

Article

An Assessment of the Relation between Architectural and Structural Systems in the Design of Tall Buildings in Turkey

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Abstract: Many professionals from several disciplines need to cooperate in designing and constructing tall buildings since their design and construction require more complex systems and technologies in terms of structure, installation, facade, vertical circulation and fire systems compared to low-rise buildings. The architects who design tall buildings have to know the architectural and structural design considerations of tall buildings and their interrelations well. This study is expected to reveal the status of tall buildings completed in Turkey and help designers understand architectural forms, floor plans, core planning and structural systems of tall buildings. For this purpose, the factors affecting architectural and structural design were examined, and the relation between the architectural–structural system was revealed for tall buildings completed in Turkey. In order to study architectural and structural considerations, 230 constructed tall buildings in Turkey were selected and analyzed in detail. According to the results of the study, it is seen that the prismatic form is widely used as the building tower form in Turkey, the shear-frame system as the structural system, the residential function as the building function, the single symmetrical central core as the building core, and the rectangular plan as the building floor plan alike.

Keywords: tall buildings; structural system; architectural system



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1. Introduction

A variety of factors, such as the housing need of the population that increased rapidly in cities, the social and cultural demands brought by rapid urbanization, the need for office units to be positioned as closely as possible to one another, the scarcity of affordable land, economic growth and technological advancements have forced buildings to rise gradually [1]. Compared to other types of constructions, the growth of tall buildings has been significantly influenced by advancements in construction technology. While the 10–12-story buildings of the late nineteenth century, with a height of 50 m, were once considered the first skyscrapers, they later evolved into 160–170 story buildings, reaching roughly 1000 m in about 100 years. Tall buildings, which were previously encountered only in North America, appear in nearly every major city around the world today [1,2]. Today the race for height is still ongoing at an accelerating rate due to innovations and developments in structural analysis and design, advancements in high-strength building materials and technology, the development of elevator and ventilation systems and the fact that tall buildings are considered symbols of power, wealth and prestige for corporations, cities and even nations [1,2].

As in the rest of the world, the number of tall buildings and the height of buildings is increasing daily in Turkey as well. Turkey's cities, such as İstanbul, Ankara and İzmir, are among the important tall cities of the world [3–6]. In the ranking of countries with the highest number of tallest buildings worldwide, Turkey ranks 14th for 150 m building height and 18th for 200 m building height. Although there are tall buildings under construction with a height of 300 m and more in Turkey, Turkey is not included in the ranking based on the building height of 300 m since their constructions have yet to be completed. İstanbul has the highest number of tall buildings in Turkey, and the tallest building in Turkey is

located in İstanbul. İstanbul ranks 29th worldwide and 1st in Europe and Turkey, based on the 150 m building height [3].

Tall buildings require more sophisticated systems and tall building technologies in terms of structural systems, installation, facade systems, vertical circulation systems, operating systems and fire safety measures. Tall buildings severely affect the region's traffic, infrastructure, climate, landscaping, city silhouette, transportation and communication systems [7]. It is essential to consider the substantial negative social, economic and ecological effects that a tall building will have on the area before determining whether to build one or not [8]. Tall buildings are more susceptible than low-rise and mid-rise buildings to the lateral loads brought on by wind and earthquakes because of their extraordinary height. Tall building design and construction require specialized knowledge of multiples variables, including earthquakes, wind, and fire [7].

Being an essential step in architectural design, the choice of the structural system plays a much more significant role in tall buildings compared to other building types. Structural and aerodynamic concerns should be addressed with other design concerns early on in the design process. Early architectural form development has a critical place in tall building design and may have critical effects on the subsequent phases of the design. Less emphasis on structural and aerodynamic considerations in the design process often leads to ineffective design solutions that naturally lead to costly construction [9]. Being among the most earthquake-prone countries in the world, Turkey has a high probability of severe earthquakes. Therefore, it is vital to make a decision on the structural system of tall buildings appropriately, integrate the structural system with the architectural design and design the building by its purpose and characteristics in Turkey.

This study examined the factors affecting the architectural and structural design of 230 tall buildings completed in Turkey, and the relations between architecture and the structural system are revealed.

This study stands out from others since it is the most recent one to examine a large enough sample of tall buildings to represent the tall buildings currently in Turkey adequately.

2. Methodology

In the study, 230 tall buildings constructed in İstanbul, Ankara, İzmir, Konya and Mersin were selected for the analysis of their major architectural and structural characteristics. The selected tall buildings were examined for height, the number of stories, building form, core planning, function, floor plans, structural system and material. The relations between architectural and structural design considerations were examined to provide an introductory design guide for architects and engineers.

The literature review and background research involve reviewing previous dissertations, books, articles, conference proceedings, journals and internet sources. The Council on Tall Buildings and Urban Habitat (CTBUH) and the databases of other related websites generally include certain information about tall buildings, such as location, height, function and building materials, but exclude the structural system, floor plans and plan measurement, core form and plan, building form, aspect ratio, etc. [3,10,11]. Related data on the buildings were acquired from articles, journals and web sources and the tall buildings without adequate information about the structural system and architectural features were excluded from the analysis.

In the Turkish Building Earthquake Code 2019 (TBEC 2019), four different Earthquake Design Classes (EDC) are given for earthquake ground motion levels: EDC1, EDC2, EDC3 and EDC4, from highest to lowest. In TBEC 2019, three different height limits are given for tall buildings according to Earthquake Design Class (EDC). According to TBEC 2019, buildings with a height of more than 70 m for EDC = 1, 1a, 2, 2a; buildings with a height of more than 91 m for EDC = 3, 3a; buildings with a height of more than 105 m for EDC = 4, 4a are classified as tall buildings [12]. In the Turkish Planned Areas Zoning Regulation 2017, buildings with a height of more than 21.50 m and buildings with a structure height of more than 30.50 m are defined as tall buildings; and buildings with a height of more than 51.50 m

and buildings with a structure height of 60.50 m are defined as very tall buildings [13]. The height of tall buildings analyzed in the study ranges between 70 m and 284 m, and the number of stories ranges from 14 to 65. The distribution of tall buildings by province and the change in the number of stories are given in Figure 1. The average age of the examined tall buildings as of 2021 is 10.54. The number of buildings exceeding 100 m is 111, the number of buildings exceeding 150 m is 52, the number of buildings exceeding 200 m is 7, and the number of buildings exceeding 250 m is 4.

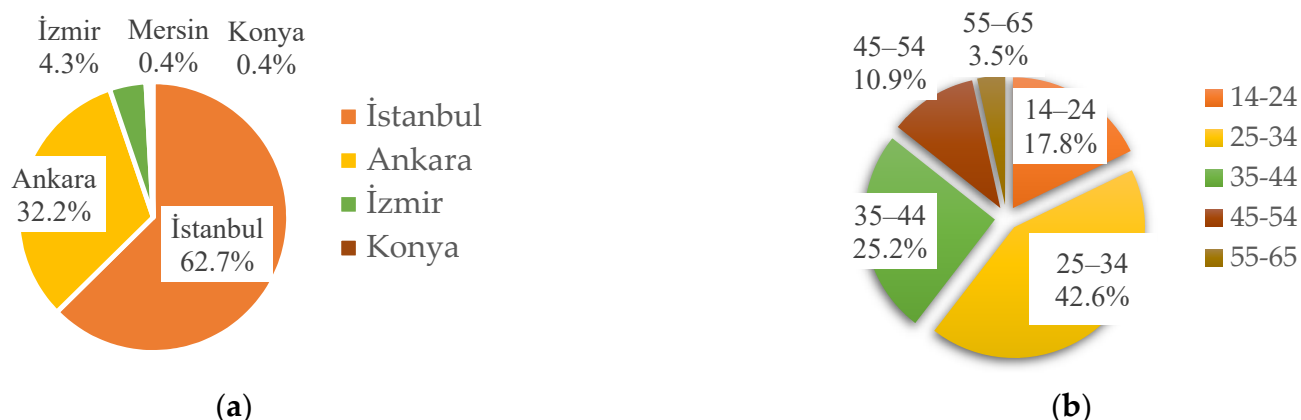


Figure 1. The tall buildings examined in Turkey: (a) Distribution by provinces; (b) Number of stories.

3. Analysis of Architectural and Structural Design Considerations of Tall Buildings

3.1. Analysis of Architectural Design Considerations of Tall Buildings

This section presents an analysis of architectural design considerations for 230 samples of tall buildings completed in Turkey. Architectural design considerations of tall buildings are building function, building form, building floor plan and building core planning. These four parameters and their analysis are separately discussed in detail below.

