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Comparison of Tubular System and Conventional System Building

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Abstract

Contemporary skyscrapers employ robust structural systems that promote cylindrical and flexible designs with minimal damping. However, this flexibility leaves them vulnerable to wind-induced vibrations and earthquakes, leading to discomfort for occupants. Tube systems are vital in reducing these effects and improving tall building performance. But for 10 storied buildings, both the Tube system and Conventional system effectively resist lateral loads. In low-rise buildings, the conventional system is employed for countering lateral loads. However, within this system, lateral forces are countered through the use of columns and beams. Shear walls sometimes contribute to the transfer of lateral loads. The tubular system is a highly prevalent approach for countering lateral loads in tall buildings. The tubular system conveys lateral loads through closely spaced periphery columns interconnected by deep spandrel beams. This paper focuses on the analysis of a 10-story pre-existing building initially designed with a moment-resisting frame. The subsequent examination involves evaluating its behavior using a Tubular system approach. The overall column count is utilized during the redistribution of the moment-resisting frame, forming a framed tube system while maintaining an equivalent concrete area. The two systems are evaluated for their suitability by analyzing horizontal displacement, drift, and column forces using the standard software package ETABS 2018.

***Keywords**: tubular system; conventional system; horizontal displacement; drift; time period*

1. INTRODUCTION

Humans have always been fascinated by creating towering structures, and this interest grew during the industrial revolution. People began moving from rural areas to cities in search of work and employment prospects after the industrial revolution (Etemad and Tiwary,2019). Cities were more densely populated, increasing demand for the construction of high-rise buildings and introducing the idea of the vertical city (Rajmari and Guha, 2015). The term "tall building" lacks a precise definition, leading to variability across locations. It is not determined by a specific floor count or height but rather by whether structural dynamics, rather than statics, dominate the building's design (Etemad and Tiwary,2019). Structurally, a clearer definition of tall buildings can be established. A building is classified as tall when its design is predominantly influenced by lateral loads, signifying the governing force. In tall buildings, as height increases, lateral load impact grows. This underscores the necessity for a robust lateral load-resisting system to effectively transmit these forces to the foundation, ensuring safety. Various techniques are employed for tall building stability against lateral loads, including rigid frames, tubular, tube-in-tube, and bracing systems, often used in combination. These systems counter lateral forces, upholding high-rise structural integrity. They prioritize safeguarding the building and facilitating its resilience against lateral forces (Patel and Patel, 2016).

1.1Tube System

The tube system refers to a building that acts like a hollow tube (Nouri and Ashtari, 2013). In this system, the lateral forces caused by earthquakes and wind loads are carried through the perimeter columns. (Patel and Patel,2016). The tube system consists of closely spaced perimeter columns, with typical center-to-center distances of 1.5m, 3m, 4.5m, and 6m (Etemad and Tiwary,2019). These columns are connected by deep spandrel beams, which have a common depth ranging from 0.9m to 1.8m(Ahmed and Hussain, 2021). Additionally, a few interior columns are present to bear the vertical loads, and they are connected to the perimeter columns through long-span beams, preferably haunch beams. The spacing of the perimeter columns plays a vital role in the cost-effectiveness, strength, stiffness, and overall stability of the system. There are various types of tube systems. They are Framed Tube system, Tube in tube system, Bundled Tube system, Bracing Tube System, and Hybrid System. In this paper, only Framed Tube is considered. (Etemad and Tiwary,2019).The inaugural instance of a tube system building is the 43-story DeWitt-Chestnut apartment building in Chicago, which finished in 1963 (Nouri and Ashtari, 2013).

1.2 Conventional System

In conventional building systems, ensuring stability and safety involves a crucial consideration as the distribution of lateral and vertical loads. Here's a brief overview of this distribution process.

Vertical Load Distribution: Columns handle vertical loads by transferring the structure's weight to the foundation, strategically positioned for uniform distribution. Beams, on the other hand, horizontally support loads from floors, walls, and roofs, conveying them to columns. They ensure proper load-bearing capacity by dispersing vertical loads across columns and walls. Slabs, like concrete floors or roofs, further distribute vertical loads to beams and walls, functioning as horizontal diaphragms that evenly transfer loads to vertical elements. (Ahamed and Pratap, 2021)

Lateral load distribution in the conventional system involves strategically positioned shear walls to counter lateral forces. These vertical elements enhance stiffness and even force distribution, transferring loads to the foundation and averting excessive deformation. Core walls, particularly in tall buildings, centrally provide resistance against wind and seismic forces. It's worth noting that the distribution of loads varies according to building design, structural system, and engineering factors. Local building codes and regulations, like BNBC-2020, define load distribution requirements in conventional systems (Ahamed and Pratap, 2021).

