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A COMPARATIVE ANALYSIS OF STRUCTURAL SYSTEMS USED IN HIGH-RISE BUILDINGS

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ABSTRACT

Efficient structural systems must be designed in high-rise buildings to ensure adequacy in strength, stiffness, stability, economy, and resistance to both gravitational and lateral loads. The current study has the objective of comparatively analysing different structural systems in high-rise buildings, focusing particularly on the moment resisting frame, shear wall, outrigger, tube, and diagrid structural systems. The research utilized a descriptive cross-sectional design, and a total of 150 professionals were chosen purposively. The primary data were collected through the use of a structured questionnaire, while the analysis was done using frequencies and percentages in Microsoft Excel. According to the results obtained, the most commonly stated structural system was the shear wall system (24.0%), followed by the diagrid structural system (22.0%). Regarding lateral load resistance, the diagrid structural system emerged as the best performer (86.7%), followed by the outrigger system (80.0%) and tube system (76.7%). The shear wall system was identified as the most economical (78.0%), and also, the one with the highest rating regarding faster construction (70.0%), whereas the moment resisting frame system had the highest rating in regard to construction ease (76.0%). The material efficiency was also found to be the highest in the diagrid system (88.0%). Overall, the study indicated that diagrid and outrigger systems offered better lateral resistance and material efficiency, while shear wall systems provided a favourable balance of economy and construction efficiency. The findings highlight the importance of considering structural performance, cost, material utilisation, and constructability when selecting structural systems for high-rise buildings.

Keywords: *High-Rise Buildings; Structural Systems; Lateral Load Resistance; Shear Wall; Diagrid System; Structural Efficiency.*

1. INTRODUCTION

High-rise buildings have emerged as an integral part of modern urban planning in response to growing populations, urbanization, lack of space, and rising need for both living and non-residential purposes. With increased height, the structure becomes complicated because the building should be designed in such a way that it can withstand gravity forces, wind forces, seismic forces, and other kinds of environmental loads. In addition to strength and stability of a structure, a high-rise building should also have stiffness so as to manage lateral deflection, drift between stories, and vibrations. Thus, choosing the right structural system for high-rises has become one of the most crucial parts of its design process.

A number of structural systems have been designed for the special needs of tall structures, which include moment resisting frames, shear walls, outrigger systems, tube systems and diagrid systems. Moment resisting frames are flexible and have a relatively easy construction method, whereas shear wall systems give considerable resistance to lateral loads. The outrigger systems add to the stiffness of tall structures by connecting the core of the building with the columns outside, while the tube systems take advantage of the outer structure of the building for the efficient resistance to lateral and gravitational loads. Diagrid systems are becoming increasingly popular due to their high lateral stiffness and material efficiency, achieved through the use of diagonally placed structural members. However, the performance of each system varies according to building height, structural configuration, loading conditions, construction technology, material availability, and economic considerations.

A comparison of the above-mentioned structural systems is crucial in identifying the strengths and weaknesses of each of them in relation to high-rise construction. Aspects like structural stability against lateral loads, economic efficiency, fast construction, use of materials, and simplicity of construction are of paramount importance in selecting an appropriate structural system for a particular building project. This study is concerned with the comparative analysis of the structural systems that are commonly applied in the high-rise construction sector. The main objective of this study is to identify the strengths and weaknesses of various structural systems through a systematic comparison of them. The study is intended to provide a systematic understanding of the strengths and limitations of different structural systems and to support more effective decision-making in the planning and design of high-rise buildings.

2. LITERATURE REVIEW

Walsh, Saleh, and Far (2018) assessed various structural systems employed in slim tower construction, especially considering the structural performance and effectiveness of such systems for tall and slim structures. The researchers explored the impact of different structural systems on the structural performance of slim towers under difficult structural situations. They emphasized the significance of choosing the right structural system in order to have appropriate stiffness and stability. It was concluded that the choice of structural systems is a vital factor in controlling the performance of slender high-rise buildings.

