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A Comparative Analysis for Land Utilization: Steel and R/C Interlaced Structures

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ABSTRACT

In architecture, interlace structural concept is considered as a new design approach for cosmopolitan cities with high density to minimize the land use and increase the interaction. With various architectural approach, land resources can be minimized by this interlace concept for residential complexes. Such buildings will eliminate the reduction of land resource problem and on the other side safety measures in structural design is incorporated by interlace concept of buildings. This new concept can be constructed steel or reinforced concrete. In this paper, an analytical approach has been presented for these buildings in architecture and structural design. In the research, design considerations were taken for interlaced structures with reinforced concrete and steel. Components of steel structure, isolated footing, and columns. This paper is presenting a step wise process for interlaced structures. They are identification of project area, layout and model preparation, analysis and design of concrete interlaced structure, analysis and design of steel interlaced structure, drafting of the plans and costing and estimation of the structures. Comparison of both reinforced concrete and steel structures were carried out. The main aim of the paper is to provide a comparison between steel and concrete interlaced structure. A cost estimation was carried out to determine optimum design and construction for interlaced structures.

1. Introduction

In today's developed countries, which are also famous with their busy and colorful cities, finding land for residential and commercial buildings has become a big problem. Increasing population, wide range in demands and expectations, and scarcity of land have been the main reasons for this challenge. Architects and the engineers of our time have pushed themselves to find

resolutions to combine functional spaces for both private and public use while also increasing the quality of space, conforming and raising living standards and protecting the environment.

Some of these designs are less than ideal in more than one aspects listed above; but there are significant examples around the world to prove that successful examples for combining public and private spaces in the same complex is possible.

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Historically, buildings used to serve for both residential and commercial purposes. The lower levels were used for commercial purposes while the owner of the building/business used the upper floors as residences. This was very common while the owner of the land and the business was the same person. In time, mixed-use facilities became less popular for various reasons, lands becoming too scarce and too pricey for one person to hold being one of them^[1].

One of the resolutions to address the lack of land is to increase the density of cities. As one of the pioneers of the topic, Clark discussed that the density of the large cities increases at the center and decreases at the suburbs^[2]. However, it should also be kept in mind that density is more than just a number; it certainly depends on the city's age, history, culture, policies, geography, attitudes and economy^[3,4]. So, it may not be appropriate to generalize the situation about the density of cities with 320 different backgrounds, histories and cultural values.

Increasing the height of the buildings in order to increase the occupants in the building is one of the first obvious solutions to increase the density of the cities. Tall buildings have been the research topic of many studies in architecture, engineering and urban planning in the recent decades. With all the technological advancements in the fields of architecture and structural engineering in the last century, design and construction of high-rise structures have been a challenge for both architects and engineers. Today's built environment is a proof of all the improvements in the area. It was a success to build a 10 story building few decades ago, today there are several buildings with more than a hundred floors. This success came with several discussions as they brought up some other challenges that needed to be addressed. Today, there have been several studies in literature assessing tall structures in different aspects such as structural performance^[5-11], environmental sustainability^[12,13], and their effects on urbanism^[14-16]. All of these topics are interconnected to each other and have been discussed widely in the built-environment platforms.

While designing taller buildings and accommodating more space seemed like an appropriate method to increase the density of the cities, the effects of density on the environment are still in question. Claiming that increased density leads to reduced emissions due to shorter travel routes and that it promotes public transportation and lays the opportunity for more effective public transportation, which helps towards a sustainable development, the same study also suggests that tall buildings increase pollution since they change wind direction^[17].

Gehl in his study also defines tall buildings as either

workaholic business environments or cages^[18]. Al-Kodmany lists the studies that agreeing on the negative effects of urban sprawl on the environment due to various reasons such as wasteful use of water, scattered shopping plazas, and amplified air and water pollution^[19]. Urban sprawl is seen as the main reason for the loss of natural habitat and damaged natural ecosystems. It is also linked to serious health problems caused by automobile dependent lifestyle^[19].