3.1.1. Analysis of Building Function

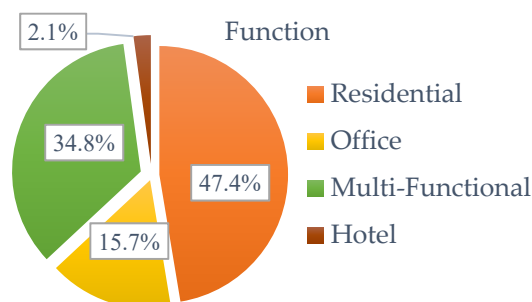
The building function is one of the tall buildings' most significant architectural parameters. Generally, according to their function, tall buildings are divided into two categories, single-functional or multi-functional. A tall building is categorized as single-functional if 85 per cent or more of its total floor area is dedicated to a single usage; it is categorized as a multi-functional tall building if it is designed for two or more different usage functions, where each of the functions occupies a significant proportion of the tower's total space [3,9,14]. Therefore, this study classified tall buildings according to functions like residential, office, hotel and multi-functional.

Among the tall buildings examined, it is observed that residential use is the most preferred function with 47.4%, followed by multi-functional use with 34.7%. The reason behind the high ratio of residential and multi-functional tall buildings in Turkey could be explained by meeting the housing needs in developing countries with a rapidly increasing population such as Turkey and the idea of easy rental and sale of buildings by creating a social center with commercial units open 24 h.

The findings given in Table 1 and Figure 2 for the building function classification of the sample group consisting of 230 tall buildings in Turkey reflect a similarity with the study of Odabaşı et al. (2021) [15]. If the multi-functional tall buildings in Turkey are divided into components, residential with commercial use is common, followed by residential with commercial and office, residential with commercial and hotel use, respectively. When the function of the ten tallest buildings of the tall building group in the study is observed, five are multi-functional, three are residential, and two are office buildings.

Table 1. Classification of selected tall buildings by function.

Function	Number	%
Residential	109	47.4
Office	36	15.7
Hotel	5	2.1
Multi-Functional	80	34.8
Total	230	100

**Figure 2.** Analysis of selected tall buildings by function.

3.1.2. Analysis of Building Form

The building form is a significant parameter among the architectural design evaluations of tall buildings. It is one of the most significant factors affecting the behavior under the loads and aesthetics of tall buildings. Therefore, a form that will minimize the wind forces affecting the building should be chosen in tall building design. Architectural design applications such as aerodynamically effective design, aerodynamic building form, aerodynamic building top, reduction of the building plan cross-sectional area, and improvement in the building corners are carried out in order to control the wind-induced lateral drift of tall buildings and to ensure the usability of the building [2,16].

Broadly, a tall building can be divided into three sections: the head/top, the main body/tower and the base [12,14]. In this study, the main body/tower of buildings was analyzed as the tall building form, and it was classified into two main groups, single and multiple forms, according to their number. Single tall building forms are classified as prismatic form, setback form, tapered form, tilted form, twisted form and single building forms; the remaining forms are classified as free form. Multiple forms are classified under three headings as discrete clustered form, tied across height form and partially disjointed form (Figure 3).

According to the classification given in Figure 3, considered in the study, the prismatic form is the most commonly used tall building form, with a rate of 71.7% in Turkey. The free form was designed at a rate of 8.7%, the setback form at a rate of 8.3%, and tapered form at a rate of 7.0%, and multiple forms were designed at a rate of 4.8% (Table 2 & Figure 4).

Table 2. Classification of selected tall buildings by building form.

Building Form	Form Group	Number	%
Prismatic	Single	165	71.7
Tapered	Single	15	6.5
Setback	Single	19	8.3
Free	Single	20	8.7
Clustered	Multiple	5	2.2
Tied Across Height	Multiple	6	2.6
Total		230	100

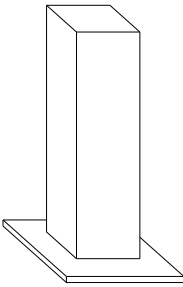
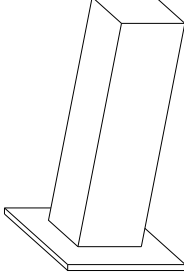
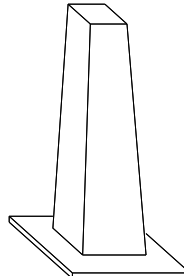
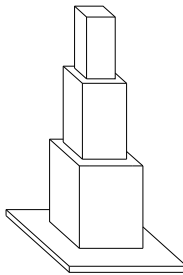
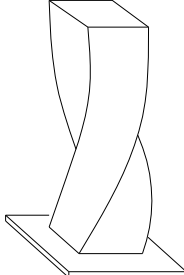
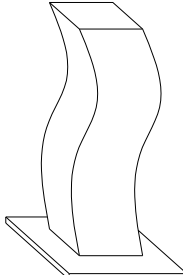
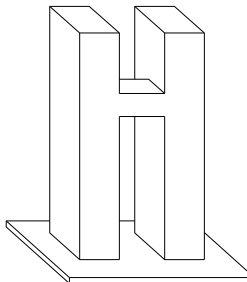
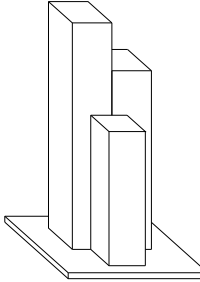
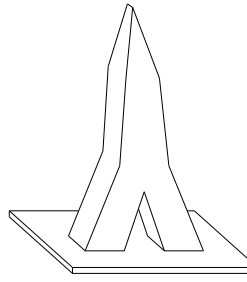
Single Forms		
Prismatic Form	Tilted Form	Tapered Form
		
Setback Form	Twisted Form	Free Form
		
Multiple Forms		
Discrete Clustured Form	Tied Across Height Form	Partially Disjointed Form
		

Figure 3. Tower form classification for tall buildings.

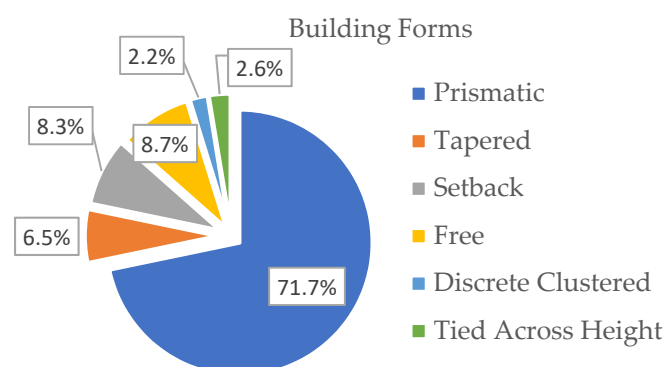


Figure 4. Analysis of selected tall buildings by building form.

It is observed that tilted, twisted and partially disjointed forms are not used in the tall buildings examined in Turkey. The reason why the prismatic form is widely preferred in tall buildings in Turkey can be explained by the fact that the structural design and application of the prismatic form are more straightforward than other building forms.

The building forms of the ten tallest buildings of the tall building group analyzed in Turkey are as follows: four in prismatic form, four in free form and two in tapered form.

3.1.3. Analysis of Building Core

The core, a vertical circulation element in tall buildings, is another significant architectural parameter. Buildings' cores contain all vertical circulation elements such as elevators, staircases, fire-escape stairs, mechanical shafts, toilets and elevator lobbies. Most main structural elements, such as shear walls, which provide lateral stability against earthquake and wind forces in tall buildings, are integrated into the core to simplify the architectural design.

In tall buildings, the core layout is critical to the building's space efficiency and operational effectiveness and plays a significant role in the structure's ability to cope with lateral loads [17]. Core dimensions vary according to the tall building's function, height and floor plans. Limitations on the shape and dimensions of the core, caused by the desire to increase the useful area on the floors by reducing the core dimensions in tall buildings and increase the efficiency of the elevators in terms of use, cause the stair to be placed in a way that does not ensure its relationship with elevators and corridors [17]. The core of tall buildings can be classified as below;

According to core placement; central, external, peripheral, atrium,

According to core form; open, closed-form,

According to core number; single, multiple,

According to the core arrangement; symmetrical, asymmetrical,

According to core relation with building geometry; compatible and incompatible (Figure 5) [14,18].