Singh et al. (2024) performed analysis of the performance of high-rise reinforced concrete structures when subjected to dynamic loads through various structural systems. In the paper, the behaviour of reinforced concrete structures when subjected to dynamic loads was examined and the effects of structural system on their performance were studied. According to the authors, there is variation in structural behaviour and resistance of different structural systems when subjected to dynamic loads. The study highlighted that choice of suitable structural system is crucial for the performance of reinforced concrete structures under dynamic loads.

Ilgın (2023) Analyzed new developments related to the architecture and structural design of tall timber residential structures. The paper analyzed the growing use of timber as a material for building tall residential structures and reviewed the progress made in structural design and engineering. The author pointed out the possible advantages associated with the use of timber structures, such as low self-weight of the structure, efficiency, and environmental benefits. It became clear from the review that due to the progress in engineered timber and structural design, more opportunities emerged for building tall timber structures, but proper structural systems were crucial nonetheless.

Tiwary (2022) performed an initial comparison study of the seismic behaviour of several types of outrigger systems in a 40-storey reinforced concrete structure. The research considered the effect of different outrigger systems on the seismic response of high-rise structures. The results revealed that the choice and placement of an outrigger system played an important role in the seismic performance of a building. It is evident from the study that the choice of an outrigger system has a positive impact on the behaviour of a building during earthquakes.

Szolomicki and Golasz-Szolomicka (2019) Reviewed technological developments and current trends in contemporary tall buildings. Technological developments that had led to the progress in construction of tall buildings were analyzed. It was stressed by the authors that new technologies helped increase structural effectiveness, safety, sustainability, and construction performance. Review also focused on the increasing significance of advanced structural systems and construction technologies due to the complicated requirements of modern high-rise buildings.

3. RESEARCH METHODOLOGY

The study employed descriptive cross-sectional research design with a sample size of 150 respondents purposely selected to examine five high-rise structural systems. The data were gathered using a questionnaire and analyzed using frequency and percentage in Microsoft Excel.

3.1 Research Design

The current research employed a descriptive cross-sectional research approach for comparative evaluation of various structural systems in tall buildings. The research examined five main structural systems such as moment-resisting frame, shear wall, outrigger, tube, and diagrid systems. This comparative assessment was done in terms of application, lateral load resistance, economy, erection speed, material efficiency, and ease of construction.

3.2 Study Population and Sample Size

The sample population comprised the professionals associated with the planning, designing, and construction of tall structures like civil engineers, structural engineers, architects, site engineers, and construction professionals. The sample size was 150 respondents for the research.

3.3 Sampling Technique

The method of purposive sampling was applied to choose participants who have knowledge and experience in constructing high-rise buildings. The selection of the respondents was made according to the criteria of their experience and desire to participate in the research.

3.4 Data Collection

Primary data were gathered via a structured questionnaire. The questionnaire evaluated the selected structural systems based on their use, resistance to lateral loads, economic viability, rate of construction, efficiency in material use, and constructability. Resistance to lateral loads was evaluated in terms of high, medium, and low performance while the others in terms of percentage responses.

3.5 Data Analysis

Analysis of the data collected was carried out using Microsoft Excel software along with the use of descriptive statistics. Calculations of frequencies and percentages were made in order to give an account of the answers given. A comparative percentage analysis was carried out to compare the five structural types.

4. RESULTS

Table 1 shows the distribution of 150 respondents based on the structural systems most commonly applied in high-rise buildings. The structural systems that were studied in this research included moment resisting frame, shear wall, outrigger, tube, and diagrid structural systems. Figure 1 shows a graphic presentation of the distribution of respondents under various structural systems.