As urban sprawl have become inevitable and the central areas of the towns have been more popular and in demand, efforts on building design have started to focus mostly on improving their energy efficiency. While most of this efficiency would depend on the operational costs, construction materials and the processes they go through are also important^[20]. There are many factors affecting the design of structural systems for buildings such as architectural aesthetics, structural efficiency, spatial organizations and availability of resources. Structural systems have evolved significantly throughout the years and have become both efficient and economical in the recent decades. Economic demands, architectural trends and technological developments in structural analysis both necessitated and enabled these changes^[21-23]. Steel and reinforced concrete, as the most common structural materials of the century, have been discussed widely due to their effects on the environment. Though it may not entirely be possible to compare two separate buildings with different construction materials, Guggemos and Horvath conclude that concrete dominated the energy use and emissions during the construction phase while the impact of steel is higher at the life-cycle stage^[24]. Kua and Maghimai in a more recent study, compared different proportions of steel to replace reinforced concrete to compare the Life Cycle Analysis results^[25]. They suggest adopting energy-efficient steel making technologies and increasing the share of secondary steel use to reduce the global warming potential and embodied energy^[25].

Despite all the negative environmental effects listed above, and the debates about the structural materials and their effects on the environment, big cities around the world have started to look alike in the recent decades in terms regarding dense city centers and urban sprawl. Some cities attempt to challenge this by putting certain regulations about building heights into use. A study about Beijing shows that costs of the building height restrictions in terms of land prices, housing output, and land investments and improvement are substantial. The building height restrictions also leads to a shortage in the housing supply, which in turn contributes to urban sprawl. As a result, housing prices increase by 20% and the city edge in-

creased by 12% [26]. The EH/CABE guidelines of the UK Government have a specified set of evaluation criteria that are concerned with both the building and its relation to the area to establish high quality environment for the users [27]. However, despite all these regulations, cities have continued to become increasingly homogenous. Once the design of tall buildings was not the biggest challenge for architects anymore, their attempts focused on the impacts of tall buildings on human scale and social life [28,29]. To keep the decrease the effects of tall buildings while keeping the density at the desired levels, a new design trend started to emerge. With this new approach, commutes would be shorter as residents and workplaces would be together as building complexes would have multiple functions. This has become a much desired trend in large cities in a short period. Many developed or developing countries that have faced with land availability problem started hosting more and more high-rise and interlaced buildings to create more space, entertainment facilities and recreation parks for interaction. Currently, different concepts have been proposed for building giant residential complexes. In this current research, the concept of interconnecting the buildings has been considered as a solution for space development strategy as a social constraint in case of land availability for big cities. The most renowned of these examples is the Interlace in Singapore, designed by Ole Scheeren. Scheeren toppled the proposed twelve 24-story towers, arranged them in 31 six-story rectangular blocks that appear woven, and rotated them 120 degrees. Instead of 115 feet distance between the proposed towers, Scheeren created 200 feet space between towers allowing views to the forest, ocean and other buildings around [30].

In interlace concept, the outline is a diagrammatical exceptional and novel arrangement, yet not an intensely and yearningly urban one. It is here at the urban scale that the undertaking misses the mark. At the huge size of the Interlace, there are various architectural design possibilities are available as seen in Figure 1. Figure 1 simplifies a possible arrangements in design that gives alternatives in structural and constructional perspective. In architecture and design, economy also plays an important role. Therefore, a material selection and comparison for interlace design is given in this paper.



Figure 1. The Interlace Buildings

The aim of this paper is to present a comparative study demonstrating a model for proper and effective utilization of land. The research work includes a complete compre-

hensive analysis of a steel interlaced residential building and a concrete interlaced residential building and their design with various considerations in design and construction.

