# COMPARATIVE CONSTRUCTION COST FOR STEEL STRUCTURES AND REINFORCED CONCRETE STRUCTURES WITH MOMENT-RESISTING FRAME (MRF)

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**Khosro Zehro Zehro: COMPARATIVE CONSTRUCTION COST FOR STEEL STRUCTURES AND REINFORCED CONCRETE STRUCTURES WITH MOMENT-RESISTING FRAME (MRF)**

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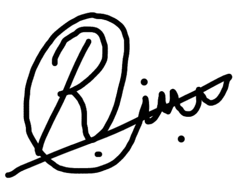

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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## ABSTRACT

The innovation in building construction technologies, structural systems, materials, and analytical approaches facilitate the analysis and design of multi-story structures. The structural designer has several options for selecting the structure's material and system; steel and reinforced concrete (RC) frames with various structural systems can be used to construct multi-story buildings. It is essential to consider that the chosen material must satisfy the design requirements and the allowable construction cost. For clients, contractors, and estimators, estimating cost is the major issue in multi-story construction. The activity and material prices often change according to using different parameters that affect the total project cost. Therefore, preparing comparative research on steel and RC framed structures is essential to specify better materials regards to entire construction cost considering the performance and execution time. This research is beneficial in selecting the right material and suitable design parameters for the multi-story frame members. Various models are evaluated and designed in the study by utilizing four different structural analysis parameters such as spans, stories' number, story height, and multiple materials. The total calculated amount of materials carried out the cost estimation of the multi-story models in the ideCAD software from analyzed and designed structures and the obtained prices in Erbil-Iraq's market. Finally, the resulting costs of entire construction models were compared and found that the structures with steel were revealed to be significantly more costly than the RC structures in all cases.



***Keywords**:* Structural frame; cost; estimation; steel structure; construction material; MRF; RC

# ÖZET

Bina inşaat teknolojileri, yapısal sistemler, malzemeler ve analitik yaklaşımlardaki yenilik, çok katlı yapıların analizini ve tasarımını kolaylaştırır. Yapısal tasarımcı, yapının malzemesini ve sistemini seçmeye karar vermek için çeşitli seçeneklere sahiptir; Çok katlı binaların yapımında çeşitli taşıyıcı sistemlere sahip çelik ve betonarme çerçeveler kullanılabilir. Seçilen malzemenin tasarım gereksinimlerini ve izin verilen inşaat maliyetini karşılaması gerektiğini dikkate almak önemlidir. Müşteriler, yükleniciler ve tahminciler için maliyet tahmini, çok katlı inşaatta en önemli sorundur çünkü faaliyet ve malzeme fiyatları, toplam proje maliyetini etkileyen farklı parametrelerin kullanımına göre genellikle yukarı doğru değişmektedir. Bu nedenle, çelik ve betonarme iskeletli yapılar üzerinde karşılaştırmalı araştırma hazırlamak, performans ve uygulama süresi dikkate alınarak tüm inşaat maliyeti açısından daha iyi malzemeler belirlemek için gereklidir. Bu araştırma, çok katlı çerçeve elemanları için doğru malzeme ve uygun tasarım parametrelerinin seçilmesinde faydalıdır. Açıklıklar, kat sayısı, kat yüksekliği ve çoklu malzemeler gibi dört farklı yapısal analiz parametresi kullanılarak çalışmada çeşitli modeller değerlendirilir ve tasarlanır. Hesaplanan toplam malzeme miktarı, ideCAD yazılımındaki çok katlı modellerin analiz ve tasarlanan yapılardan maliyet tahminini ve Erbil-Irak pazarında elde edilen fiyatları gerçekleştirdi. Son olarak, tüm inşaat modellerinin ortaya çıkan maliyetleri karşılaştırıldı ve çelikle yapılan yapıların her durumda betonarme yapılardan önemli ölçüde daha maliyetli olduğu ortaya çıktı.

***Anahtar Kelimeler:*** Yapısal çerçeve; maliyet; tahmin; Çelik yapı; inşaat malzemesi; ana dirençli çerçeve (ADÇ); betonarme

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# LIST OF ABBREVIATIONS AND SYMBOL

| | |
|---|---|
| **ACI:** | American Concrete Institute |
| **AISC:** | American Institute for Steel Construction |
| **ASCE:** | American Society for Civil Engineering |
| **MRF:** | Moment-resisting Frame |
| **RC** | Reinforced Concrete |
| **RCS** | Reinforced Concrete Structure |
| **SS** | Steel Structure |
| **S** | Number of stories |
| **H** | Height of story |
| **L** | Span length |
| **N** | Number of spans |

# CHAPTER 1
# INTRODUCTION

## 1.1 Overview

In past years, the huge investment in the building industry has given the researchers a strong incentive to find proper structural material and systems to save total construction costs. Previous researchers have attempted to choose a suitable material and system of structures with the best construction techniques and minimum cost (Soetanto, 2006).