Table 1: Distribution of Respondents According to the Most Commonly Used Structural System

Structural System	Frequency (n=150)	Percentage (%)
Moment-Resisting Frame System	30	20.0
Shear Wall System	36	24.0
Outrigger System	27	18.0
Tube System	24	16.0
Diagrid System	33	22.0
Total	**150**	**100.0**

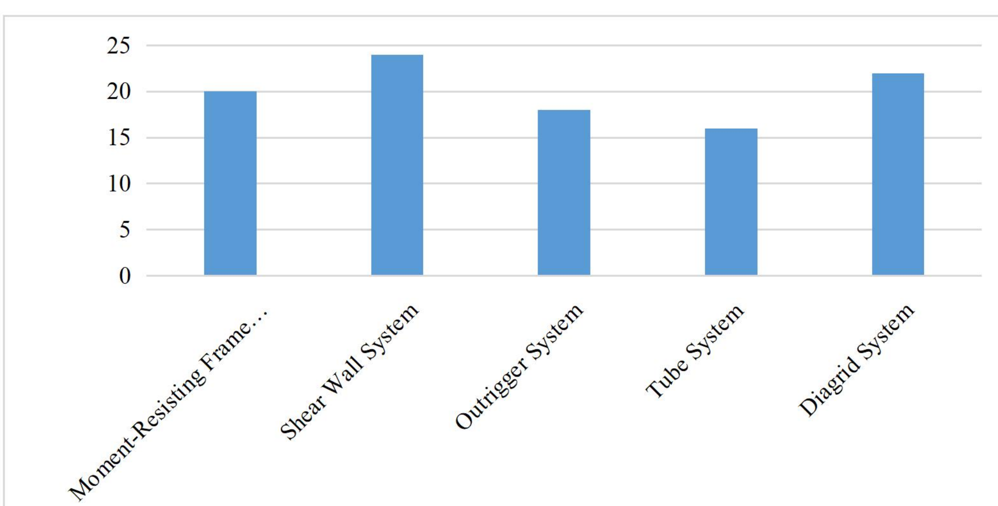

Figure 1: Graphical Representation of Distribution of Respondents According to the Most Commonly Used Structural System

The outcomes have revealed that the most frequent structural system is the shear wall system with the frequency rate of 24.0%, then there was the diagrid system with the frequency rate of 22.0% and moment resisting frame system with the frequency rate of 20.0%. Also, there was the outrigger system with the frequency rate of 18.0% and finally, the tube system with the frequency rate of 16.0%. It has been revealed that the shear wall and diagrid systems were relatively frequent in high rise building structures.

The comparison of the selected structures is provided in Table 2 and is based on the ability of the structures to resist lateral forces in the case of high-rise structures. The structures have been classified according to the level of their performances; high, moderate, and low-performance levels. Figure 2 shows the comparison graphically.

Table 2: Comparative Performance of Structural Systems in Terms of Lateral Load Resistance

Structural System	High Performance	Moderate Performance	Low Performance	Total (%)
Moment-Resisting Frame	50.0%	36.7%	13.3%	100
Shear Wall System	73.3%	22.7%	4.0%	100
Outrigger System	80.0%	17.3%	2.7%	100
Tube System	76.7%	19.3%	4.0%	100
Diagrid System	86.7%	11.3%	2.0%	100

