Study of different tubular systems on the lateral load resistance

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ABSTRACT

Worldwide, high rise construction is recent trend in the building development. Steel has many advantages which includes flexible framing system, assembling, less weight to height ratio, high availability and it doesn't harm environment. That's the reason steel has been mostly used material in the high rise buildings. Previously gravity load was considered as an important factor in the construction design. With the demand of high rise buildings now seismic force and lateral force is also gaining more attention. In High rise buildings tubular frames are most commonly used structural system. Among this framed and bundled are most famous tubular frame systems. Precise analysis is required for its design. Tubular systems are used in exterior as well as interior, mainly for resisting seismic force and lateral force. In this research Framed tube system and bundled tube system is analysed for lateral load resistance using ETABS software. For analysis purpose 8 stories steel building was considered. Different factors like lateral displacement at top floor, base shear, storey drift and steel weight were analysed for framed and bundled tubular system.

Keywords: Framed tube structure, Bundled tube structure, Story drift and displacement, Base shear, Seismic force, Lateral load resistance

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1. Introduction

As the population is increasing and demand of jobs in big cities are also increasing, this causes the high demand of land in such cities. Because of this reason, high rise constructions are mostly preferred. With enhancement in the technologies and engineering, high rise building is improving its reliability. For this purpose researches are still doing research in the construction and fabrication techniques. Few organizations and nations use high rise constructions as a pride and their publicity. With the integration of enhancement in the structural engineering and advancement in the civil material allows to develop a high rise constructions.

The major research in the high rise construction is on lateral resistance and seismic force, which will improve the construction quality with respect to lateral force. Resisting element for lateral force plays an important role against protecting the building against any lateral forces like wind force or seismic force. Figure 1 shows the general overview of lateral force at different floor in high rise building. In Multi Storey building, the lateral force at the top Storey is highest and it is least at the basement. Hence lateral force is not usually considered for small Storey buildings, but for high rise structures, lateral and seismic force study is very much crucial.

1.1. Tube system

For lateral Resistance in many high rise construction, tube system is advised in the structural engineering. It provides a high resistance against lateral and seismic forces. Tube works similar to hollow cylinder which is placed at 90° to the horizontal. In 1960 Fazlur Khan developed the tube system and from that time, it is widely been used in the high rise constructions [1].

This tube are made up of either steel, concrete or both of them. In the simple way, columns which are placed together, are tied using deep spandrel beams through moment connections.

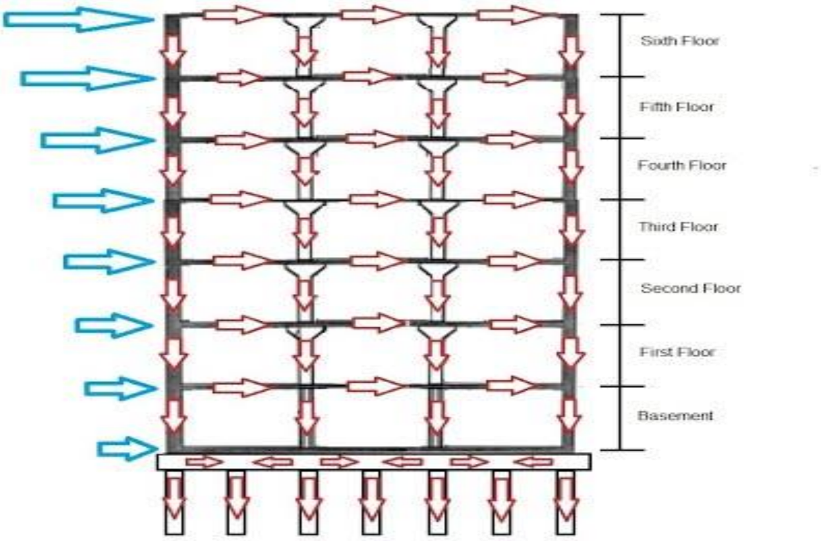

Figure 1. Overview of lateral force

Assembled columns creates a rigid frame which creates a dense and stronger structure at exterior. The result of this structures is high lateral load resistance and hence very few internal columns are required and it can be located at the centre of the construction. Hence to resist the gravity load interior can be framed easily. Using the same structure khan build first building in Chicago, which is known as DeWitt-Chestnut [2].

