become undeniable. This trend reflects a broader societal recognition of the need to adapt urban infrastructure to accommodate the

evolving needs of an aging population, signifying a significant shift in urban development priorities towards fostering inclusivity and improving the quality of life for all residents.

Despite significant research into the implementation of external elevators in existing buildings, there is a notable gap in addressing seismic concerns. Earthquakes present a longstanding societal challenge, particularly in regions prone to seismic activity, where structural integrity is paramount for mitigating potential damage and ensuring public safety [6-10]. Therefore, it is imperative to evaluate the structural implications of installing external elevators, considering their potential vulnerability to seismic forces. This necessitates a comprehensive analysis of how such elevators interact with existing building structures during seismic events, identifying potential weak points and devising strategies to reinforce them effectively, while minimizing losses and safeguarding communities against the devastating impacts of earthquakes.

The primary objective of this study is to conduct an in-depth examination of the implications associated with the installation of an external elevator within the context of a specific architectural setting: a typical 4-story reinforced concrete educational building situated at Kyungpook National University in Daegu, Republic of Korea. The methodology adopted for this analysis revolves around RSA (Response Spectrum Analysis), a robust analytical tool widely employed in seismic engineering to assess structural response under dynamic loading conditions [11-17]. By applying RSA techniques to SAP 2000, the study seeks to elucidate how the integration of an external elevator may influence the overall structural behavior and integrity of the existing RC frame.

Through an RSA analysis, this study seeks to elucidate the multifaceted impacts of installing external elevators on

existing building structures, particularly focusing on variations in elevator placement. By examining structural implications and seismic responses across different locations of external elevator installations, the research aims to provide comprehensive insights into how such modifications influence the overall performance and resilience of the building. The anticipated findings hold significant relevance for both academic researchers and industry practitioners involved in the broader discourse surrounding the integration of external elevators into existing building infrastructure. This study also aims to serve as a valuable reference for informing future retrofitting projects and urban development initiatives, ultimately contributing to the advancement of sustainable and accessible built environments.

## 2. Description of the Analysis Design

### 2.1. Structure description

The research focuses on analyzing a 1970s educational building (128°60'85"E, 35°88'76"N), specifically examining its reinforced concrete frame structure located within the Department of Architectural Engineering at Kyungpook National University in Daegu, South Korea.

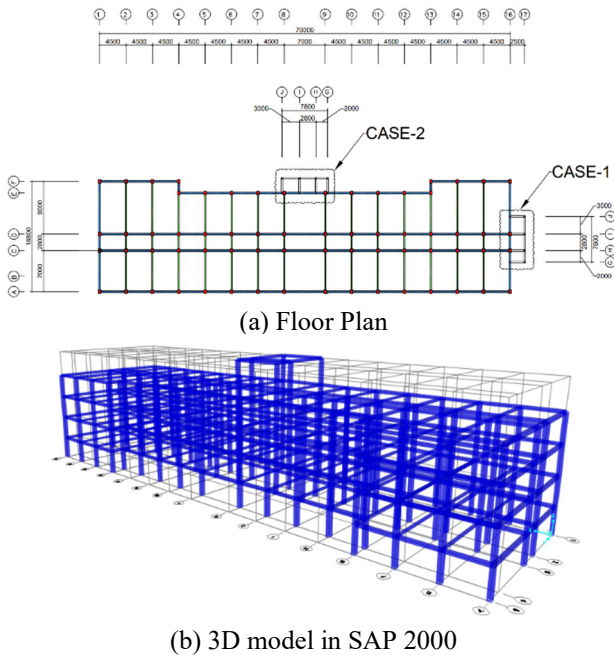


Figure 1. Design of the specific RC frame structure

The investigation focuses on an RC frame structure depicted in Figure 1, covering an area of 1316m<sup>2</sup>. The structure is 70m long, 18.8m wide, and 17.8m high, with four stories, each 3.5m tall. Notably, there is a stair room on the roof, reaching a height of 3.8m, as shown in Figure 1.

Two variations of external elevator structures for the specific RC frame structure shown in Figure 1 are positioned along the middle of the x and y directions of the entire structure, as indicated by the cloud mark. Each external elevator structure measures 7.8m in length and 2.5m in width, including an elevator lobby (2.5m × 4.8m) and an elevator well (2.5m × 3m).