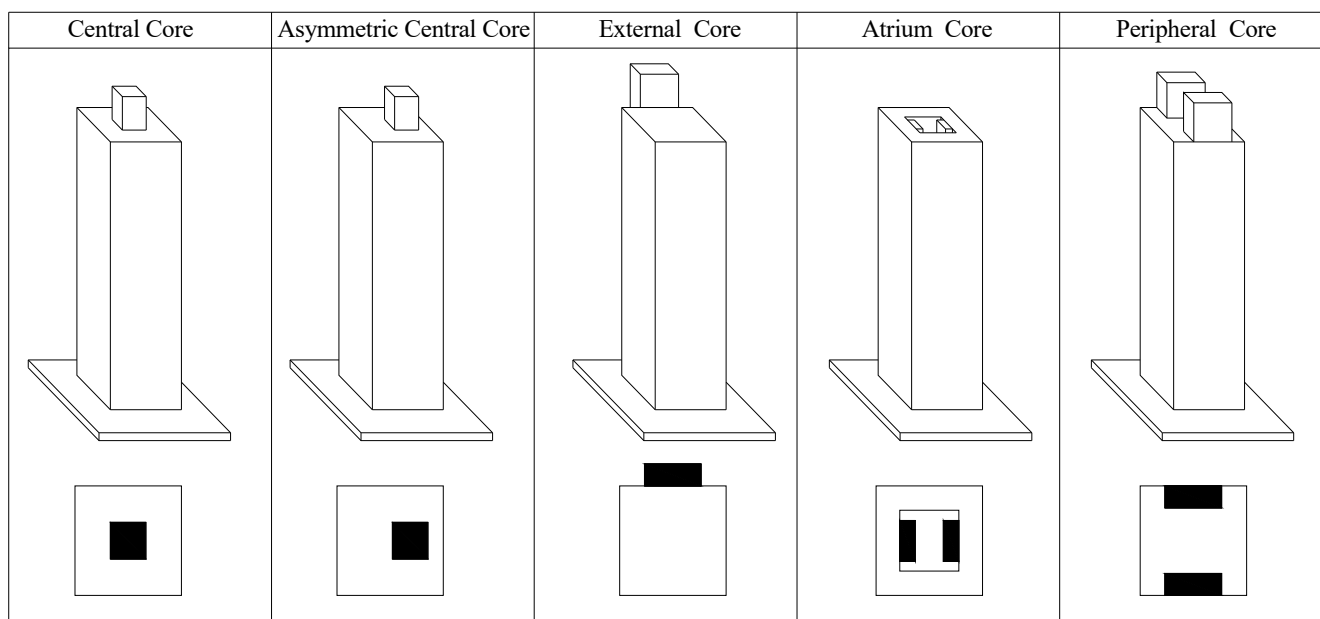


Figure 5. Core arrangement classification for tall buildings.

The core design considerably affects the overall space efficiency of buildings, the vertical circulation, and the distribution of mechanical and electrical shafts. The elevator strategy drives the core size and greatly impacts all tall buildings in terms of design. The ideal solution balances several factors such as the number and the speed of elevators, group sizes, building zones and core arrangement by considering the space usage and cost [17,19]. In order to achieve the maximum space efficiency of a tall building, the core gross floor area should be reduced to an acceptable rate while ensuring effective vertical circulation with elevators and conforming to the fire code requirements [17].

In the study, the tall buildings in Turkey were analyzed according to the core number, core arrangement, core placement and core relation with the building geometry.

As seen in Table 3 and Figure 6, 57.0% central core, 26.5% edge core, 15.2% asymmetric central core and 1.3% atrium core are designed in tall buildings in Turkey. While a single

core is used at 83.0% in tall buildings in Turkey, multiple cores are designed at 17.0%. Cores were arranged symmetrically in 59.6% of the examined tall buildings and asymmetrically in 40.4%. When the cores of tall buildings in Turkey are analyzed according to their relation with the building geometry, it is observed that 95.7% are compatible with geometry and 4.3% are incompatible with geometry.

Table 3. Classification of selected tall buildings by core planning.

Core Planning	Number	%
Central Core	131	57.0
Asymmetric Central Core	35	15.2
Peripheral Core	61	26.5
Atrium Core	3	1.3
Total	230	100

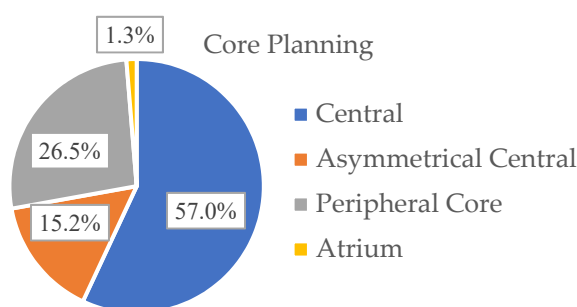


Figure 6. Analysis of selected tall buildings by the core planning.

Central cores are more widely used than other core types due to opening up the exterior spaces for light and scenery, enabling easier access to fire-escape stairs, resisting lateral loads, opening up the perimeter for light and view, and enabling efficient workplaces. In addition, the fact that the central cores do not create a torsional moment in case of symmetry under the lateral loads is another crucial reason why they are preferred more than asymmetric central cores and edge cores [17,20].

When the ten tallest buildings of the building group studied in Turkey are analyzed in terms of building core, it is seen that seven of them are central cores, three of them are peripheral cores, nine of these cores are single core and one is multi-core. All the cores in the ten tallest buildings are compatible with the floor plan, eight are designed symmetrically and two are designed asymmetrically.

3.1.4. Analysis of Building Floor Plan

One of the substantial architectural factors representing the geometry and form of tall buildings is their floor plan shape. The floor plans of tall buildings consist of rectangle, triangle, polygon, circle, ellipse, parallelogram, curvilinear and multiple geometries (Figure 7) [16]. The use of aerodynamic building forms is an effective method for reducing the wind loads on tall buildings. For example, for tall buildings with a circular and ellipse plan form, the highest lateral drift value under the effect of wind loads is almost half of the buildings having a rectangular plan form [1,21].

As seen in Table 4 and Figure 8, a rectangular floor plan is the most widely used tall building plan in Turkey, at 59.6%. Rectangular floor plan is followed by multiple geometry, polygon, ellipse, curvilinear, triangle, circle and parallelogram with rates of 11.8%, 7.4%, 7.4%, 6.5%, 3.0%, 3.0% and 1.3%, respectively. Rectangular plan is the most common floor plan of all time in tall buildings in Turkey, as it is in the whole world, and there has been an increase in the use of aerodynamic floor plans such as circle and ellipse in recent years [16].

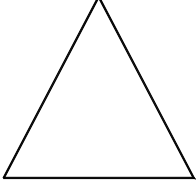
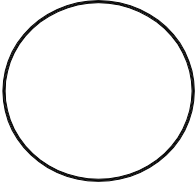
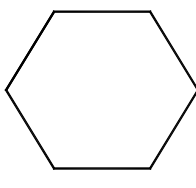
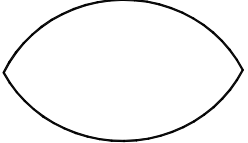
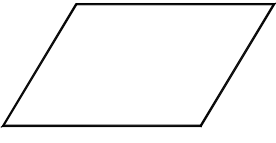
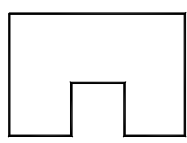
Rectangle	Triangle	Circle	Polygon
			
Ellipse	Parallelogram	Curvilinear	Multiple Geometry
			

Figure 7. Floor plan classification for tall buildings.

Table 4. Classification of selected tall buildings by floor plan.

Floor Plan	Number	%
Rectangle	137	59.6
Polygon	17	7.4
Triangle	7	3.0
Circle	7	3.0
Ellipse	17	7.4
Parallelogram	3	1.3
Curvilinear	15	6.5
Multiple Geometry	27	11.8
Total	230	100

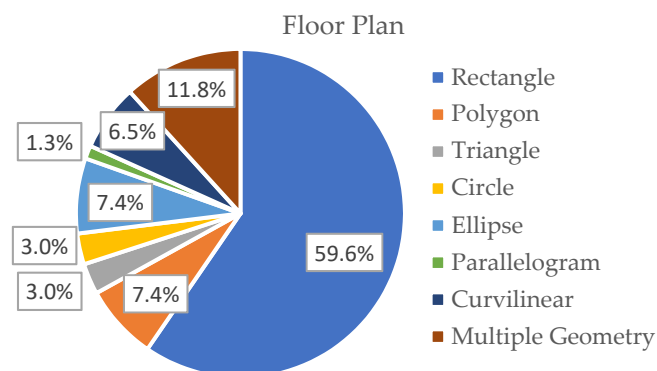


Figure 8. Analysis of selected tall buildings by floor plan.

When the ten tallest buildings of the tall building group studied in Turkey are examined in terms of building floor plan, it is seen that four of them are rectangular, two of them are a triangle, one of them is a circle, one of them is a parallelogram, one of them is free and one of them is multi-geometry.

3.2. Analysis of Structural Design Considerations of Tall Buildings

This section presents an analysis of structural design considerations for 230 tall building samples completed in Turkey. Structural design considerations of tall buildings are

structural system material and tall building structural system. These two parameters and their analyses are separately discussed in detail in the section below.

3.2.1. Analysis of Structural Material

Reinforced concrete, steel and composite materials are used in tall buildings' lateral and vertical structural elements. The composite structures can be generated as composite components in structural systems or combinations of steel and concrete components [1,3,4].

The structural system material of tall buildings in Turkey is 93.5% reinforced concrete, 6.1% composite and 0.4% steel (Table 5 and Figure 9). The findings given in Figure 9 for the material classification of 230 tall buildings in Turkey show similarity with the tall building CTBUH database for Turkey.

Table 5. Classification of selected tall buildings by structural material.