1.1.1. Framed tube system

Tube system provides a high strength at the exterior of the building which provides a better scope to the interior for resisting gravity force. This is not only the advantage of tube system, but it also free up lot of interior space hence provide a large scope to the interior architecture as well. Braced tube system and Framed tube system are most famous structural system in the lateral load resisting system. Few researches defines the tube system as a hollow cylinder, placed at 90° to the horizontal [3]. Beedls also defines the tube system as a hollow cylinder. According to this research the exterior of the building should be rigid as much possible [4]. And even though structure is very much similar to the hollow tube, but the behaviour is complex [4]. It is possible to get the shear lag effect, which could provide a modification in axial distribution force in column.

1.1.2. Bundle tube system

In this type of system, unlike framed tube many tubes are clubbed together to act as a resistance to the lateral and seismic force. This system target high heights and more floor area. The shear lag in flanges get reduced heavily because of the presence of internal web [3]. The causes the even distribution of stress across different columns, which provides higher stiffness as compared to framed tube system. By this columns in this structure can be placed further away which creates more internal space. Fazlur Khan First used this system in the Chicago for the construction of Sears Tower. In that construction, few tube was discontinued as a benefit of bundled form [2]. This minimises the plan of construction at various stages up the heights.

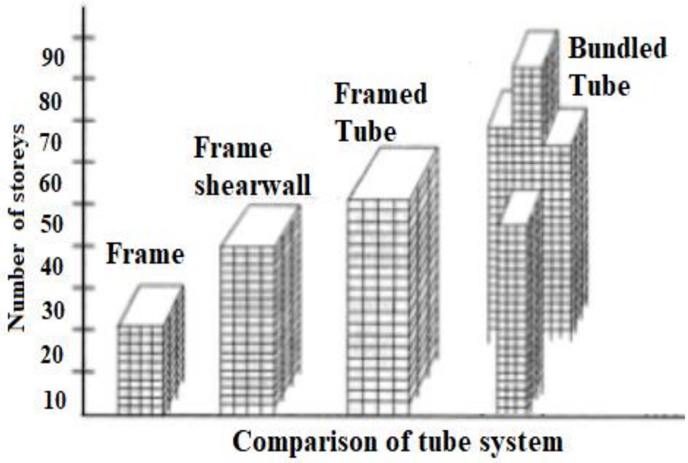

Figure 2. Various tube system

Different type of Bundled system are as follow:

a) Framed Bundle tube system : In this system, the frame tube connects with multiple tubes, hence it works as a bundle frame tube. sears tower is one of the example of the Framed Bundle tube system.
b) Braced Bundled tube system : This system is very much similar to the frame tube system, but in this single brace connects with multiple tubes, hence it works as a bundle of brace tube. Figure 2 illustrates the structure of Brace bundle tube
c) Brace-Frame Bundled tube system : This system is nothing but a combination of both Framed Bundle tube and Braced Bundled tube system. In this brace tubes and framed tube connect internally and forms a bundled tube.

With increase in demand of high rise buildings, it is important to study the lateral force resisting techniques and enhancement in this. For the betterment of structures it is necessary to select the appropriate tubular system for the construction of high rise buildings considering the factors like Storey drift, Storey displacement and Base shear.

High rise buildings faces the concerns of lateral and seismic force. Ignorance towards this forces can result in the failure of the construction in earthquake like situations. The main goal of this research is to minimize the above problems.

The goal of this research is:
1. To analyse different parameter like Maximum Base shear, Steel Weight, Maximum Story Displacement, Maximum Storey Drift.
2. Generate Analytic model by ETAB software.
3. Compare Analytical Result Value.