2. Methodology and Analysis

Research started with architectural and structural investigation. Identification of project area, Layout and model preparation were conducted. Then, analysis and design of concrete interlaced structure, and steel interlaced structure were compared. Drafting of the plans and costing and estimation of the structures using Microsoft project was carried out. Project management plan was carried out for economical implementation. Comparison of both the structures was carried out. Results are important to decide the better and economical structure of a result of comparison of concrete and steel structures. Methodology is given in Figure 2. The various software were used in the research. This research is based on a virtual investigation. The first step in this research is data collection and analysis of this research. In the research, the following realistic design constraints are considered and work has to be done accordingly to overcome these constraints.



Figure 2. Flow chart for Methodology

Environmental Constraints: Since the building is to be constructed in seismic zone, effect of seismic load needs to be considered in the application of loads. Since the area is affected by earthquake forces, a provision is made by considering the seismic loads during design as per the standards, to overcome the environmental design constraints.

Social Constraints: Due to decrease in the land resources with the increasing population of a country, it is proposed to have a building with proper utilization of space.

Health and Safety Constraints: Since the structure takes more expansive and interconnected approach, despite safety provisions in structural design are incorporated. As the building experiences greater loads, to ensure safety, the building is designed for loads giving much importance for safety considerations.

The starting point in selection of a site is the assessment of the sustainability of the site, for the purpose for which building is required, its type and orientation system. The following information is obtained in the planning and data collection phase. The type of building, its

size and shape and overall land area required, The type of city for which the building characteristics is helpful, The population growth and development of the city, The type of materials used and their availability.

The goal of site selection is to find a suitable location to accommodate all functions of the building through evaluation of feasibilities of possible locations from environmental, geographic, economical and engineering stand points. The various steps which are involved in selecting the suitable sites in are: Requirements of land area, Evaluation of factors affecting location, Preliminary office study of the site, Site inspection, Environment study, Review of outline plans and estimates of cost and revenues., Final evaluation and selection, Report and recommendations. The residential building should be located at a place where cost of development is at optimum level and it is an integral part of the city. For evaluation of different available sites following factors are considered: Presence of other buildings, Topography of the area, Obstructions, Wind consideration, Atmospheric factors, Geological factors, Environmental factors, Availability of construction materials, Availability of utilities, Social consideration.

3. Design for the Interlaced Buildings

This part of the study includes the whole planning of the structure. Which includes planning for all the floors. The structure consists of 4 block of 7 floors each. Every block has one apartment on each floor. Elevation views are given in Figure 3 to present the connection in between the buildings. USA Standard codes were used in the design of the buildings.

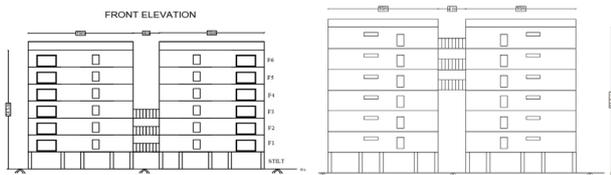


Figure 3. Elevation X-direction and Y direction View

4. Reinforced Concrete Building Analysis

Structural analysis is the computation of deformations, deflections and internal forces or stresses within structures, either for design or for performance evaluation of existing structures (Figures 8, 9). Structural analysis needs input data such as structural loads, the structure geometry and support conditions and the materials properties [31,32]. Output quantities may include support reactions, stresses and displacements. Advanced structural analysis may include the effects of vibrations, stability and non-linear behavior. The 3D model made by an engineering software (Figure

4) for the structure is shown and the bending moment diagram of the structure is shown in the Figure 4. In Figure 5, reinforced concrete sections as beam and column are given.