Besides, it is necessary for all owners, consultants, contractors, and customers to strive to develop all aspects of market safety, satisfy consumers, cost delivery, environmental impacts, profitability, and help the employee. If the problems of increasing construction cost could be determined before execution, it will be easier to schedule the solution and cheaply be worked with. The selection of members' material and the choice of the procurement method have a major impact on the outcome of framed structure projects (Goodier et al., 2006).

Significant growth as the demand for commercial and residential multi-story (tall) buildings can be seen in the last century. In modern engineering construction, the design of tall buildings structures has got a significant branch and can use different structural frame systems to design buildings (Zalka, 2020).

Generally, design can be defined as "formulating an idea then converting it into a real model" (Blockley, 2005). In the construction projects, the concept of design and process of design is mostly identified in several aspects. The decision to select a structural building frame is among the important items in the multi-story construction projects since the type of structure is relatively optimized in responding to projects' and customers' expenses (Ballal and Sher, 2003).

In an attempt to improve construction cost and efficiency, innovative materials and techniques are used, and the construction sector tries to achieve new approaches and developments. The correct choice of materials dramatically impacts the quality and short- and long-term cost of the constructed project. Within the short-term, the structure must satisfy its customer's requirements, like; building finalizes with the reasonable cost, and building changes for the future client's needs is as the long-term effects (Sadat, 2014).

In the initial phases of the multi-story project design, the cost is the significant factor for strategic decisions (Günaydın and Doğan, 2004). It should be considering the advantages of multiple structural solutions such that the suitable option can be discovered and selected quickly throughout a construction project. The precise cost estimation during the construction of structures is from essential points in cost management. It is also a practical detail of cost predicting in similar future projects, so the estimated cost's ultimate objective can be received (Sarma and Adeli, 2002).

Researchers have found advanced techniques to make the building execution cheaper, faster and much more specific. There will be an alternative option of materials for structural building construction, i.e., steel, concrete, masonry, or timber. While there are several variables, but steel and RC are used more than other options as they simplified the construction of structures (Masterman, 2006).

When considering a specific type of building construction, the student might be faced with the decision, "Should be using the steel or RC in the structure?". Here will be various thoughts, the supporters of RC will be referred that steel materials will corrode, but those who prefer steel structures refer to that the concrete material has a heavier weight and take more spaces in the building plan (McCormac, and Brown, 2015).

In the structural construction design stage, determining the structural system and members material is essential since every modification through the construction process will have substantial consequences on the cost of construction and schedules. It can also affect the configuration of other fundamental structural items like foundation works, cladding stage, and other finishing activities. In a specific location, the building structure code will recommend a material rather than the others. For example, many areas have fire risk places, so the desirable condition for fireproof material is RC's selection (Barrett Byrd Associates, 2014). By increasing the height of the multi-story buildings, the structural system becomes more critical for resisting lateral loads than resisting gravity loads (Moon, 2005).

In structural frame buildings, designers and developers sometimes incorrectly predict the cost of steel in frame construction compared to RC frames. Many designers believe that steel material is more costly relative to RC and shows lower interest in using steel for structural frames (Papavasileiou and Charmpis, 2016).

Some properties such as; considerable strength related to lightweight, easiness of installation, site implementation, transportation cost, different levels of strength and a wide range of sections are the fundamental factors that utilize steel in most multi-story buildings. Choosing a material used in building structures may also be influenced by conditions of foundation soil. For instance, the lighter weight material (e.g., steel) must be used in the structural frame if the soil condition under the foundation is poor (Gunel and Ilgin, 2007).

The structural frame, combined with the foundation to construct the stiffen and strengthen the structure, is an essential part of the load resisting approach. MRFs are based on preparing horizontal load resistance beyond the frames' planes (Borse and Joshi, 2019).