Structural Material	Number	%
Reinforced Concrete	215	93.5
Steel	1	0.4
Composite	14	6.1
Total	230	100

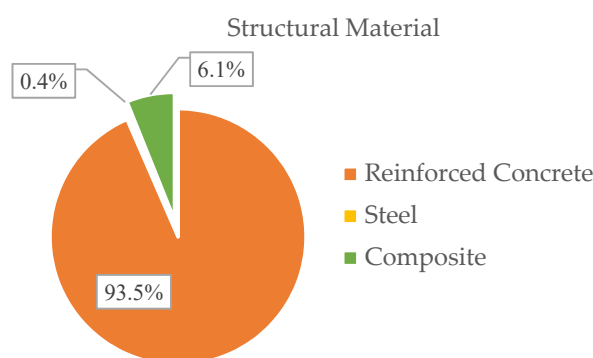


Figure 9. Analysis of selected tall buildings by structural material.

When the structural system material of the ten tallest buildings of the tall building group is analyzed in Turkey, it can be seen that six of them are reinforced concrete, and four of them are composite.

3.2.2. Analysis of Building Structural Systems

The choice of structural system for tall buildings is one of the most significant parameters of tall building design besides significantly affecting the exterior and interior use of the building [2]. There are numerous tall building structural systems and structural system classifications in literature and practice.

Generally accepted tall building structural system classifications are based on the structural system material and which system (exterior or interior) takes part in bearing lateral loads affecting the building [1,14,22–25].

Structural systems of reinforced concrete, steel and composite tall buildings can be classified based on their structural behavior against lateral loads as follows:

Frame Systems
 Core Systems
 Shear Wall Systems
 Shear-Frame Systems
 Mega Frame/Mega Column/Mega Core Systems
 Outrigger Frame Systems
 Tube (Frame Tube, Braced Frame Tube, Bundled Tube) Systems
 Diagrid Tube Systems (Figure 10).

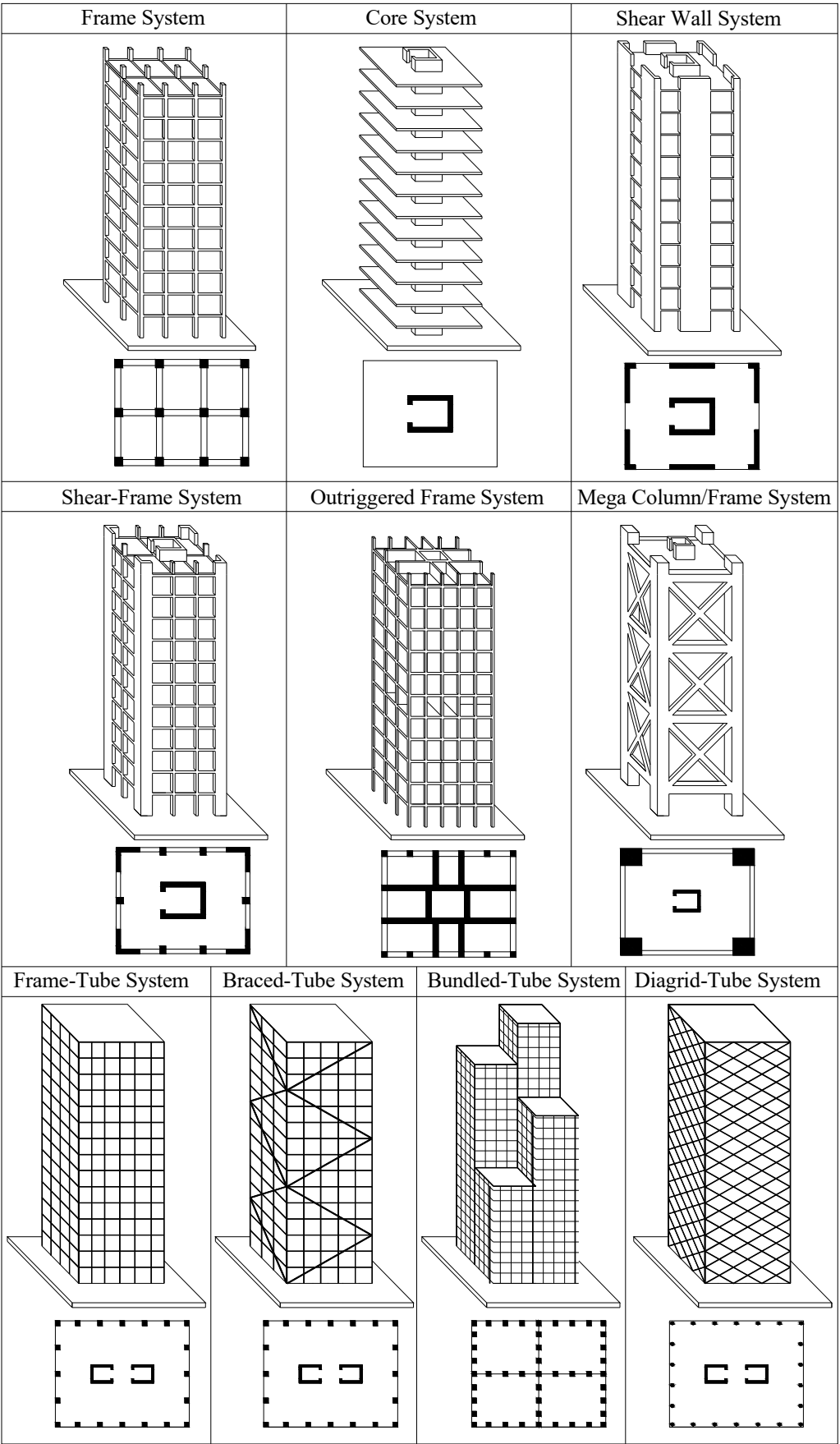


Figure 10. Structural system classification for tall buildings.

Turkey is a country that is frequently exposed to earthquakes. In terms of major earthquakes that have occurred since 1900, Turkey ranks fourth in the world with 77 earthquakes. In Turkey, which is located in one of the most active earthquake zones in the world, it is inevitable that devastating earthquakes will occur in the future, as there have been many devastating earthquakes in the past [26,27].

Hence, the large numbers of tall buildings distributed across the seismically active regions of Turkey are exposed to probable future earthquakes. Furthermore, they are occupied by larger numbers of inhabitants compared to other types of structures and, thus, would require higher safety standards because of the potential large consequences associated with loss of human lives, functionality and resources [15].

The structural design of tall buildings in Turkey is controlled by the earthquake loads due to the seismicity of Turkey, heights of existing tall buildings and the use of reinforced concrete as the structural material.

Recent earthquakes devastated the cities of Düzce ($M = 7.2$) and Sakarya ($M = 7.4$) in 1999 with approximately 18000 deaths, destroyed nearly 15400 buildings and caused USD 10–25 billion in losses [15,27]. There was no serious damage and loss of the life in tall buildings in the 1999 earthquakes because the existing tall buildings in Turkey generally have been built according to modern seismic standards since the 1990s.

It is necessary to understand very well the behavior of a tall structure during an earthquake in order to prevent disastrous collapses in Turkey, and the structural behavior of tall building structures used in Turkey are explained briefly below.

In the shear-frame system, the total stiffness and the economical height of the tall building can be increased by adding shear walls to the rigid frame system to carry the external shear forces induced by lateral loads [1,2,4].

Shear wall systems can be thought of as a vertical cantilever rigidly fixed at the base under the lateral loads. Due to the nature of the cantilever behavior in the shear wall system, the drifts are greater in the upper floors than in the other floors under the lateral loads [1,2,4].

Outriggered frame systems have been developed by adding outriggers to shear-frame systems with a core so as to couple the core with the perimeter columns. The outriggers are structural elements connecting the core to the exterior columns at one or more levels throughout the height of the building so as to stiffen the structure. In this way, the cantilever tube behavior of the system is ensured, and the stiffness of the shear-frame system is increased, while reducing the lateral drift of the building to a significant degree [1,2,4].

The tube systems can be likened to a system in which a hollow box column is cantilevering from the ground, and so the building exterior exhibits a tubular behavior against lateral loads. A frame–tube system evolved from a rigid frame system and can be defined as a three-dimensional rigid frame having the capability of resisting all lateral loads with the facade structure [1,2,4].

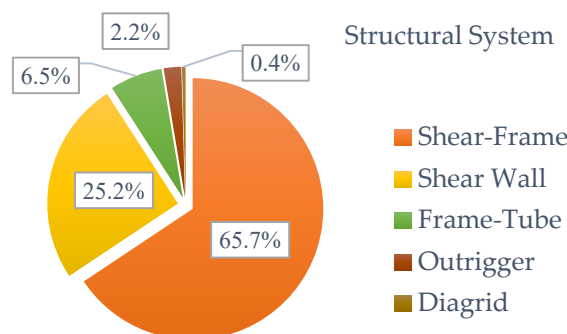
The diagrid system can be formed by using closely spaced diagonal braces instead of vertical columns and horizontal beams. The diagrid system is more effective against lateral loads than the conventional framed-tube system. Placing the elements in a closely spaced diagrid pattern provides sufficient resistance against vertical and lateral loads [1,2,4].