The structure's design utilizes color codes: red for columns, blue for girders, green for beams, and white for the external elevator structure. Girders run horizontally, including sections along the corridor, while beams integrate vertically into the

RC frame structure. The external elevator structure is positioned along the x and y directions of the RC frame structure, as depicted in Figure 1.

### 2.2. Section designs and materials description

Figure 2 illustrates the design details of the column, girder, and beam sections in the specific RC frame structure. The column measures 450mm × 600mm with ten D19 (or Φ19) longitudinal rebars and D10 (or Φ10) hoop rebars at 300mm intervals. The girder has a cross-sectional area of 135,000mm<sup>2</sup>, featuring eight D16 (or Φ16) longitudinal rebars and D10 (or Φ10) hoop rebars. The beam measures 200mm in width and 300mm in height, with four D16 (or Φ16) longitudinal rebars and D10 (or Φ10) hoop rebars.

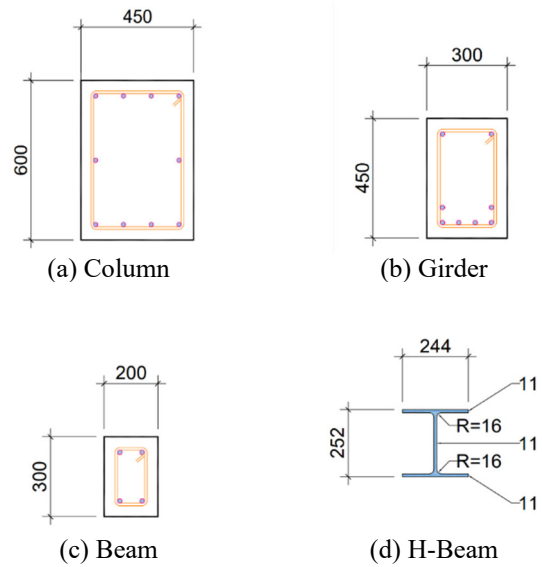


Figure 2. Design of the cross-section

The design of the H beam for the external elevator structure adheres to the specifications outlined in KS D 3502, ensuring compliance with dimensions, mass, and permissible variations for hot-rolled steel sections. The H beam measures 244mm in width and 252mm in height, with a flange and web each measuring 11mm. The cross-sectional area of the H beam is calculated to be 8206mm<sup>2</sup>.

The specific RC frame structure in this research adheres to KS F 4009:2021 standards for ready-mixed concrete. As per the Republic of Korea's Ministry of Education guidelines for 1980s educational buildings, concrete's compressive strength is specified as  $F_{ck}=15.12\text{MPa}$ , with an anticipated strength of  $F_{ek}=18.14\text{MPa}$ . Steel bars for concrete reinforcement follow KS D 3504:2021 guidelines, with a specified strength of  $F_y=240\text{MPa}$ , and an anticipated stress of  $F_{ey}=300\text{MPa}$ .

Table 1. Design of column, girder and beam

Column	LR	10-D19	SoS	0.45
	HR	D10@300	SoM	0.70
Girder	LR	8-D16	SoS	0.45
	HR	D10@300	SoM	0.35
Beam	LR	4-D16	SoS	0.45
	HR	D10@300	SoM	0.35

*LR: Longitudinal Rebar / HR: Hoop Rebar*  
*SoS: Stiffness of Shear / SoM: Stiffness of Moment*

The shear and moment stiffness values for column, girder, and beam sections, derived from design principles of typical

1980s school buildings and KISTEC 2021's Table 5.3.1, are specified. Referring to Table 1, The column section exhibits shear stiffness of 0.45 and moment stiffness of 0.7, prioritizing resistance to bending. Conversely, the girder and beam section shows shear stiffness of 0.45 and moment stiffness of 0.35, highlighting responsiveness to shearing forces. These values are essential for understanding structural behavior, consistent with historical design practices for 1980s school buildings.