2. MODELING AND ANALYSIS

This paper investigates the structural performance of different systems (Tubular system and Conventional system) in a 10-story reinforced concrete building. The building is located in Rajshahi and has a total height of 111 ft and a plan size of 152.168 X 51.5 ft. As per BNBC-2020, it is located in Zone I on S2-type Soil. Site Class is considered as SC depending on these criteria (Deep deposits of dense or medium dense sand, gravel, or stiff clay with thickness from several tens to many hundreds of meters).

Therefore, all models in this study have an equal height of 111 ft and are subjected to dynamic analysis. The gross column area of both systems is kept similar. The study includes both linear static and dynamic response spectrum analyses. The loading and seismic parameters are presented in Tables 1 and 2, respectively

Table 1. Loading Parameters

Live Load		**Dead Load**		**Wall Load**	
3 KN /m^2	62.66 lb/ft^2	3 KN /m^2	62.66 lb/ft^2	15 KN/m	1.028 kip/ft

Table 2. Seismic Parameters

Importance Factor (I)	**Zone Factor (Z)**	**Structure Type**	**Site Class, S**	**Response reduction Factor (R)**	**System Over Strength Factor, Ω**	**Design Categories**	**Deflection Amplification Factor, C_d**
1	0.12	SMRF	SC	8	3	B	5.5

Table 3. Wind Load Parameters

Exposure Type	**Building Location**	**Wind Speed, v**	**Building Type**	**Structure Type**	**Gust factor, G_f**		**Topographic Factor, K_{zt}**	**Directional factor, K_d**
					X Direction	**Y Direction**		
B	Rajshahi	110.2 mph	Standard Occupancy Structure	Flexible structure	1	0.97	1	0.85

2.1Conventional system

Modeling and analysis of the Conventional system (RUET Male Hall Building):

Considering RUET Male Hall Building as a standard comparative model and modeling it in ETABS-2018 in the same manner. All the properties of the RUET Hall building and the conventional system model are similar. Here this model has been compared to the tubular system. Thus, the plan and elevation of the building before and after the analyzed figures have been shown. The Slab Thickness of 7 in is considered

Table 4. Geometric Property of Conventional System

Beam Size (in)	Slab Thickness (in)	Total height (ft)	Story height (ft)	Length of the building (ft)	Width of the building (ft)	Compressive concrete, fc' (psi)	Yield Strength of steel, fy' (psi)
12X21	7	111	11	152.168	51.5	3000	60000