As can be seen in Table 6 and Figure 11, the shear-frame system is predominantly used, at a rate of 65.7% in Turkey. The shear-frame system is followed by the shear wall system with a rate of 25.2%, the frame-tube system with a rate of 6.5%, the outrigger system with a rate of 2.2%, and the diagrid system with a rate of 0.4%. It is observed that braced-tube, bundled-tube, mega column and mega frame systems are not used as structural systems of tall buildings in Turkey. The shear-frame system is widely used in the form of core shear-frame systems in Turkey. The shear-frame system is widely used in Turkey because it provides freedom in design and can be economical and efficient in terms of construction.

When the structural systems of the ten tallest buildings of the tall building group studied in Turkey are observed, it is seen that seven of them are shear-frame systems and three of them are outrigger systems.

Table 6. Classification of selected tall buildings by structural system.

Structural System	Number	%
Shear-Frame	151	65.7
Shear Wall	58	25.2
Frame-Tube	15	6.5
Outrigger	5	2.2
Diagrid	1	0.4
Total	230	100

**Figure 11.** Analysis of selected tall buildings by the structural system.

The foundation types of tall buildings in Turkey are mat slab foundations and piled foundations, depending on the characteristics of the soil site. When the slab systems of tall buildings in Turkey are examined in terms of materials, it is seen that 95.2% of the slabs are reinforced concrete, and 4.8% are composite. The slab types of tall buildings in Turkey are 42.2% slab with beams, 31.3% flat plates, 11.3% waffles slabs, 4.8% composite slabs, 4.8% multiple slab types, 3.9% ribbed slabs and 1.7% post-tensioned slabs.

4. Interrelations among Design Considerations of Tall Buildings in Turkey

Relations between architectural and structural design considerations that are examined in this study are:

Building form and building structural system
 Building height and building structural system
 Building structural system and structural material
 Building floor plan and building structural system
 Building function and building structural system
 Building structural system and building core type
 Building height and building structural material
 Building height and building function

These interrelations and their analyses are discussed in detail in the section below.

4.1. Relation between Building Form and Building Structural System

Figure 12 illustrates the tall building forms in Turkey and the structural systems used in these building forms. The grey bars on the left axis of the graph demonstrate the total number of tall buildings.

In prismatic form, the shear-frame system is used at 57%, the shear wall system at 34.5%, the frame tube system at 7.3%, the outrigger system at 0.6%, and the diagrid system at 0.6%. Only the shear-frame system is used in all the buildings with the tapered form. In setback form, the shear-frame system is used at 94.7% and the frame-tube system at 5.3%. In free form, 80.0% shear-frame and 20.0% outrigger system are used. In multiple forms, 90.9% shear-frame system and 9.1% frame-tube system are used.

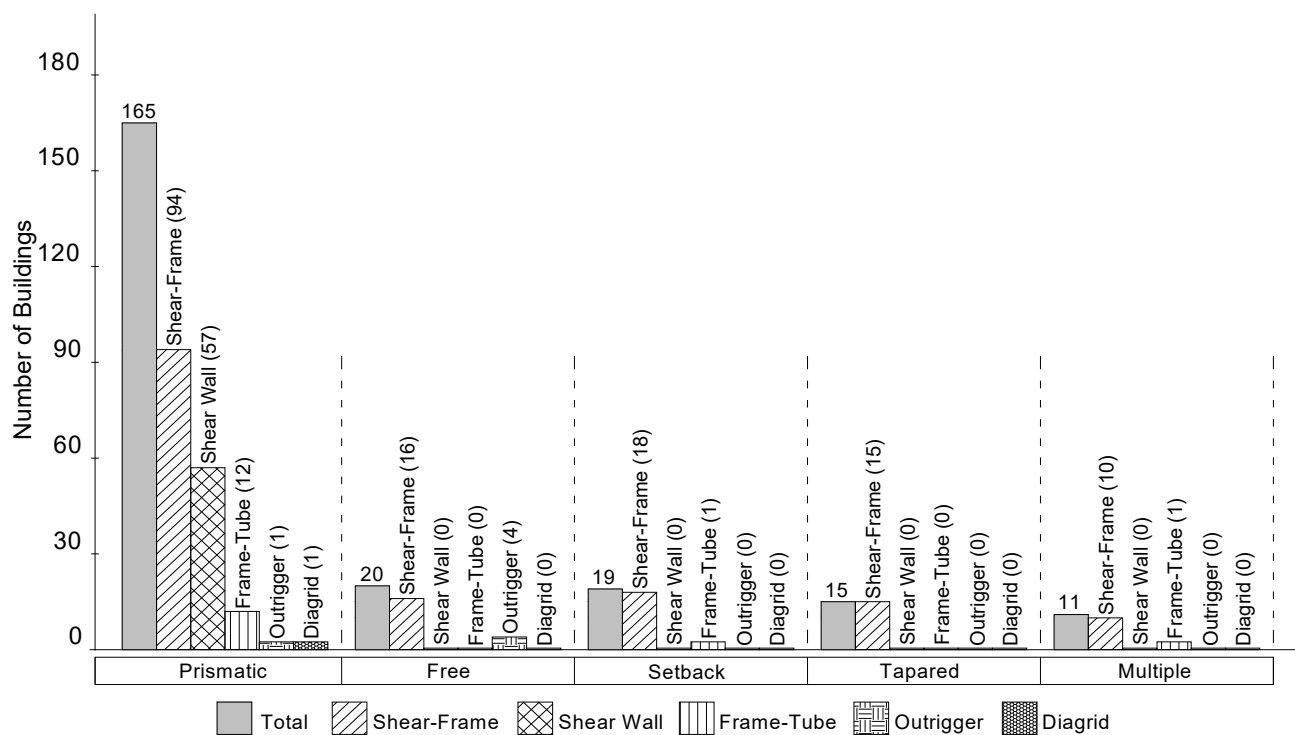


Figure 12. Relation between building form and structural system.

It is observed that the shear-frame system is the most common in the tall building forms analyzed in Turkey. However, the shear wall system is also widely used together with the shear-frame system in tall buildings with prismatic form.

The reasons behind the common use of shear-frame systems and shear wall systems can be clarified by the predisposition of designers and contractors to reinforced concrete construction in Turkey, the suitability of these systems for reinforced concrete construction, design and construction ease, and effective resistance to lateral loads in tall buildings with such a height and number of stories constructed in Turkey with these systems. Since architectural design flexibility is required in free, setback, tapered, multiple forms, shear-frame and frame-tube structural systems are used in these forms. The shear-frame (tunnel formwork) system is not used in these forms as it limits the architectural design due to its construction.

4.2. Relation between Building Height and Building Structural System

Figure 13 illustrates the variation of heights of the buildings according to the structural system. The grey bars on the left axis of the graph demonstrate the total number of tall buildings.

In the shear-frame system, 13.9% of the building heights are in the range of 70–99 m, 49.7% are in the range of 100–149 m, 31.8% are in the range of 150–199 m, 2.0% are in the range of 200–249 m and 2.6% of them are in the range of 250–299 m. The tallest building constructed with a shear-frame system in Turkey is 284 m high. In the shear wall system, 44.8% of the building heights are in the range of 70–99 m, 48.3% are in the range of 100–149 m and 6.9% are in the range of 150–199 m. The tallest building constructed with a shear wall system in Turkey is 160 m high. In the frame-tube system, 33.3% of the building heights are in the range of 70–99 m, 46.7% are in the range of 100–149 m and 20.0% are in the range of 150–199 m. The tallest building constructed with a frame-tube system in Turkey is 181 m high. In the outrigger system, 20.0% of the building heights are in the range of 150–199 m and 80.0% are in the range of 200–249 m. The tallest building constructed with the outrigger system in Turkey is 220 m high. There is one tall building constructed with a diagrid system in Turkey, and the height of this building is 151 m.

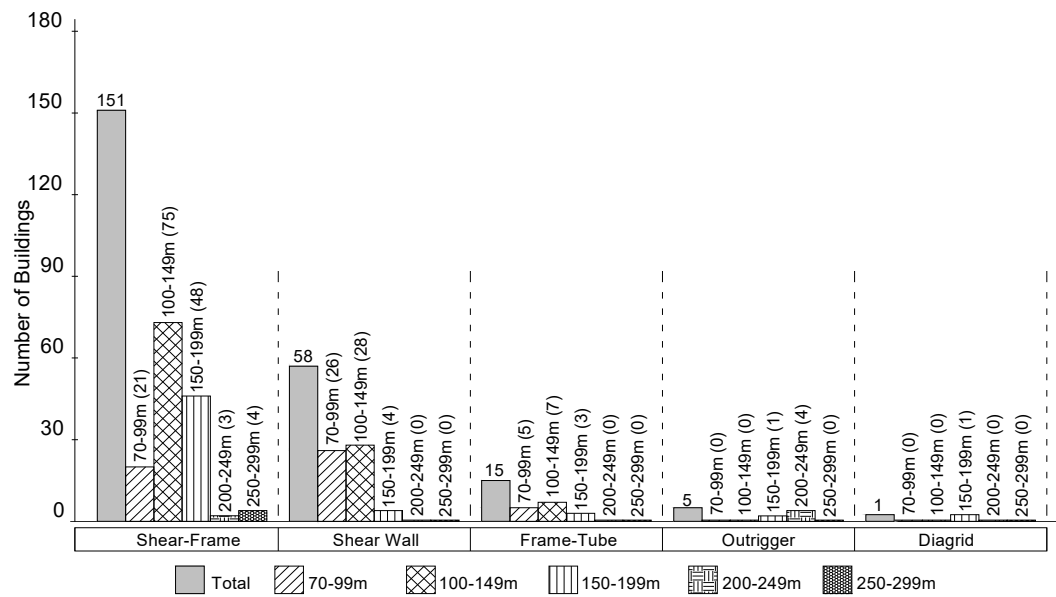


Figure 13. Relation between building height and structural system.