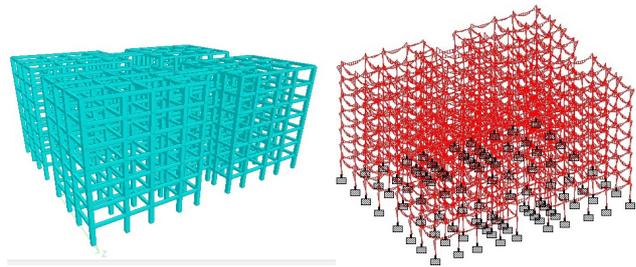


Figure 4. 3D software model and Bending Moment Diagram About Z Axis

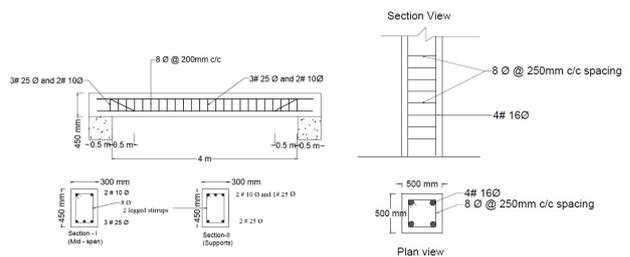


Figure 5. Concrete Beam and Column

5. Steel Analysis and Design

Structural analysis is the computation of deformations, deflections and internal forces or stresses within structures, either for design or for performance evaluation of existing structures. Structural analysis needs input data such as structural loads, the structure geometry and support conditions and the materials properties [33]. Output quantities may include support reactions, stresses and displacements. Advanced structural analysis may include the effects of vibrations, stability and non-linear behavior [34,35]. Analysis of the steel structure is done using an engineering software. As seen in Figure 6. The critical beam and critical column which carries the maximum bending moment and maximum axial force respectively is depicted in Figure 7 and Figure 8. Details are given for comparison purposes.

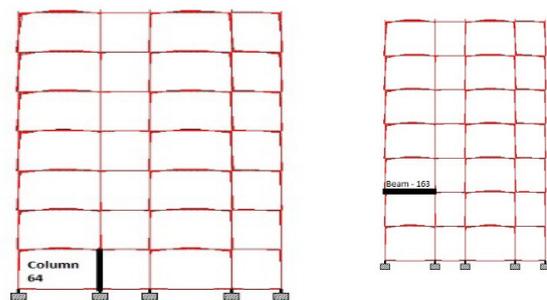


Figure 6. Critical Column and Beam

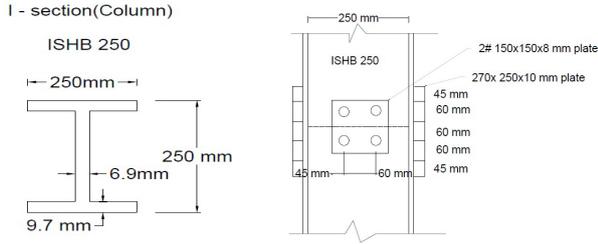


Figure 7. Column I Section and column splice

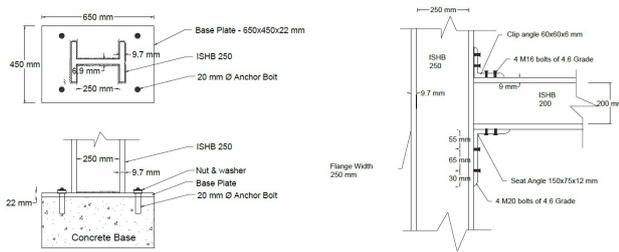


Figure 8. Column Baseplate Connection and Beam column Connection

6. Cost Estimation Process

Estimation is done on Concrete and steel structures in between Table 1 to Table 5 where there is a proper face of accommodation.

Table 1. R/C Building Cost Estimation

No	Description of Bar	Length (m)	Numbers	Total Length	Kg/m	Weight (kg)	Rate/kg	Total Amount
1	Main Straight Bar (25 mm)	3.4	2	6.8	3.982	27.79	\$ 19.49	\$ 541.71
2	Main Bent Up Bar (25 mm)	3.736	1	3.736	3.982	14.87	\$ 19.49	\$ 289.9
3	Anchor Bars (10 mm)	3.13	2	6.26	0.616	3.86	\$ 4.79	\$ 18.48
4	Stirrups (8 mm)	1.6	16	25.6	0.395	10.112	\$ 0.91	\$ 9.02
								\$859.11