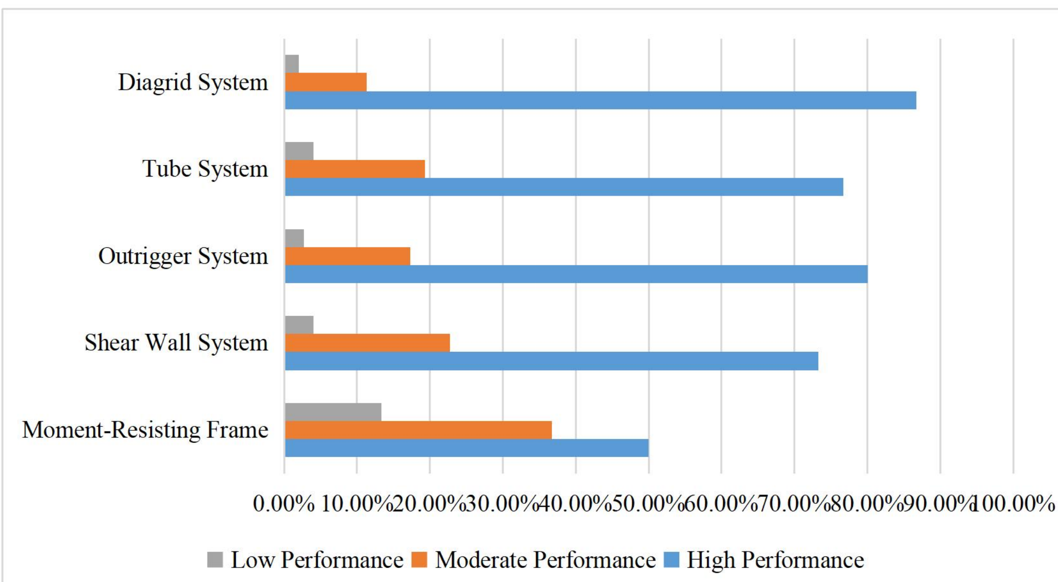

Figure 2: Graphical Representation of Comparative Performance of Structural Systems in Terms of Lateral Load Resistance

Findings from the study indicated that the diagrid system exhibited the best high-performance score of 86.7%, outrigger system scored 80.0%, while the tube system had a high-performance score of 76.7%. The shear wall system also performed impressively in that 73.3% was rated as having high performance. However, the moment-resisting frame exhibited the worst high-performance score of 50.0% and the highest low-performance score of 13.3%. Generally, the findings indicated that the diagrid and outrigger systems were better compared to other structural systems.

The comparison of the chosen structural systems according to important construction and economical parameters, namely economy, fast construction, efficiency of materials, and easy construction is illustrated in Table 3. Figure 3 demonstrates the graphic depiction of the comparative evaluation of the mentioned parameters for the different structural systems.

Table 3: Comparison of Structural Systems According to Major Construction and Economic Factors

Structural System	Economical (%)	Faster Construction (%)	Material Efficiency (%)	Ease of Construction (%)
Moment-Resisting Frame	72.0	68.0	64.0	76.0
Shear Wall System	78.0	70.0	72.0	68.0
Outrigger System	60.0	56.0	82.0	54.0
Tube System	64.0	62.0	80.0	58.0
Diagrid System	58.0	60.0	88.0	52.0