4.3. Relation between Building Structural System and Building Structural Material

Figure 14 illustrates the structural systems of tall buildings and the materials used in these structural systems in Turkey. The grey bars on the left axis demonstrate the total number of buildings in a specific structural system. In Turkey, reinforced concrete, composite and steel are used as structural system materials in shear-frame systems at rates of 92.0%, 7.3% and 0.7%, respectively. Shear-frame systems generally consist of a reinforced concrete central core that resists most lateral loads and reinforced concrete or composite perimeter columns in Turkey.

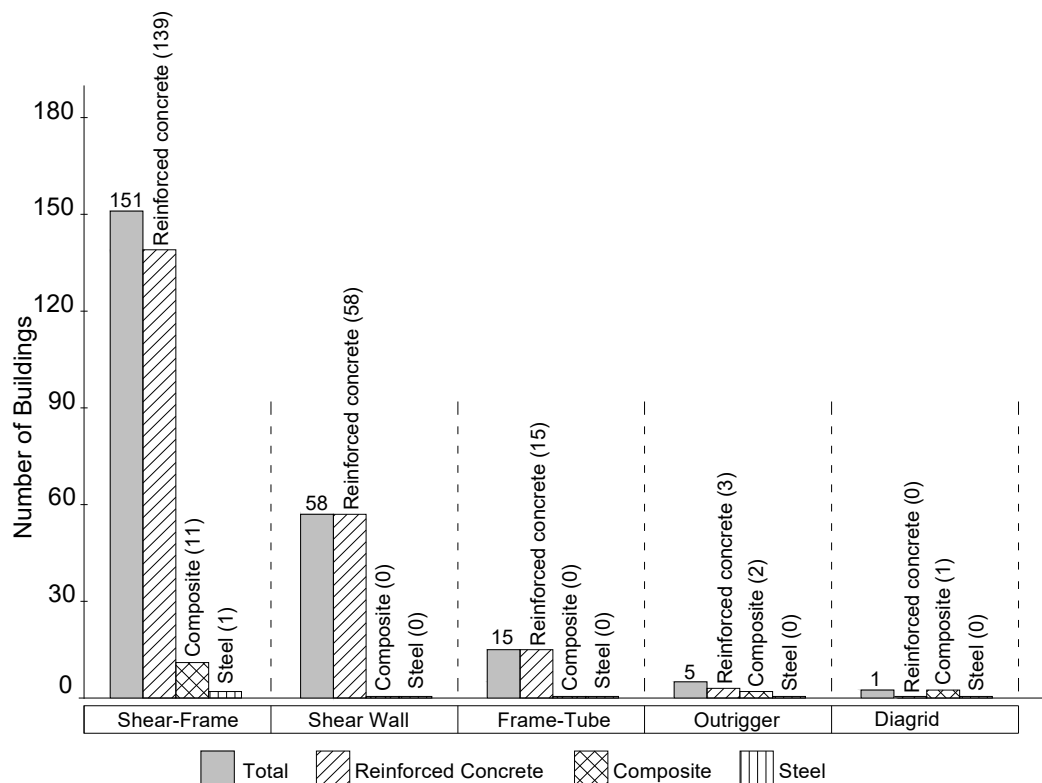


Figure 14. Relation between structural system and structural material.

While shear wall and frame tube systems use only reinforced concrete as the structural system material, only composite is used as the structural system material in the diagrid system. A total of 60.0% reinforced concrete, and 40.0% composite are used in the outrigger system in Turkey. The tunnel formwork system is generally applied in the shear wall system in Turkey, and only reinforced concrete is used in the system due to system application. In tall buildings with outrigger and diagrid structural systems, the desired effectiveness can be achieved against lateral loads using reinforced concrete and composite materials.

Nowadays, the use of reinforced concrete and composite building materials (99.6%) in tall building structural systems is considerably higher than steel construction materials in Turkey, as it is in the whole world [1–3,9,14,15,17].

4.4. Relation between Building Floor Plan and Building Structural System

Figure 15 illustrates the tall building floor plans and the number of structural systems used in these floor plans. The grey bars on the left axis of the graph demonstrate the total number of tall buildings. In the tall buildings with a rectangular floor plan, 51.8% use the shear-frame system, 38.7% use the shear wall system, 6.6% use the frame-tube system, 2.2% use the outrigger system and 0.7% use the diagrid system. In tall buildings with a polygon floor plan, 82.3% use the shear-frame system, 11.8% use the frame-tube system and 5.9% use the shear wall system, whereas outrigger and diagrid systems are not used. In tall buildings with a triangle floor plan, 85.7% use the shear-frame system and 14.3% use the outrigger system; the shear wall system, frame-tube system and diagrid system are not used. In tall buildings with a circular floor plan, 57.1% use the shear-frame system, 14.3% use the shear wall system, 28.6% use the frame-tube system, whereas the outrigger system and diagrid system are not used. In tall buildings with an elliptical floor plan, 94.1% use the shear-frame system and 5.9% use the shear wall system, whereas the frame-tube system, outrigger system and diagrid system are not used. In tall buildings with a parallelogram floor plan, 66.7% use the shear-frame system and 33.3% use the outrigger system, while the shear wall system, frame-tube system and diagrid system are not used. In tall buildings with a free floor plan, 86.6% use a shear-frame, 6.7% use a frame-tube and 6.7% use an outrigger system while shear wall system and diagrid system are not used. In tall buildings with multiple geometry floor plans, 96.8% use the shear-frame system and 3.7% use the frame-tube system, while the shear wall system, outrigger system and diagrid system are not used.

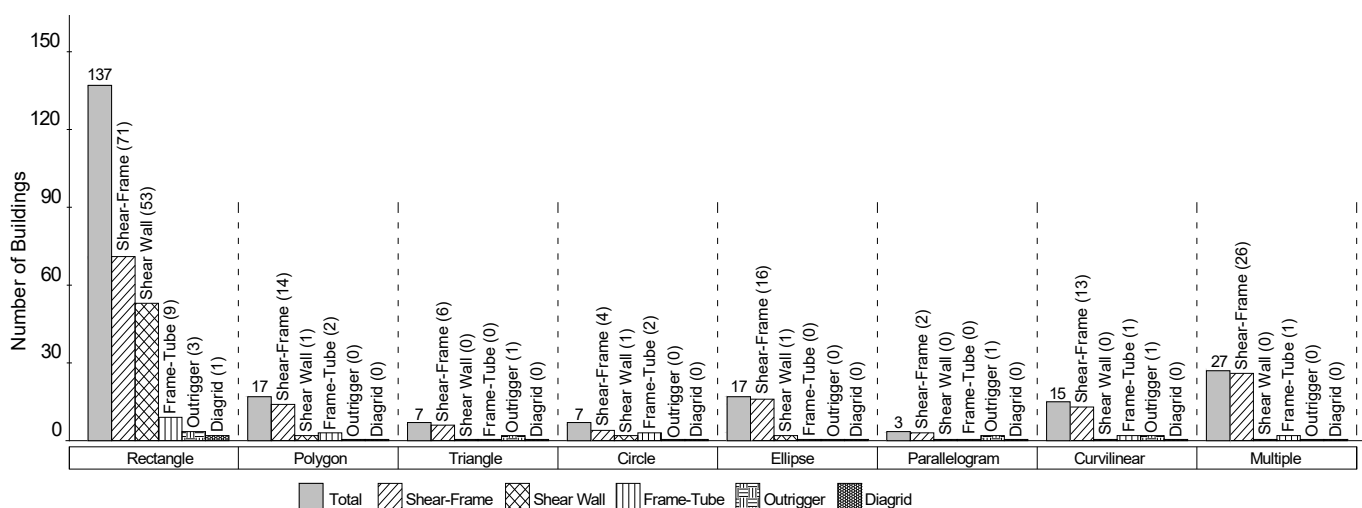


Figure 15. Relation between floor plan and structural system.

4.5. Relation between Building Function and Building Structural System

Figure 16 illustrates the functions of tall buildings and the number of structural systems used in these functions. The grey bars on the left axis of the graph demonstrate the total number of tall buildings.