1.2. Related work

Frame tube structure has started receiving high attention, with the number of high rise construction increasing. Safety of such high rise construction was always a primary issue for structural engineering. Lateral forces and seismic forces are one of the safety measure in such a constructions.
Ray P.S. Han proposed a first frame tubed structure in his research "Analysis of framed tube structures of arbitrary sections" In this study, analysis of frame tube structure with consistent panel property and at arbitrary section was Considered [5]. finite strip method (FSM) was used in this research. Result was built in a small sized matrix which makes analysis with redundant frame tube structure, simpler and convenient. For the analysis purpose, triangle and rectangle cross section were considered. finite element method was used to obtain the results. For experimental analysis 30 storey building with frame tube structure was used. Result shows the improvement in the stiffness [5].
Memaria and Motlaghb proposed a "Seismic evaluation of an existing reinforced concrete framed tube building based on inelastic dynamic analysis". In this research columns and beams are placed with little distance and then finite strip method was used for analysis [6]. In this research 32 floor structure with RC frame tube was used for study with respect to time domain and deformation force analysis. Capacity, plastic deformation and Drain 2D programs were studied and reviewed. As result of this research, shear lag was explained and the deformation with respect to time is demonstrated [6].
Shin in his research discussed the lag in shear of tubular system in the building structure [7]. Archana and Reshmi proposed a research "Comparative Study on Tube in Tube Structures and Tubed Mega Frames" explained the importance of each tubular system with respect to Story drift and displacement, Base shear, Seismic force [8]. Hamid proposed an optimised design for tubular system. The goal of this research was to study the different parameters which affects the tube and the shear stress, additionally this study proposed an optimal design for tube system [3]. Parametric study was conducted for analysis of different factors like depth of columns and beam, moment frame internal wall. 40 Floor building was considered for the study of parameters. story drifts, and shear lag behaviour was also analysed. It was observed that shear lag and action tube had maximum effect [9]. Nimmy used SAP version 2000 to investigate the result of tube based construction. Lateral force resistance improvement is the main goal of this research [10]. For analysis of lateral load resistance, 3 different type of model developed in SAP version 2000. Continuum technique was used for analysis of stiffness factor. Spectrum response, static equivalence and time domain study was carried out and 3 different models analysis was used for seismic force resistance [1].

2. Matrial and methods

2.1. Structure dimensions and material used

In this research, a 8 floor reinforced concrete frame was used . It is prepared with 5 bays in longitudinal x direction and 3 bay in transverse Y direction. In this geometry the plan dimensions where kept at 25 meter * 15 meter. For the analysis purpose 3.3 meter floor to floor height is configured. The width of bay is configured at 5 meter along y and x directions. Thickness is kept as 300 micro-meter. To avoid the lateral force's torsional effect, structures are kept in symmetrical manner in orthogonal direction. Column was kept in the square fashion with 500mm * 500 size and throughput same to the height of the structure is used for the column. Floor thickness is kept as 150mm and beam size is maintained as 300mm * 450mm. Fixed based is considered. The land is located with the medium typed soil. IS 1893(Part-1):2002 standards is considered. 5 response reduction factor is used for moment resistance. 5% damping in structure is considered. Importance measure is kept 1.

For parametric analysis, symmetric building was considered. A steel based construction with 8 floors were modelled and analysed using ETABS software for 2 different structures, which are frame tube and frame bundle tube. Seismic force, lateral load and wind load, dead and live load were considered for analysis and design [11][12]. Static spectrum analysis and response spectrum study for lateral earthquake load was carried out. For the experimental purpose the extreme situation was considered and construction location was set in V zone. , Story drift and displacement, Base shear, Seismic force, Lateral load resistance are some of the parameters which were used for comparison purpose.

2.2. Configuration

Configuration of the construction is as follow:

1. Fe-250 is used for all steel members in the construction and M-25 grade concrete was used for slabs.
2. IS : 875 -1978 standard was consider while analysing the distribution and wind in ETABS software.
3. IS : 1893 -2002 standard was used for analysis of Earthquake.
4. IS : 800 -2007 standard was used for designing general steel frame.
5. H/500 was limit Top floor displacement
6. 0.004 h was limit inter floor drift.

Table 1. Building configuration

Plan's area	80 meter × 80 meter
Floor height	3 meter
Dead loads	1.5 kN/m2
Floor	All typical
Live loads	2.5 kN/m2
Slab's thickness	120 millimetre
Earthquake specific zone	V
Geometric Location	Basra, Iraq
Importance Factor	1.5 Basic
Speed of wind	50 meter/second
Response Reduction	5
k_1 Factor	1.06
Analysis	Static & Response Spectrum
k_2 Factor	1
Damping of Modal	2%