Table 5. Geometric Property of Column

Sr.no	Column Type	Column Size(in x in)
1	C1	15X35
2	C2	15X30
4	SW1	12X60

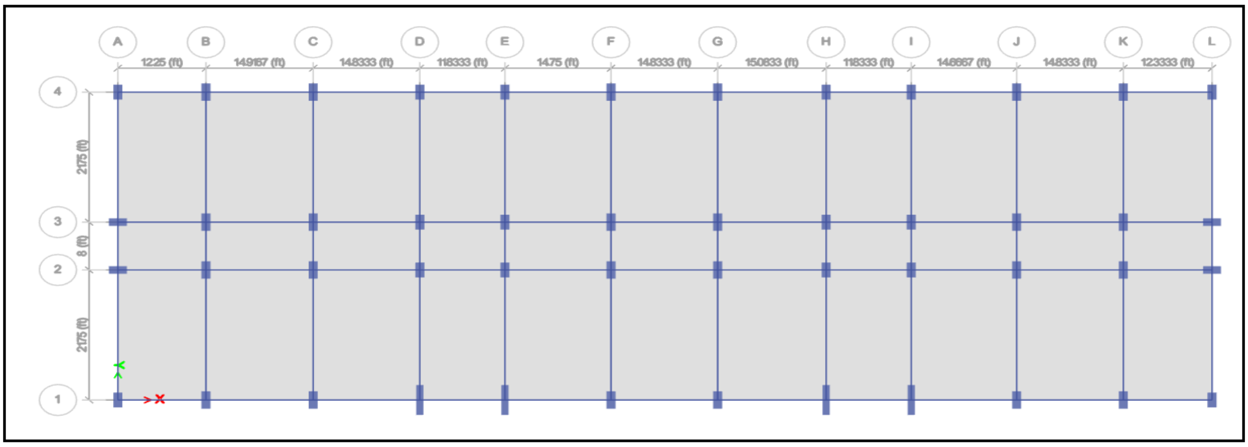

Figure 1: Plan view of the Conventional system

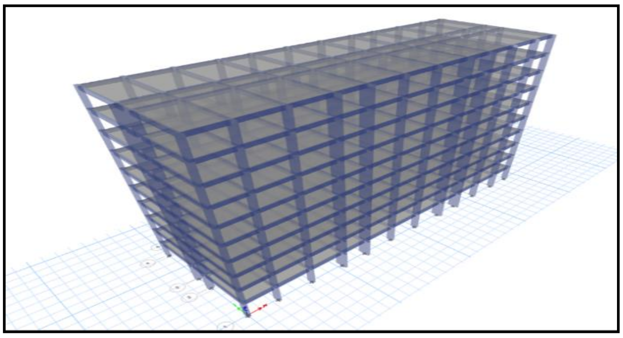

Figure 2.1:3D view of conventional system before analysis

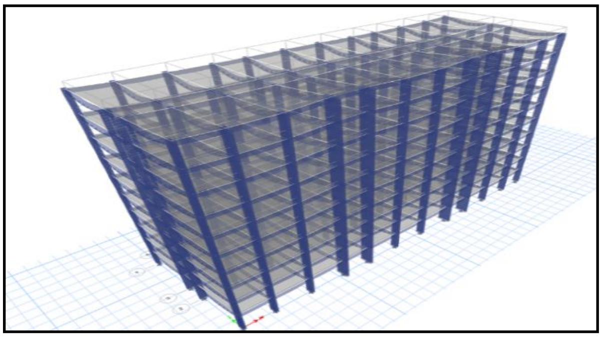

Figure 2.2:3D view of conventional system after analysis

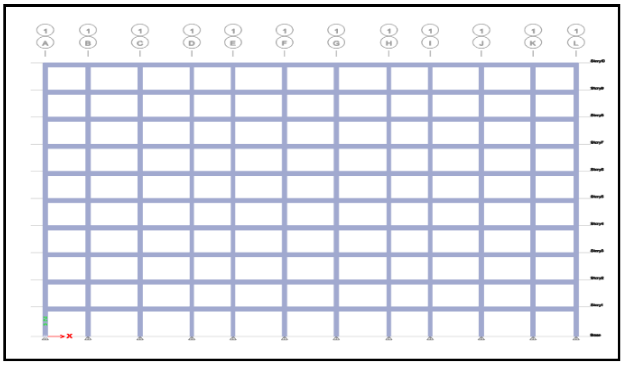

Figure 3.1: Elevation of Conventional system before analysis

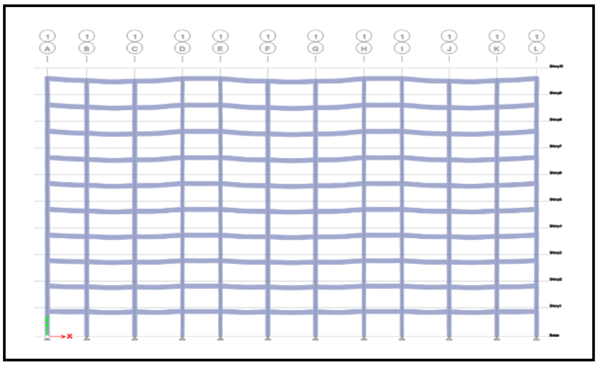

Figure 3.2: Deflected Shape of Conventional system

2.2Tube system

Modeling and analysis of Tube system with 7ft exterior column spacing

A 10-story building has been modeled in ETABS-2018, with perimeter columns (14 in X 14 in) spaced at 7ft on centers. Periphery columns are connected by a deep spandrel beam (12 in x36 in). Twenty interior columns (24 in X 27 in) are provided for the transfer of gravity load and they are connected to the perimeter column by a concrete girder. Slab thickness of 7 in.

Table 6. Geometric Property of Tube System

Column Size		**Beam Size (in)**	**Total height (ft)**	**Story height (ft)**	**Length of the building (ft)**	**Width of the building (ft)**	**Compressive concrete, fc' (psi)**	**Yield Strength of steel,fy (psi)**
Interior (in)	**Exterior (in)**							
24 X27	14 X14	12X36	111	11	152.1683	51.5	3000	60000