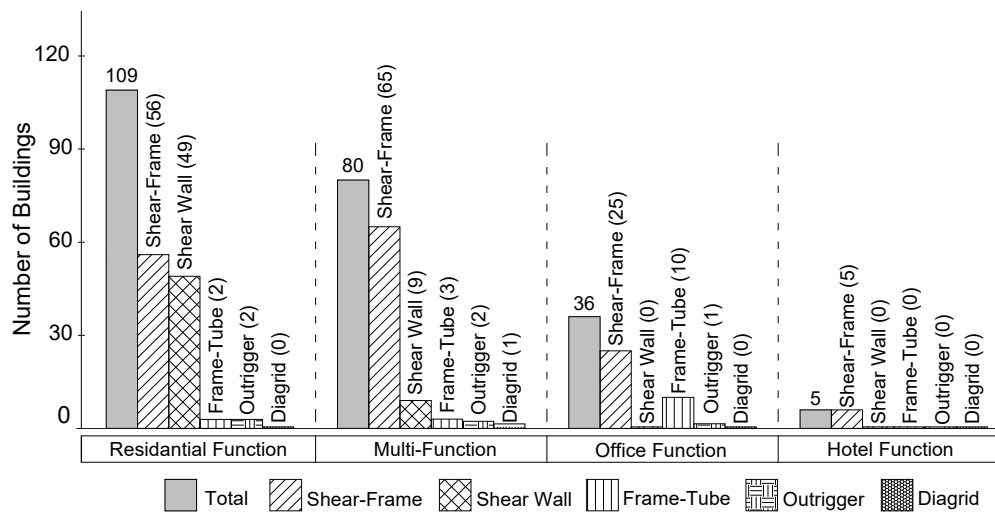


Figure 16. Relation between building function and building structural system.

4.6. Relation between Building Structural System and Building Core Planning

Figure 17 illustrates the tall building structural system and the number of core types used in these systems. The grey bars on the left axis of the graph demonstrate the total number of tall buildings. In the shear-frame system, the central core is the most common design, with a rate of 53%. The central core is followed by the peripheral core at 31.8%, the asymmetric central core at 13.2% and the atrium core at 2.0%. The central core is the most common design in the shear wall system, with a rate of 67.2%. The central core is followed by an asymmetric central core at 22.4% and the peripheral core at 10.4%. In the frame-tube system, 60.0% of the tall buildings are designed with the central core, 26.7% with the peripheral core and 13.3% with the asymmetric central core, while the atrium core is not designed. In the outrigger system, 60.0% are designed with the central core and 40.0% with the peripheral core, while asymmetric central core and atrium core are not designed in this system. The peripheral core is designed in one completed tall building with the diagrid system in the analyzed sample tall building group.

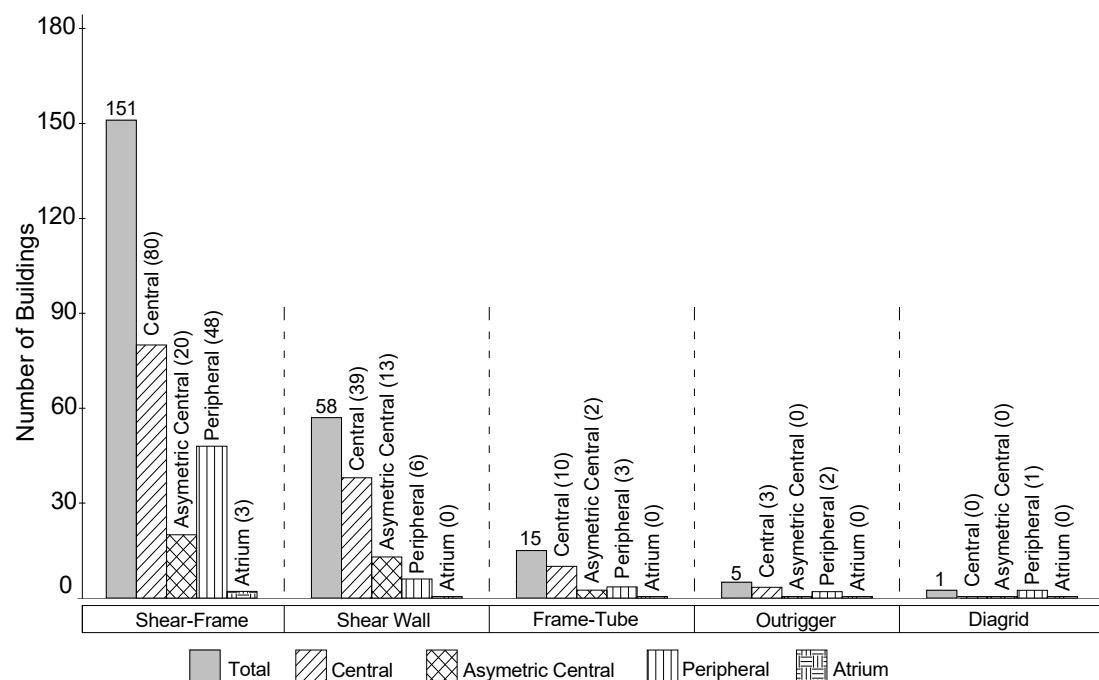


Figure 17. Relation between building structural system and building core type.

4.7. Relation between Building Height and Building Material

Figure 18 illustrates the change in the height of buildings constructed with building materials used in tall buildings in Turkey. The grey bars on the left axis of the graph demonstrate the total number of tall buildings at a given height.

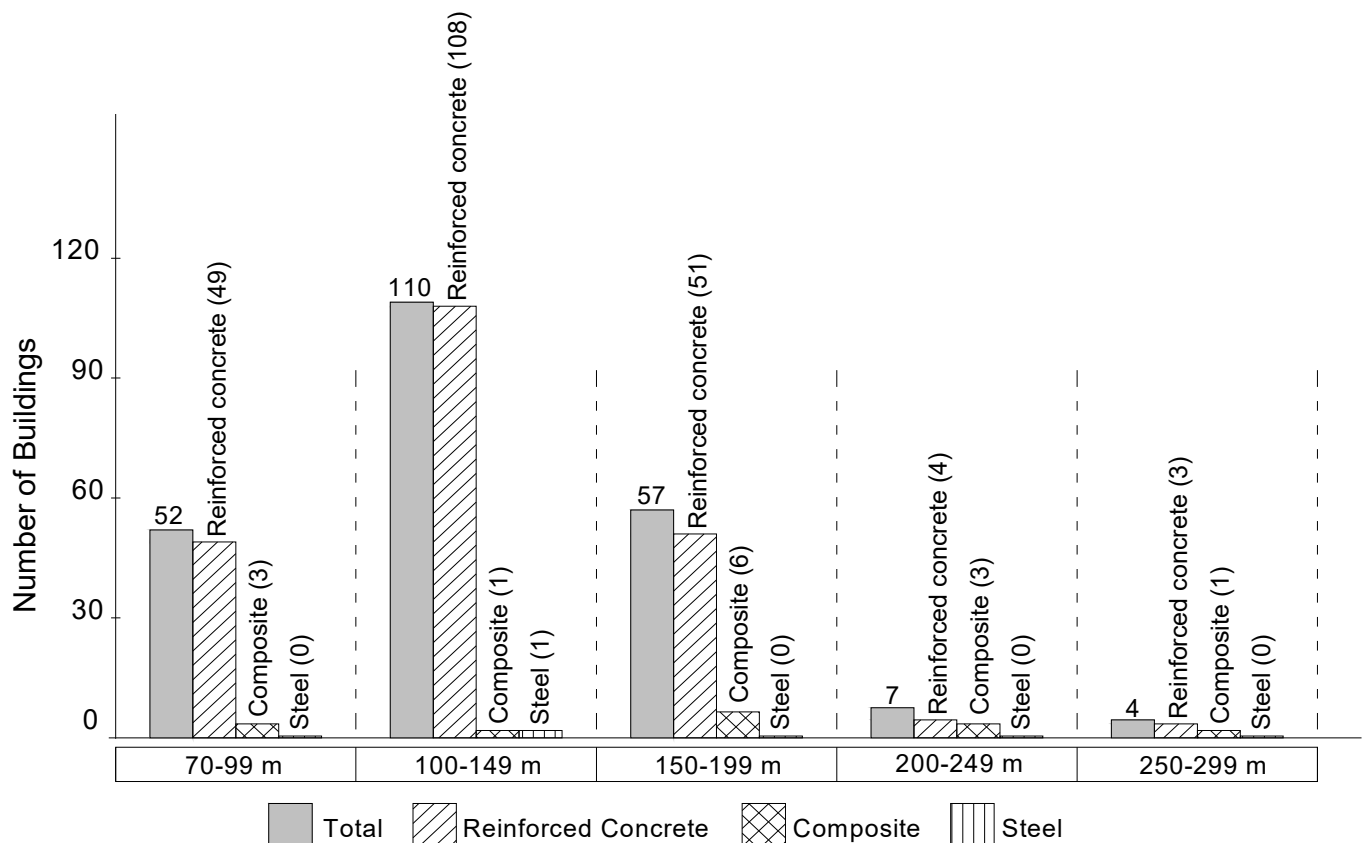


Figure 18. Relation between building height and building material.