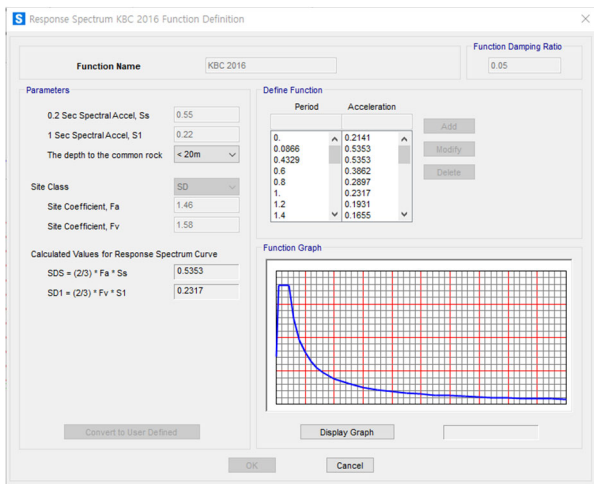
**Table 2.** Design of H-Beam

<b>H Beam</b>	Weight per unit volume	77 kN/m <sup>3</sup>
	Mass per unit volume	7.85 kN/m <sup>3</sup>
	Modulus of elasticity (E)	206000 MPa
	Poisson (U)	0.3
	Coefficient of Thermal expansion (A)	1.200E-05
	Shear Modulus (G)	79230.77
	Minimum Yield Stress (F <sub>y</sub> )	235 MPa
	Minimum Tensile Stress (F <sub>u</sub> )	370 MPa
	Expected Yield Stress (F <sub>ey</sub> )	260 MPa
	Expected Tensile Stress (F <sub>eu</sub> )	410 MPa

This research utilizes H-beams in the external elevator structure, inspired by similar projects in mainland China and adhering to Chinese standard GB/T 700-2006 for carbon structural steels. The H-beams meet standards outlined in KS D 3503:2018 for rolled steels for general structure and align with design guidelines from SS235, with specified minimum yield and tensile strengths detailed in Table 2.

**2.3. Approach of RSA**

The research employs the response spectrum methodology based on KISTEC 2021 to analyze the target structure, utilizing the response spectrum derived from KBC 2016. The earthquake hazard map of the Republic of Korea, also from KBC 2016, guides the definition of the response spectrum for site class SD, determined by the location of the target building at Kyungpook National University's Department of Architectural Engineering in Daegu Metropolitan City. The corresponding response spectrum for the SD classification is illustrated in Figure 3.



**Figure 3.** Response spectrum (KBC 2016)

Calculating spectral accelerations is vital for seismic analysis, with KBC 2016 offering an equation as a framework. This equation considers seismic characteristics for structural

assessment, providing 1-sec and 0.2-sec spectral accelerations as equations (1) and (2) show below. These parameters reveal structural response to seismic forces over different time intervals, quantifying ground motion magnitude for comprehensive seismic analysis.

$$S_{D1} = S \times F_v \times \frac{2}{3} \tag{1}$$

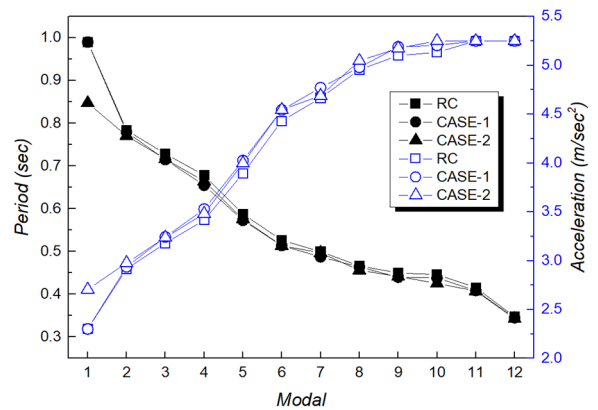
$$S_{DS} = S \times 2.5 \times F_a \times \frac{2}{3} \tag{2}$$

Where *S* represents the effective ground acceleration value for a 2400-year return period earthquake is obtained from Table 0306.3.1 of KBC 2016. Factors *F<sub>a</sub>* and *F<sub>v</sub>*, sourced from Table 0306.3.3 and Table 0306.3.4 respectively, contribute to calculating *S<sub>D1</sub>* for the 1-sec spectral acceleration and *S<sub>DS</sub>* for the 0.2-sec spectral acceleration. Computed values for the 1-sec and 0.2-sec spectral accelerations are 0.22g and 0.55g respectively, visually depicted on the right side of Figure 3.