2.3. Bundle tube structural system

For the parametric analysis, one structure was designed with bundle tube system with 8 floors. The steel structure was used to model the construction in ETABS version 2005 software. RCC was considered for the Slabs while other structure element for example column and beam was considered with steel material. The plan area was 80 meter X 80 meter. Plan area of each tube was maintained at 40 meter X 40 meter. Length of exterior beam was 5 meter and interior beam was 10 meter. Each section was optimized to reduce the projected design section of beam and column. For this purpose building with 8 floor were divided into 4 different part considering the height of building. In this type of building, there were 3 type of column and 4 type of beam as illustrated in the figure. This structure is present till the 6 floor. At all other floor columns at corner were present. Built up boxed section was used for designing column, while for designing beam, I-section were used. Plan area, evolution and 3 dimensional view of 8 floor bundle tube system is illustrated in figure 3,4 and 5 respectively .

Table 2. Plan Configuration parametric analysis

Plan Area	80m X 80m
Plan Area of each tube	40m X 40m
Exterior beam length	5 meter
Interior beam length	10 meter
Floor	64

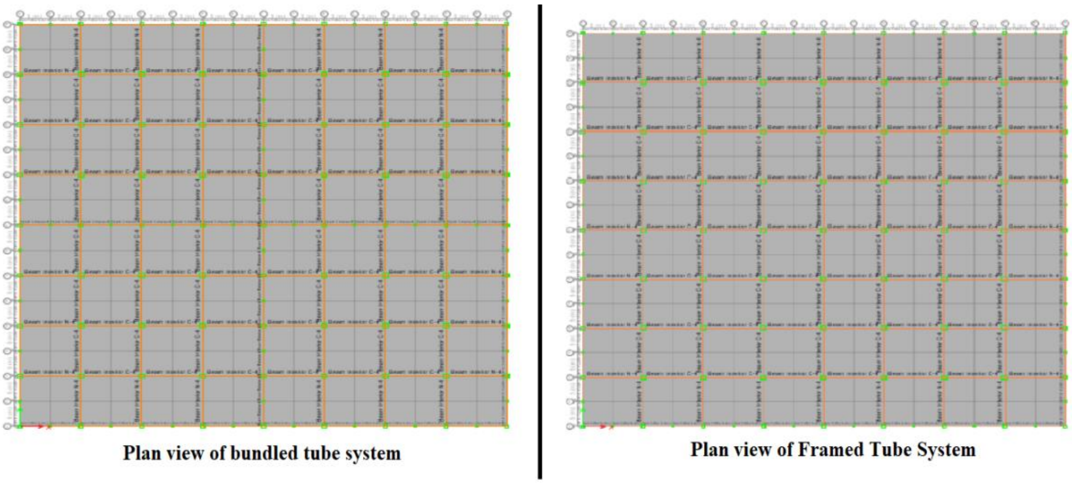

Figure 3. Plan view comparison

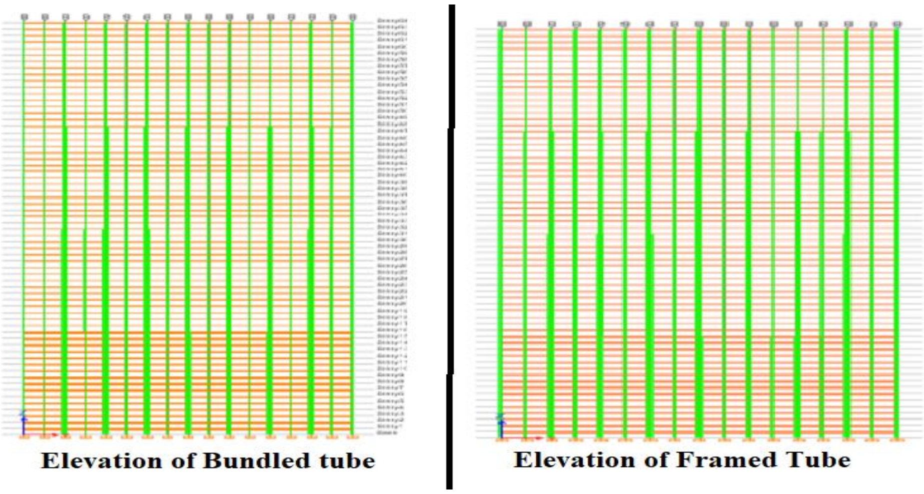

Figure 4. Elevation view comparison

2.4. Frame tube structure

For the parametric analysis, one structure was designed with bundle tube system with 8 floors. The steel structure was used to model the construction in ETABS version 2005 software. RCC was considered for the Slabs while other structure element for example column and beam was considered with steel material.