The heights of tall buildings constructed with reinforced concrete material are in the range of 70–99 m for 22.8% of them, 100–149 m for 50.2%, 150–199 m for 23.7%, 200–249 m for 1.9% and 250–299 m for 1.4%. The tallest building constructed with reinforced concrete in Turkey is 284 m tall. The heights of tall buildings constructed with composite building material are in the range of 70–99 m for 21.4% of them, 100–149 m for 7.1%, 150–199 m for 43%, 200–249 m for 21.4% and 250–299 m for 7.1%. The tallest building constructed with composite material in Turkey is 261 m tall. There is one tall building constructed with steel construction material in the examined tall building sample group, and the height of this building is 120 m.

4.8. Relation between Building Height and Building Function

Figure 19 illustrates the variation of building heights according to the functions of tall buildings completed in Turkey. The grey bars on the left axis of the graph demonstrate the total number of tall buildings for building functions.

The heights of tall buildings with a residential function in Turkey are in the range of 70–99 m for 21.1% of them, 100–149 m for 54.1%, 150–199 m for 22.1%, 200–249 m for 1.8% and 250–299 m for 0.9%. The tallest building with residential function constructed in Turkey is 284 m tall. The heights of tall buildings with an office function in Turkey are in the range of 70–99 m for 22.2% of them, 100–149 m for 50.0%, 150–199 m for 22.2%, 200–249 m for 2.8% and 250–299 m for 2.8%. The tallest building with an office function constructed in Turkey is 284 m tall. The heights of tall buildings in Turkey with hotel functions are 70–99 m for 60.0%, 100–149 m for 20.0% and 150–199 m for 20.0%. The tallest hotel function

building built in Turkey is 180 m tall. The heights of multi-function tall buildings in Turkey are in the range of 70–99 m for 22.5%, 100–149 m for 32.0%, 150–199 m for 30.0%, 200–249 m for 5.0% and 250–299 m for 2.5%. The tallest building with multiple functions constructed in Turkey is 280 m tall.

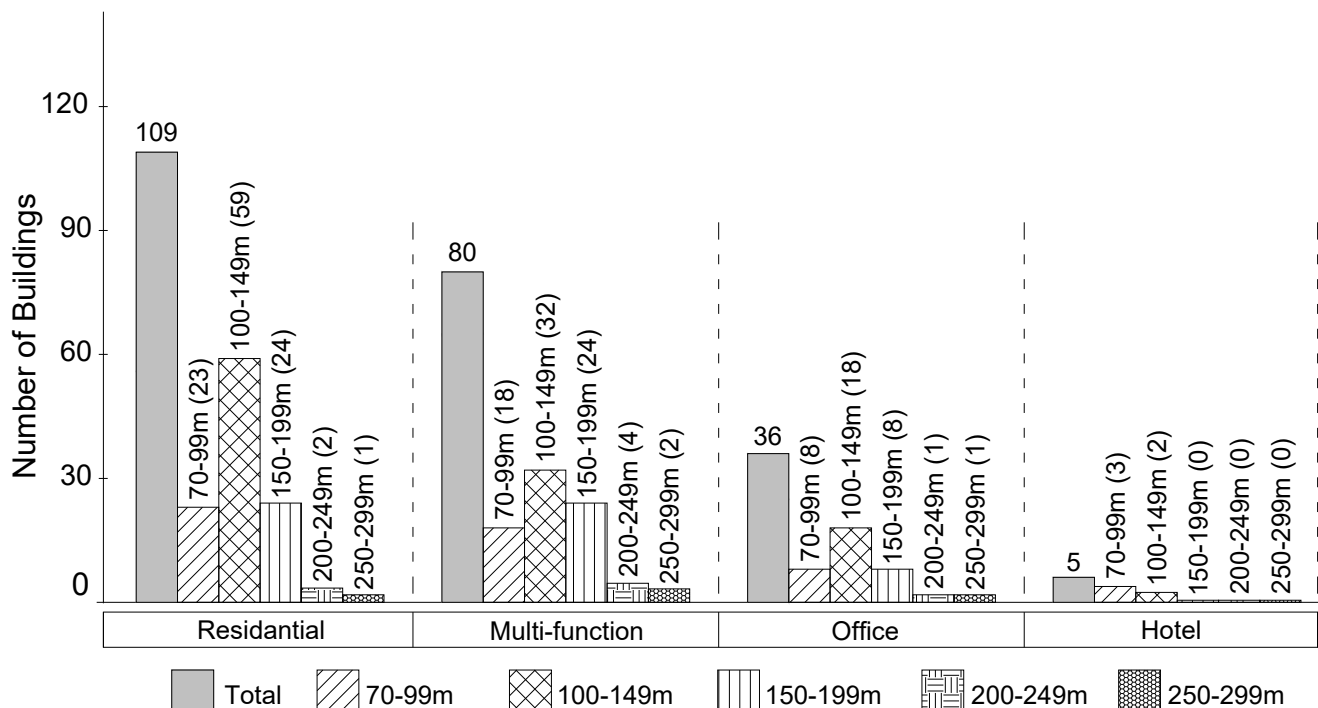


Figure 19. Relation between building height and building function.

5. Conclusions

The increase in demand and interest in tall buildings, especially in big cities in the world and Turkey, the desire to build the tallest and most extraordinary buildings, and the desire for unconventional architectural and structural designs have defined tall architecture. In the design of tall buildings, architects should offer structural strength, compatibility with the requirements of other disciplines, as well as visual appeal. This study is expected to shed light on the status of tall buildings completed in Turkey and aid designers in comprehending the architectural forms, floor plans and structural systems of tall buildings. Based on the information obtained from the 230 tall buildings examined in Turkey, the presented results are intended to assist tall building designers in their architectural and structural design decisions and put forward the basis for comprehensive studies about this subject. Additionally, these results may provide architects and engineers with a design manual for their future tall building designs, enabling them to understand the possibilities and constraints of the architectural and structural design of existing tall buildings. To properly assess the structural system, integrate it with architectural design and take into account both the tall building architecture and structural design, tall building architects need to be knowledgeable about the structural systems and aerodynamic shapes. Otherwise, it is likely that structural and aerodynamic solutions found after the completion of the architectural design may be economically costly or even impossible to implement.

In this study, building height, number of stories, building form, core plan and building floor plan were analyzed concerning the architectural design aspects of tall buildings in Turkey. The highest building ever built in Turkey is 284 m tall and contains 65 storeys. In tall buildings in Turkey, the residential function is typical, followed by the multiple function, and an increase in the multiple function has been noticed in recent years. In tall buildings in Turkey, the rectangular floor plan is frequently employed as the building floor design. In tall buildings in Turkey, the central core is by far the most prevalent core type,

and core designs that are compatible with floor plans, as well as single and symmetrical core designs, are popular. It has been noted that the prismatic building form is frequently utilized in Turkish tall building design and that the use of a free building form has grown recently. While the setback, tapered, discrete clustered and tied across height forms are rarely used, twisted, tilted and partially disjointed forms have never been encountered. It is observed that aerodynamic forms are not used sufficiently in tall building designs in Turkey, and this phenomenon can be analyzed and discussed in detail in future academic articles. Considering the increasing height of buildings in Turkey, tall building designers should consider aerodynamic concerns along with other design concerns early on in the design process.

In this study, structural system material and structural systems were studied in relation to the structural design elements of tall buildings in Turkey. In tall structures in Turkey, reinforced concrete is frequently utilized as the structural system material. However, it has been noticed that the use of composite materials has increased concurrently with an increase in building height in recent years. The most commonly used structural system in tall buildings in Turkey is the shear-frame system, followed by the shear wall system, frame-tube system, outrigger system and diagrid system. Since the heights of the completed tall buildings in Turkey are lower compared to tall buildings in other countries, the braced-tube system, bundled tube system and mega-frame system, which are used in super tall buildings and mega tall buildings, are not used as tall building structural systems in Turkey.

For all structural systems of Turkey's tall buildings, the central core is the most favored arrangement by a wide margin; peripheral and atrium core types are used either once or never for each category in the structural system. Furthermore, while all structural systems are employed in the prismatic form, the most typical design for tall structures, they are rarely or never used in other building forms in Turkey aside from the shear-frame system. Tall buildings over 200 m in Turkey have been designed with shear-frame system and outrigger system.

A new area of expertise was required for the design of tall buildings, which will be among the essential components of cities in the future for a variety of reasons, including the growing number of buildings, the lack of space for new buildings, the perception of tall buildings as a status symbol for nations and cities. In order to meet this need in Turkey, tall building-related courses should be made mandatory in architecture and engineering programs, regulations should cover tall building-related issues, and in-service training for architects and engineers should provide them with the most recent information on tall buildings.

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