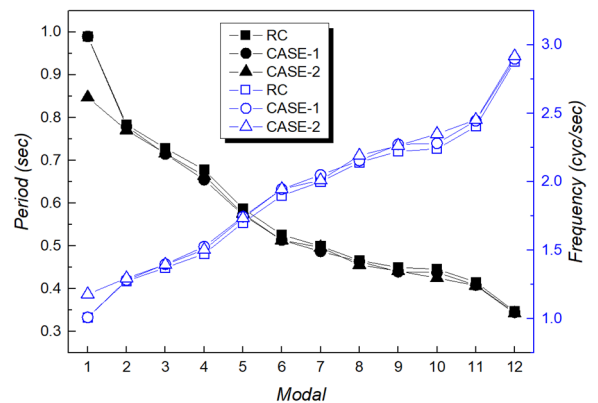
**3. Discussions**

**3.1. Modal analysis**

Modal analysis results for a specific RC frame structure, with and without the external elevator structure (CASE-1, CASE-2, and RC), are displayed in Figure 4. Figure (a) illustrates the correlation between various modals, periods, and accelerations, while Figure (b) depicts the relationship between different modals, periods, and frequencies.



(a) Period & Acceleration



(b) Period & Frequency

**Figure 4.** Result of Modal analysis

Within Figure 4, figures (a) and (b) provide comprehensive insights into the period analysis conducted for a specific RC frame structure under varying conditions, with and without an external elevator. The analytical results elucidate crucial differences in structural behavior and response, shedding light on the impact of the external elevator on the structure's dynamic characteristics.

Analyzing the results, it becomes apparent that the RC frame structure devoid of an external elevator exhibits longer periods compared to its counterpart with the elevator. This discrepancy underscores the significant reduction in the structural period attributable to the presence of the elevator. Particularly striking is the contrast between the results of RC and CASE-1, where the difference in periods is pronounced, indicating the substantial influence of the external elevator on structural dynamics. However, when comparing the results of RC and CASE-2, the difference in periods is minimal. This suggests that the location of the external elevator, specifically whether it aligns with the longer axis (x-direction) or shorter axis (y-direction) of the existing building, impacts its influence on structural periods. Aligning the elevator with the shorter axis appears to have a more positive influence on period analysis, as indicated by the minimal difference in periods between RC and CASE-2.

In general, longer periods imply reduced sensitivity to higher frequency ground motions, potentially enhancing the structure's ability to withstand seismic events and increasing ductility capacity. However, longer periods may also exacerbate resonance effects, amplifying seismic response and causing damage. Therefore, aligning the external elevator with the shorter axis of existing RC buildings emerges as a favorable strategy, offering potential benefits in terms of structural performance and seismic resilience.

Figure (a) displays acceleration analysis results for a specific RC frame structure with (CASE-1, CASE-2) and without (RC) an external elevator. The analysis indicates that the RC frame structure without the elevator experiences lower acceleration than structures with the elevator, suggesting a significant increase in acceleration due to the elevator's addition. Particularly, comparing RC with CASE-2 highlights this acceleration increase. Additionally, comparing CASE-1 and CASE-2 shows that the location of the external elevator influences structural performance during seismic events. Faster acceleration implies faster velocity and longer displacement, contributing to structural damage. The finding of the acceleration emphasized that aligning the external elevator with the shorter axis (y-direction) of the existing building appears to positively influence the structure by lowering acceleration under seismic events, potentially enhancing seismic resistance.

The analysis, depicted in Figure (b), underscores the impact of an external elevator on the frequency characteristics of an RC frame structure. It is discerned that the absence of an external elevator leads to a discernibly lower frequency when compared to the scenario where an external elevator is present. This distinction is particularly pronounced when juxtaposing the results between the RC frame structure and CASE-2 configurations. Such a disparity strongly suggests that the inclusion of an external elevator brings about a notable enhancement in the structural frequency. However, when contrasting the outcomes between CASE-1 and CASE-2 configurations the placement of the external elevator within the existing building exerts a significant influence on the

structural frequency. Specifically, aligning the external elevator with the longer axis (x-direction) of the building manifests in a higher frequency response. Conversely, aligning it with the shorter axis (y-direction) yields a reduction in frequency. In general, Higher frequencies are predisposed to align more closely with the natural frequencies of structures, thereby amplifying the potential for resonance and subsequent structural damage. Consequently, the alignment of the external elevator along the shorter axis of the building not only lowers the structural frequency but also holds promise for bolstering the seismic resilience of the structure under seismic events.