Each section was optimized to reduce the projected design section of beam and column. For this purpose building with 8 floor were divided into 4 different part considering the height of building. In this type of building, there were 3 type of column and 4 type of beam as illustrated in the figure. This structure is present till the 6 floor. At all other floor columns at corner were present. Built up boxed section was used for designing column, while for designing beam, I-section were used. Plan area, evolution and 3 dimensional view of 8 floor bundle tube system is illustrated in figure 3,4 and 5 respectively.

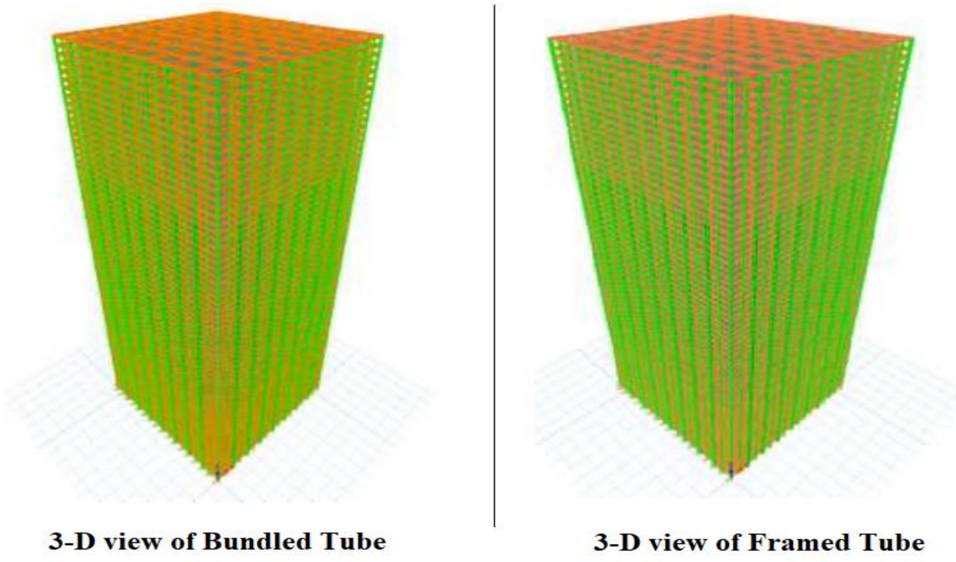

Figure 5. 3-D view of bundled and framed tube system

3. Results

In this section, all the governing load for both the system is analysed. The aim of this section is to study different forces with respect to bundled tube system and framed tube system.

3.1. Comparison of time period, max base shear and steel weight

To understand the stiffness it is important to study the time period comparison of both framed tube and bundled tube system. Low time period indicates the high stiffness in the construction. Maximum base shear is also an important factor in structural engineering. It defines the maximum possible lateral force on the structure's base caused by the seismic actions. Max steel weight for framed tube system and bundled tube system in tonnes is compared.

Table 3. Comparison of time period, max base shear and steel weight

Measure	**Bundled tube system**	**Framed Tube system**	**unit**
Time period	5.822	6.3	seconds
Maximum base shear	74373	73681	kN
Maximum steel weight	5100	5062	tonnes

As shown in table 3, the time period for bundled and framed tube system was compared. From the result, it was observed that the time period for bundled tube system was less than that of framed tube system. The same values are illustrated in chart 1.

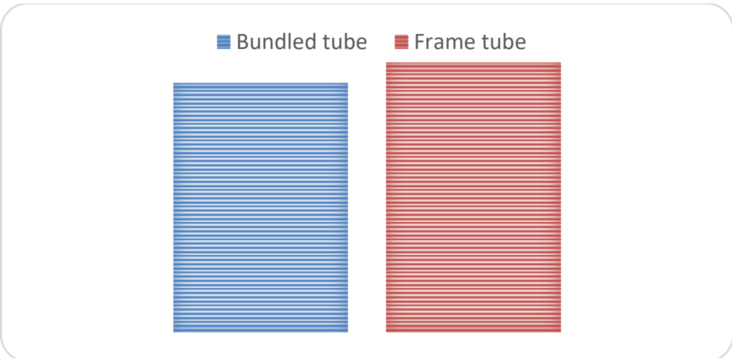

Chart 1. Comparison of time period

Chart 1 illustrates the comparison of time period. From time comparison of chart 1, it is clear that bundled tube system has more stiffness than frame tube system.