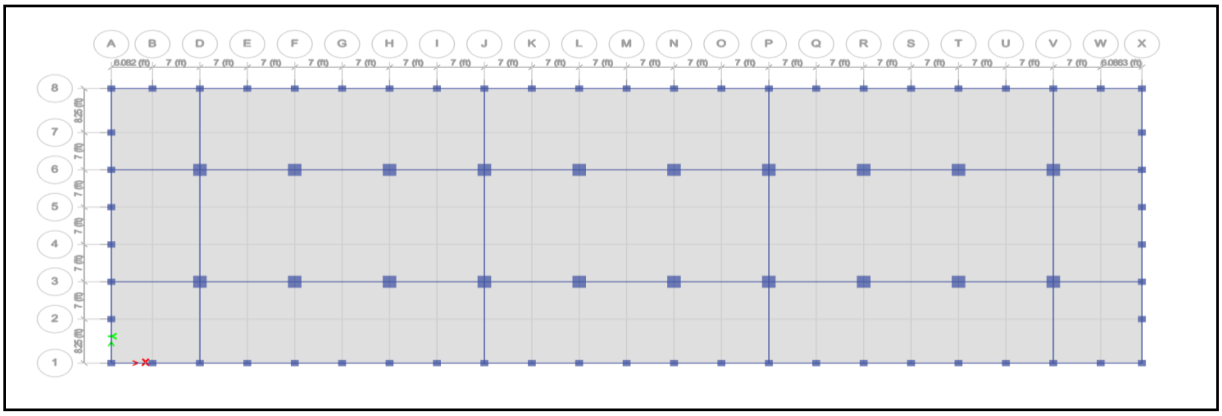

Figure 4: Plan view of Framed tube system

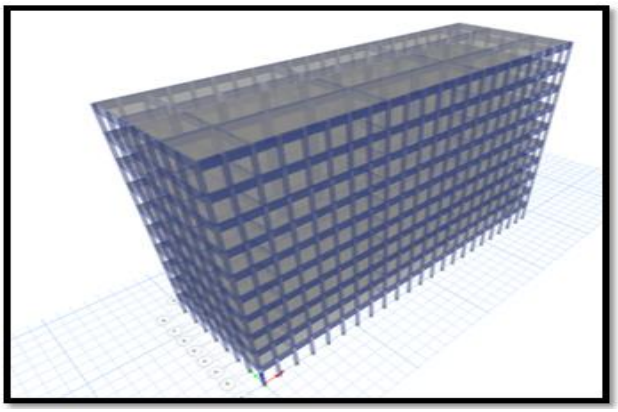

Fig.5.1:3D view of tube System Before Analysis

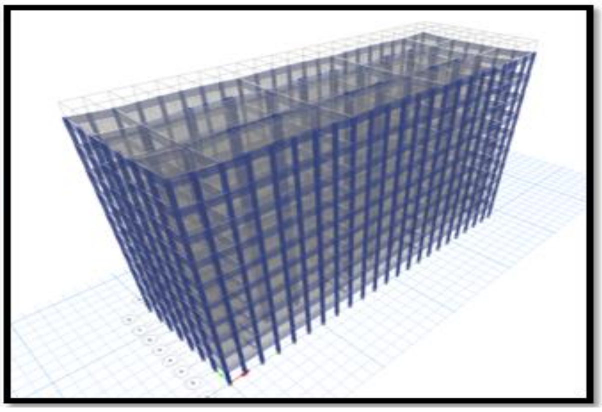

Fig.5.2:3D view Deflected Shape of tube System

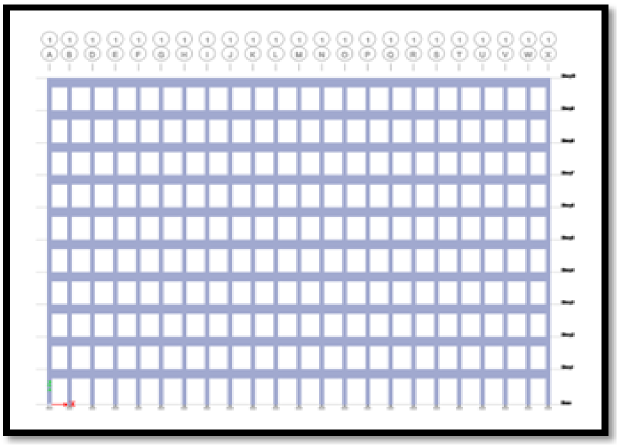

Fig.6.1: Elevation of tube System Before Analysis

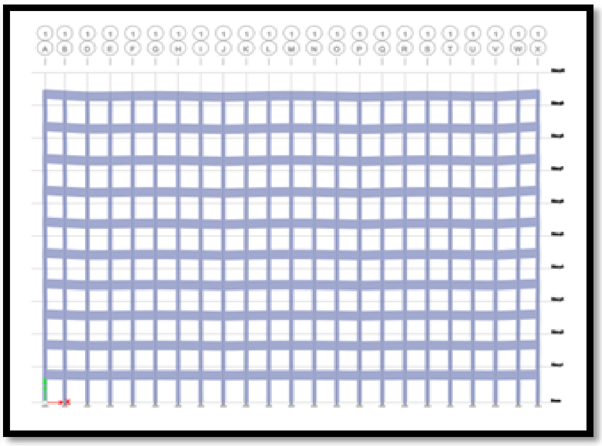

Fig.6.2: Deflected shape of tube System Analysis

3. RESULT AND DISCUSSION

All models have been analyzed by equivalent static and response spectrum methods. The response spectrum has been scaled up to more than 99% of the total static base shear. Maximum drift, lateral deflection, base shear, and time period considering specific load combinations of all models have been extracted and shown them in Tables7,8 respectively.