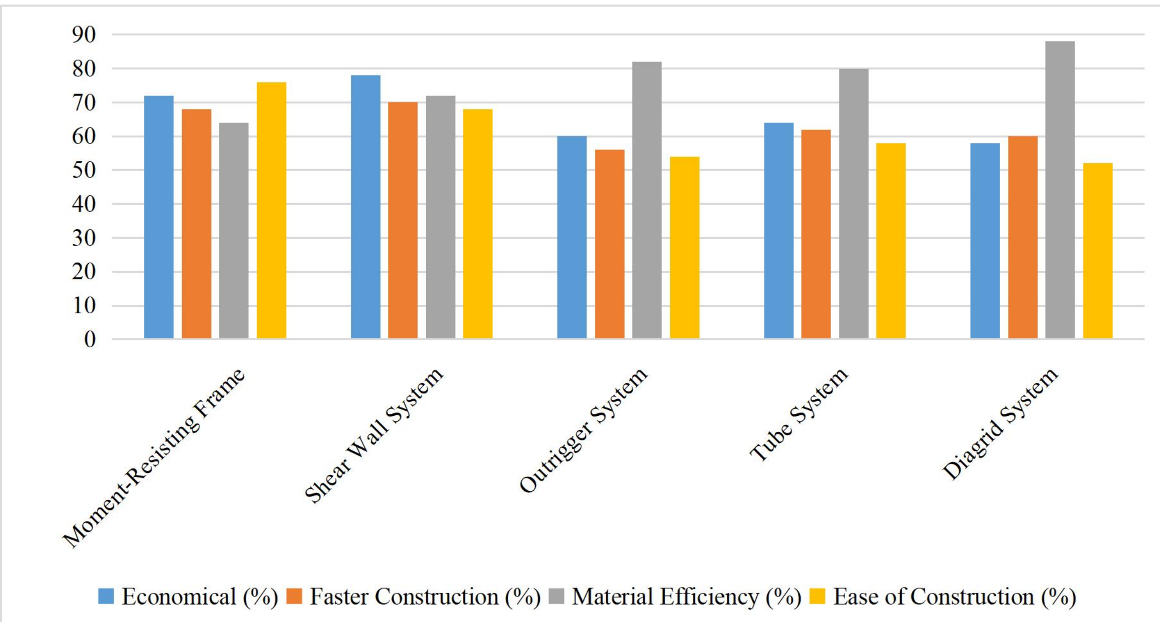

Figure 3: Graphical Representation of Comparison of Structural Systems According to Major Construction and Economic Factors

The results showed that the shear wall system is considered to be the most economical (78.0%), while the moment resisting frame system ranked highly on the easy of construction category (76.0%). Material efficiency was shown to be highest in diagrid system (88.0%), outrigger system (82.0%) and tube system (80.0%). Shear wall system was the highest rated system with regards to rapid construction, ranking at 70.0%. All in all, the findings suggested that the conventional systems have an upper hand in terms of economy and constructability while advanced systems have material efficiency.

5. DISCUSSION

It is observed from the current results that there were distinct variations regarding the effectiveness and implementation of structural systems in tall buildings. Amongst all the structures, shear wall system was found to be the most common one (24.0%), while the structure with the highest high-performance rating in terms of lateral load resistance included the diagrid system (86.7%), outrigger (80.0%), and tube (76.7%). It can thus be said that structural systems designed to enhance lateral stiffness and load distribution had higher effectiveness for high-rise buildings. Lower high-performance rating (50.0%) for moment-resisting frame system revealed that despite its wide application, it offers relatively lower lateral load resistance than other systems.

The results also revealed the conflict between the structural efficiency, economy, and constructability. The shear wall system is considered to be the most economical (78.0%) and quick-to-construct (70.0%) among the analyzed types of structure, while the moment-resisting frame possesses the best constructability (76.0%). In turn, the most efficient in terms of materials is the diagrid system (88.0%), outrigger system (82.0%), and tube system (80.0%), however, not the most economical and easy to construct. In general, the findings have proven the existence of a good balance of economy and constructability in the case of the use of shear wall structures, and diagrid and outrigger structures have proven to be more structurally and materially efficient, therefore depending on many factors such as height and cost of the building.

6. CONCLUSION

The current study found that proper choice of structural system is critical in providing safety, stability, economic efficiency, material efficiency and constructability in high-rise building structures. Out of the five structural systems studied, the shear wall system was the most widely used (24.0%) and most economical (78.0%), and rated highest in terms of faster construction (70.0%). In terms of lateral load performance and material efficiency, the diagrid system proved to be the most efficient (86.7% and 88.0%, respectively), and therefore suitable for structurally efficient high-rise buildings. Similarly, outrigger system proved to have excellent lateral load resistance (80.0%) and material efficiency (82.0%), and tube system showed relatively better lateral load performance (76.7%). On the other hand, moment resisting frame system had the best rating in terms of easier construction (76.0%), making it more practicable even with relatively low lateral load resistance. From the results, no structural system was found to outperform other structural systems across all evaluation parameters. This means that selection of structural system should be done taking into account building height, load conditions, lateral stability needs, cost of the project, material efficiency and construction time.

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