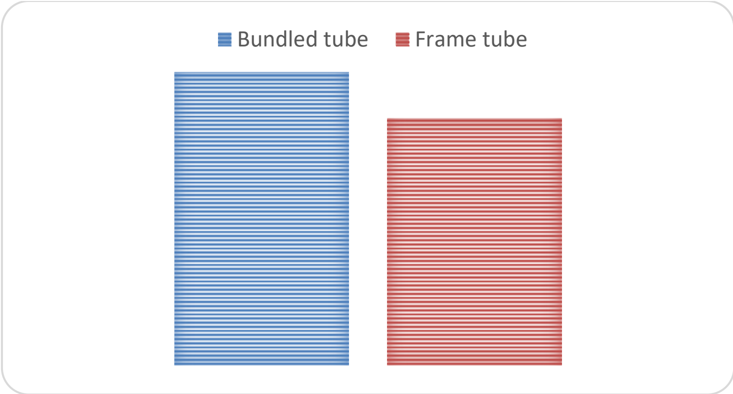

Chart 2. Comparison of base shear

As discussed in section 3 - methodology, both of this buildings are symmetric. Hence the base shear will be same in both directions [13]. From chart 2, it is clear that the base shear for bundle tube system is higher compared to the framed tube system. This is because the bundled tube system is stiffer than the framed tube system. Bundle tube system attracts higher lateral force hence its base shear value is higher than framed tube system.

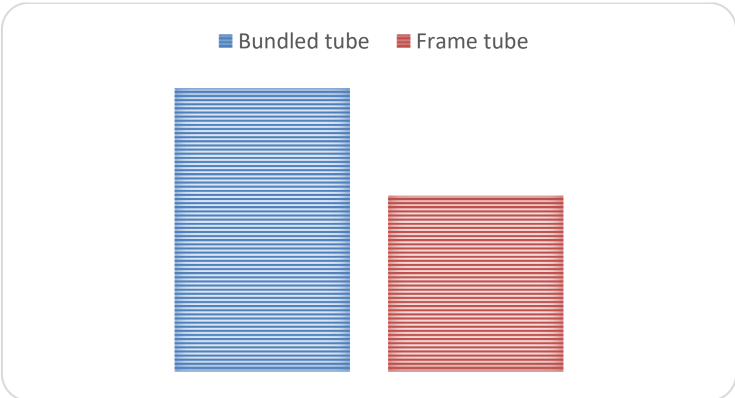

Chart 3. Comparison of steel weight

Chart 3 illustrates the comparison steel weight for framed tube system and bundled tube system in tonnes. For bundle tube the steel weight was 5100 tonnes, while for framed tube the steel weight was 5062 tonnes. This shows that the steel weight for bundled tube system is slightly higher (0.70 to 0.80) than the framed tube system.

3.2.Maximum storey displacement

Storey displacement graph is illustrated in chart 4. From this chart it is observed that the curve obtained is uniform in its nature for both bundled tube and framed tube structure. In this comparison the storey displacement for 8 storey is presented. This comparison can help to get the detailed information about storey displacement with respect to the storey in bundled tube system and framed tube system.

Table 4. Storey displacement at different storey

Storey	**Bundled Tube system**	**Framed Tube System**
7	260	300
6	240	275
5	200	220
4	170	185
3	130	150
2	90	95
1	50	55
0	0	0