### 3.2. Base Shear and Base Moment

The assessment of roof displacement and base shear force is fundamental in evaluating the dynamic behavior and seismic performance of structures. Within the framework of the response spectrum analysis, these analyses offer critical indicators of structural integrity and response under seismic loading conditions. In this research endeavor, comprehensive scrutiny is applied to all monitored points located on the foundation and roof of the specified RC frame structure. Figure 5 serves as a visual representation of the correlation between roof displacement and foundation base shear forces in both the x and y directions.

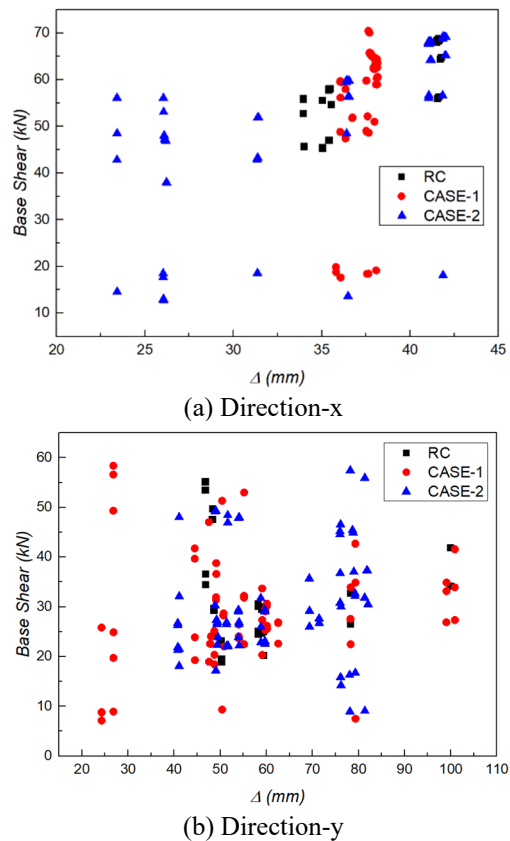


Figure 5. Results of displacement and base shear

Figure (a) compares how the external elevator affects displacements in the x-direction for monitored points in RC, CASE-1, and CASE-2. The findings show varied effects: maximum displacement of CASE-1 slightly increases compared to RC and CASE-2. However, an analysis of average displacement in Table 3 reveals that the external elevator can decrease overall structure displacement. Specifically, CASE-1 (57.0966mm) and CASE-2

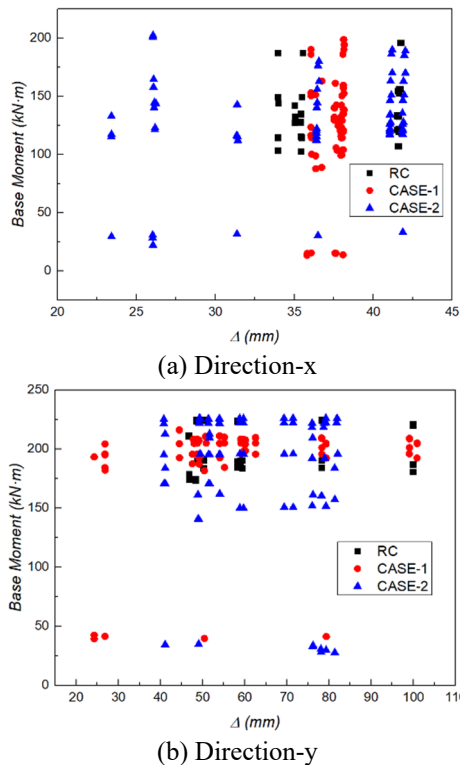
(54.4749mm) demonstrate shorter average displacements than RC (60.0865mm), and the shorter displacement appears when the elevator aligns with the longer axis of the existing RC structure. Nevertheless, since the x-direction represents the robust axis of the specific existing RC structure, the benefits of CASE-2 may not significantly influence the structure overall.