Table 5. Steel Building Cost Estimation

No	Description	Length (m)	Number	Area (m ²)	Volume (m ³)	Weight (kg)	Rate/ kg	Rate
1	Beam	14.65	35	0.005094	2.6119485	20,503.8	\$ 0.60	\$12,302
2	Column	24.5	25	0.006971	4.2697375	33,517.4	\$ 060	\$20,110
3	Clip Angle	0.2	140	0.000684	0.019152	150.34	\$ 0.60	\$90.20
4	Seat Angle	0.2	140	0.0027	0.0756	593.46	\$ 0.60	\$356.07
5	Flange Splice		150	0.00675	0.10125	795	\$ 0.60	\$477
6	Web Splice		150	0.0018	0.027	212	\$ 0.60	\$127.2
7	Bolts 16 mm		560	\$3.33			\$ 25.87	\$14,487.2
8	Bolts 20mm		660	\$2.66			\$ 25.48	\$16,816.8
Total								\$64,775.2
Total cost of the steel framed structure - 4 * 64775.29 = \$259,101.16								

Table 2. Beam (5m) - Per Building

No	Description Of Bar	Length (m)	Numbers	Total Length	Kg/m	Weight (kg)	Rate/ unit	Total Amount (Rs)
1	Main Straight Bar (25 mm)	5.4	2	10.8	3.982	43.005	\$ 19.49	\$ 838.17
2	Main Bent Up Bar (25 mm)	5.736	1	5.736	3.982	22.84	\$ 19.49	\$ 445.15
3	Anchor Bars (10 mm)	5.13	2	10.26	0.616	7.55	\$ 4.79	\$ 36.16
4	Stirrups (8 mm)	1.6	26	41.6	0.395	16.43	\$ 0.91	\$ 14.95
								\$ 1334.43

Table 3. Beam (3m) - Per Building

No	Description of Bar	Length (m)	Numbers	Total Length	Kg/m	Weight (kg)	Rate/kg	Total Amount
1	Main Straight Bar (16 mm)	3.788	4	15.152	1.580	24	\$ 7.49	\$ 179.76
2	Stirrups (8 mm)	1.98	14	27.72	0.395	10.95	\$ 0.91	\$ 9.96
								\$ 189.72

Table 4. Concrete Estimation

Beams (3 m) - quantity = 56.7 m ³ Rate/ m ³ = \$191 Total amount = \$10829.7	Beam (5 m) - quantity = 94.5 m ³ Rate/m ³ = \$191 Total amount = \$18049.5	Column - quantity = 153.125 m ³ Rate /m ³ = \$191 Total amount = \$29246.87 Total cost of concrete = \$ 58124.7
Total cost of concrete framed structure = \$60,507.96		
Total concrete structure for 4 frames - 4 * 60,507.96 = \$242,031.84		

7. Conclusion

The main objective of this paper is to provide a comparison between the reinforced concrete and steel interlaced

structures. The reinforced concrete is the most widely used material for construction of high-rise structures. Steel is an alternative can be used to build high rise structure. Decision was taken to analyze, design and compare a six floor Interlaced building both in concrete and steel as materials and to find out which one is economical in general construction of the building. In this paper, the planning of the Interlaced Structure includes plan of the Residential and Elevations of the building. The planning was drawn with the aid of software. The sustainability constraint regarding the durability of the interlaced structure was tackled while the environmental effects of wind and the erratic weather conditions are encountered by suitable design procedures provided by the Bureau of USA Standards. The Knowledge on analysis of the building was obtained by using an engineering software. From the analysis results, the capacities of critical elements were identified and an appropriate design was carried out by us. The design of the components of the Structural system was done manually as per USA Standard codes. In addition to the Design of the Structural members, Determination of the effective cost by estimation for the concrete and steel members is done. Optimum design of structure is found out as a result and it is found to be the reinforced concrete structure. According to research results, concrete material cost is found less than the steel material cost. However, due to labor and time components, steel would have advantage over the concrete.

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