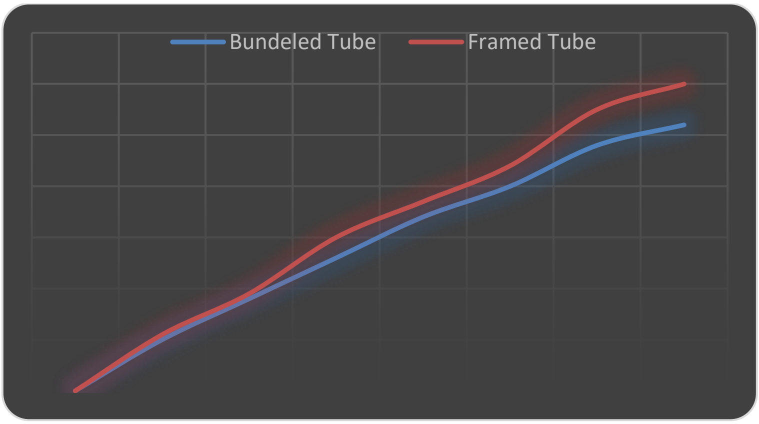

Chart 4. Comparison of maximum storey displacement

Chart 4, illustrated the comparison of storey displacement for 8 floor building. It has been observed that the storey displacement grow consistently for both bundled tube and framed tube system. From chart 4, it is clear that the displacement for bundled tube is less than that of framed tube. The difference between their displacement gradually increases as the height of the building increases. At the top storey the maximum storey displacement for bundled tube is 260mm while for framed tube system, it is 300mm. Even though the framed tube system has high displacement, but it is still under the permissible limit.

3.3.Maximum story drift

Storey drift graph is illustrated in chart 5. From this chart it is observed that the curve obtained is uniform for both bundled tube and framed tube structure. In this comparison the storey drift for 8 storey is presented. This comparison can help to get the detailed information about storey drift with respect to the storey in bundled tube system and framed tube system.

Table 5. Storey drift at different storey

Storey	Bundled Tube system	Framed Tube System
7	0.0005	0.0005
6	0.002	0.002
5	0.0017	0.0015
4	0.0022	0.002
3	0.0028	0.0023
2	0.0027	0.0022
1	0.001	0.001
0	0	0

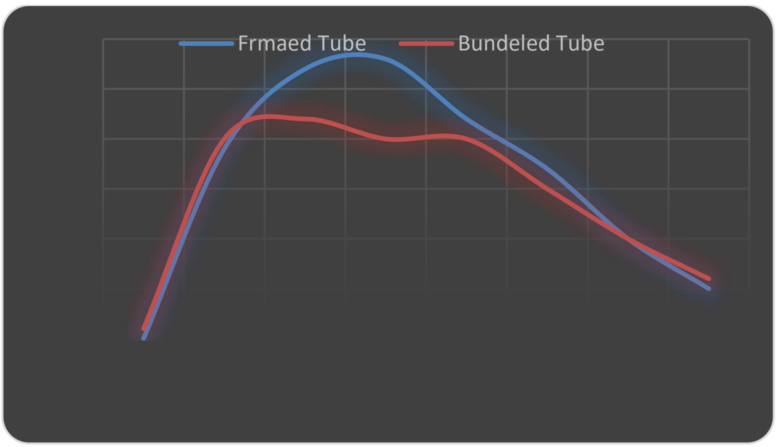

Chart 5. Comparison of Storey Drift

Chart 5, illustrated the comparison of storey drift for 8 floor building. It has been observed that the storey drift grow consistently till middle portion of the building. For framed tube system, the max storey drift was found at lower portion of building. In bundled tube system, the maximum drift was observed at the middle for the building. However the maximum drift for both of the system is observed to be in the permissible limit.

4. Conclusion

In this research the comparison of bundled tube system with framed tube system is carried out and its results were compared. The main of this research was to identify the effect of lateral force with respect to each system. Story drift, storey displacement, base shear and steel weight comparison is carried out for both structures. From the result, it was observed that the time period for bundled tube system was less than that of framed tube system. It shows that bundled tube system has more stiffness than frame tube system. Results shows that the base shear for bundle tube system is higher compared to the framed tube system. This is because the bundled tube system is stiffer than the framed tube system. Bundle tube system attracts higher lateral force hence its base shear value is higher than framed tube system. It is also observed that the steel weight for bundled tube system is slightly higher (0.70 to 0.80) than the framed tube system. It has been observed that the storey displacement grow consistently for both bundled tube and framed tube system. The storey displacement is less for bundled tube as compared to framed tube system. It has been observed that the storey drift grow consistently till middle portion of the building. For framed tube system, the max storey drift was found at lower portion of building. Even though the storey drift and storey displacement for bundled tube was less, it is under permissible limit for framed tube structure too. From the research, it can be concluded that the bundled tube system has added advantages over framed tube system when compared for the lateral load resistance.

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