Figure (b) compares the impact of the external elevator structure on displacements in the y-direction for monitored points in RC, CASE-1, and CASE-2. The results show varied effects: while displacement decreases significantly with the external elevator on the shorter axis (CASE-1), maximum displacement remains relatively unchanged. Conversely, maximum displacement significantly decreases compared to RC and CASE-2. Although many points exhibit shorter displacements in CASE-2, the potential for structural collapse is higher than in CASE-1 (28.9548mm) due to the larger average displacement (30.3978mm), as indicated in Table 3. Overall, aligning the external elevator with the shorter axis of the specific existing RC structure, as in CASE-1, appears safer based on comprehensive displacement analysis in both directions.

**Table 3.** Average displacement and average base shear

Types	Displacement	Base Shear	Base Moment
	mm	kN	kN·m
RC (Dir.-x)	60.0865	38.1530	137.3194
CASE-1 (Dir.-x)	57.0966	37.4972	125.0947
CASE-2 (Dir.-x)	54.4749	35.4205	126.5844
RC (Dir.-y)	31.1122	62.0688	202.6580
CASE-1 (Dir.-y)	28.9548	57.6702	188.8243
CASE-2 (Dir.-y)	30.3978	61.9880	179.5748

*Dir.: Direction*



**Figure 6.** Results of displacement and base moment

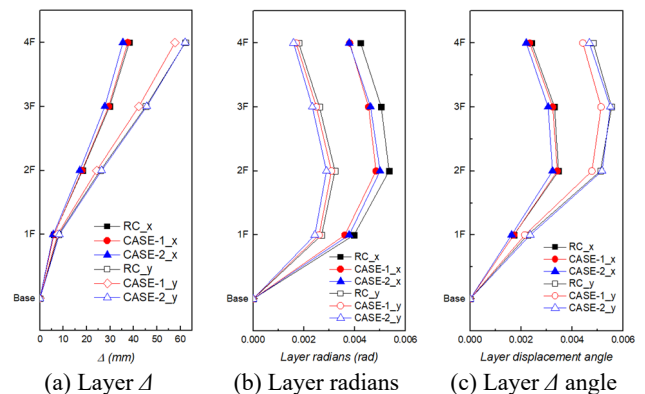
Illustrate in Figure 5, the analysis of maximum base shear results, depicted in Figure (a) for direction-x and Figure (b) for direction-y, reveals that CASE-1 exhibits larger maximum base shear values compared to RC and CASE-2. This suggests a potential risk of structural collapse when the external elevator is aligned with the shorter axis of the building due to increased base shear. However, an examination of average base shear values in Table 3 indicates a significant decrease in base shear with the external elevator in both directions. Despite the larger maximum base shear, the smaller average base shear of 57.6702kN in CASE-1 highlights it as a safer option, particularly considering the weaker axis of the RC structure in direction y.

The evaluation of base moment and displacement encompasses all monitored points on both the foundation and roof of the particular RC structure. Figure 6 illustrates the relationship between roof displacement and foundation base moment in both the x and y directions.

The analysis of maximum base moment results, illustrated in Figure (a) for direction-x and Figure (b) for direction-y, highlights that CASE-2 demonstrates larger maximum base moment values compared to RC and CASE-1, indicating a potential risk of structural collapse when the external elevator aligns with the longer axis of the building. However, an examination of average base moment values in Table 3 indicates a significant decrease in base moment with the external elevator in both directions, suggesting that the external elevator can enhance the seismic resistance of the existing RC structure. Specifically, CASE-1 exhibits smaller average base moment values in direction x, enhancing structural performance in the robust axis, while CASE-2 demonstrates improved performance in the weak axis of the RC structure with smaller average base moment values in direction y.

### 3.3. Layer displacement, layer radians and layer displacement angle

This research emphasizes the importance of evaluating the seismic performance of the RC frame structure by analyzing average displacement and radians on each floor. The analytical findings are presented in Figure 7. Figures (a) and (b) serve as a visual representation of the analytical results, providing a clear depiction of the average displacement and radians across different floors of the specific existing RC frame structure.