Table 7. Drift, Displacement, Base Shear of Tube System and Conventional System

Load combination	System	Maximum Drift		Maximum Displacement (in)		Base shear (kip)	
		X Direction	Y Direction	X Direction	Y Direction	Fx	Fy
WY-2020	Tube System	1.2E-05	0.00018	0.2269	0.36	-119.0	-336.4
	Conventional System	5.5E-05	0.00032	0.4	1.4038	119.0	-448.5
WX-2020	Tube System	1.3E-05	0.00020	0.2494	1.494	-130.8	-492.9
	Conventional System	6.1E-05	0.00035	0.439	1.542	-130.6	-492.9
EY-2020	Tube System	-------	0.00036	-------	1.4052	-------	-340.0
	Conventional System	3E-05	0.00054	-------	1.5163	-------	-379.4
EX-2020	Tube System	0.000103	-------	0.539	-------	-340.0	-------
	Conventional System	0.00028	3E-05	1.353	-------	-369.4	-------

WY-2020 means wind load at y direction of the structure and follows the wind properties from BNBC 2020 and WX-2020 means wind load at X direction according to BNBC 2020. Similarly, EX-2020 means earthquake load in the X direction and EY-2020 means earthquake load in the Y direction according to BNBC 2020.

Table No. 7 presents load combinations and their corresponding results for two different structural systems, the Tube System and the Conventional System in a building. The values provided include drift and displacement in both the X and Y directions, as well as base shear forces in the X and Y directions (Fx and Fy) measured in kip units.

For the WY-2020 load combination, Tube System, Maximum Drift in the X direction is 1.2E-05 and in the Y direction 0.00018, Max. Displacement in the X direction is 0.2269 inches and in the Y direction is 0.36 inches, Base shear in the X direction is 118.987 kip, and in the Y direction -336.377 kip. Similar explanations can be made for the WX-2020, EY-2020, and EX-2020 load combinations, where the values of drift, displacement, and base shear are provided for both the Tube System and the Conventional System. These values represent the building's response to different load scenarios in terms of lateral movement and forces experienced by the structure.

Table 8. Time Period of type of system buildings

System	Time Period (sec)	Frequency (cycle/sec)
Tube System	2.555	0.392
Conventional System	2.714	0.368

The data allows for a comparative analysis of the two structural systems under various load conditions, helping to assess their performance and suitability in terms of stability and resistance to lateral loads. In the tube system, the maximum drift is found to be 0.00036 whereas in the conventional system, the maximum drift is found 0.00054. In the tube system, the maximum displacement is found 1.494 in, and for the conventional system maximum displacement is found 1.5163 in. maximum base shear is -492.86 kip for tube systems and the maximum base shear is -492.855 kip for conventional systems. The time period is 2.555 sec for the tube system and 2.714 sec for the conventional system. In the conventional system column area is 24,480 in^2 and the column area for a tube system is considered 24.328 in^2.

In the above parameters, the framed tube system performed better result than the conventional system with a lesser concrete area.

4. CONCLUSIONS

The paper provides a summary of research progress concerning the efficiency of two systems through a comparative analysis of their structural performance.

- Despite multiple shear walls found in a conventional system, the tube system performed better in the above parameters (Drift, Displacement, and Time Period). At the top story of the building lateral deflection of the tube system is lesser than conventional system. So, from the point of view of the lateral deflection tube system is preferable.

- In the conventional system, the time period is 2.714 sec and in a tube system time period is 2.555 sec. Re-distribution of the column slightly increases the stiffness of the building resulting in a shorter time period in the tube system.

- Typically, a larger base shear for a building is regarded as unfavorable. A heightened base shear signifies more significant seismic forces affecting the structure, potentially resulting in heightened stress and potential damage. The aim is to design a building with a lower base shear to enhance resistance against seismic forces and bolster overall structural integrity. When solely considering the base shear of the two systems, the results are nearly identical.

- Considering all the parameters, the framed tube system is preferable then the conventional system for ten-storied buildings.

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