**Figure 7.** Layer displacement, radians, displacement angle

The findings, depicted in Figure (a), indicate an increase in average displacement with the rising number of stories in the specific RC frame structure. Comparative analysis between

RC frame structures with and without external elevator structures shows that, in direction x, the structure lacking the external elevator exhibits slightly greater displacement. Furthermore, CASE-2 demonstrates shorter layer displacement than CASE-1, suggesting that aligning the external elevator with the longer axis enhances structural performance in direction x. Conversely, in direction y, no difference is observed between RC and CASE-2, while CASE-1 exhibits significantly shorter layer displacement, indicating that aligning the external elevator with the shorter axis enhances structural performance in the structural weak axis of direction y.

The analysis extends to examining joint radians on various stories, with a focus on Figure (b). In the x-direction, the specific RC frame structure without the external elevator exhibits slightly larger radians compared to its counterpart with the external elevator. Additionally, CASE-2 displays smaller layer radians than CASE-1, indicating that aligning the external elevator along the longer axis enhances structural performance in direction-x. In the y-direction, larger radians are consistently observed in the RC frame structure without the external elevator. However, CASE-1 shows smaller layer radians than CASE-2, suggesting that aligning the external elevator with the shorter axis enhances structural performance on the weak axis of the existing RC structure in the y direction.

The layer displacement angle, crucial for structural performance analysis during seismic events, has been extensively studied in prior research. This study collects data from all monitored points per story in the specific RC structure. Figure (c) visually presents the average layer displacement angle, providing insights into the structural response in both the x and y directions.

The analysis investigates how the presence of an external elevator affects the average layer displacement angle in a specific RC frame structure. Comparisons are made between scenarios with and without the elevator, revealing larger displacement angles in the absence of the elevator, both in the x and y directions. Figure (c) visually represents these trends, highlighting the external elevator's significant impact in reducing displacement angles. Comparing CASE-1 and CASE-2 reveals variations in layer displacement angles, emphasizing the impact of the different locations of external elevators on structural performance. Smaller layer displacement angles in CASE-2 highlight the efficacy of aligning the longer axis of the structure in enhancing structural performance in the x direction. Conversely, smaller layer displacement angles in CASE-1 underscore the benefits of aligning the shorter axis of the specific existing RC structure in the y direction, as the weak axis of the structure. Interestingly, no significant differences are observed between RC and CASE-2 in the y direction, suggesting limited benefits when aligning the elevator with the longer axis of the structure.

## 4. Conclusion

The research focuses on seismic analysis using RSA (Response Spectrum Analysis) on an educational RC frame structure at Kyungpook National University. It aims to evaluate the seismic impact of adding an external elevator to the existing structure, offering insights into structural dynamics and seismic resilience in retrofitting projects.

Analyzing modal characteristics reveals the positive impact of integrating an external elevator with an existing RC frame. It leads to shorter periods, higher acceleration, and

increased frequency, collectively enhancing seismic performance. However, comparing configurations, aligning the elevator with the shorter axis (CASE-1) enhances structural performance more than with the longer axis (CASE-2).

This research also analyzes base shear and base moment to assess the seismic-resistant performance improvement of an RC frame structure with an external elevator. Two configurations (CASE-1, CASE-2) of the elevator significantly reduce structural displacement in both x and y directions, indicating improved seismic performance. Additionally, shear forces and moments on the foundation decrease with both configurations, suggesting the positive impact of the structure. The RSA in this research highlights the reinforcement effect of the RC frame structure by external elevator. Comparatively, CASE-1 shows a more positive impact on seismic resistance than CASE-2, emphasizing the importance of external elevator location.

The research findings also highlight the pivotal role of the external elevator structure in reducing layer displacement, radians, and displacement angle, particularly in both the x and y directions. Decreased layer displacement is crucial for minimizing structural damage during seismic events. Additionally, the external elevator positively impacts layer radians, enhancing building stability by reducing angular deflection. A smaller layer displacement angle, facilitated by the elevator, signifies a controlled response to seismic forces, enhancing structural resilience. Comparatively, positioning the external elevator on the shorter axis of the structure yields greater benefits for seismic safety.

The research findings underscore the advantages of integrating an external elevator into the existing RC structure and highlight the varied effects of its different placements. Through the analysis of CASE-1 and CASE-2, the study underscores the critical importance of the understanding of the existing buildings. Specifically, positioning the external elevator on the shorter axis (weak axis) of the building emerges as a strategy to enhance seismic resilience.

## Acknowledgment

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