### 1.2 Reinforced Concrete

In recent decades, the framed structure construction was dominated by the in-situ type of concrete. Even since the 1990s, buildings with concrete have developed exponentially. With the development of innovative technologies, especially the formwork, concrete, and reinforcing advancements, concrete structural frames have altered considerably. For example, the Reading University Production Engineering Group report clarified that the crucial drawback in the most economical RC building construction is the formwork with its changeovers (Eustace, 2008).

The overall process for cost evaluation of RC construction is shown in Figure 1.1. Note that perhaps the output data becomes a cost of the whole structure or only one cubic meter of concrete. Combining the cost of man-hours, cost of material, and the repeating factors of activities, the input data could be minimized to the concrete quantities, steel bar, and formwork surface (Slobbe, 2015).

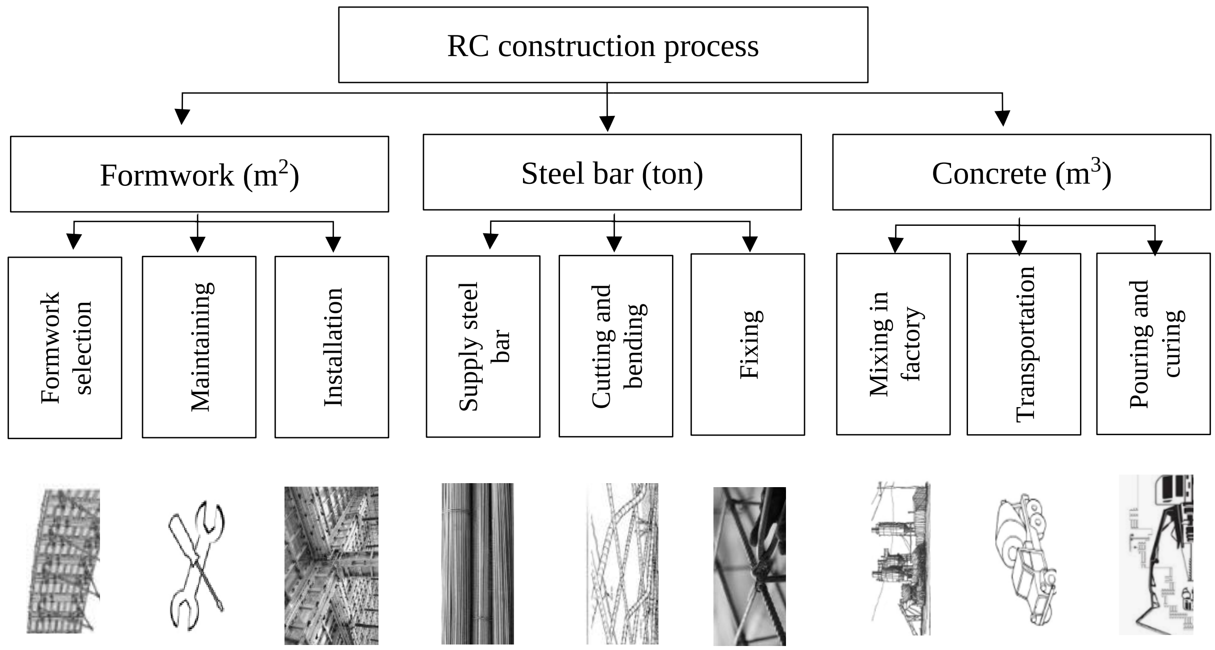



**Figure 1.1:** Analysis of RC construction activities

By cost-effective and providing safety of construction approaches, the RC structures have provided an innovative change in the building construction sector. In recent times, concrete had been used as a construction material; RC's practical use was found in 1867. The cause of using RC by engineers and architects is for its features like high resistance to fire and moldability properties that provide the structure and its parts in various decorative configurations (Azad et al., 2019).

Currently, RC becomes a default choice when deciding on the material for multi-story frame construction. The deciding on concrete is done by prevailing believes which the RC structure would be cost-effective more than corresponding structural steel. Utmost economical condition rests on such factors in the situation of RC structures. The cost depends mostly on the raw material and workers needed for concrete, formwork, and reinforcing bar. Using RC, a lightweight structure with a more reinforcing bar will be more costly than using a heavy one and less reinforcing bar (and contrariwise). For such a purpose, optimizing RC is deemed more complicated than steel (Del Pico, 2012).

There is no data available to determine RC or steel used in structural construction, but RC is considered the favorite materials. As specified by Barrett Byrd Associates (2014), some other properties do the RC more favor that includes:

a) *Cheaper in construction:* It is believed that RC structures become cheaper related to steel structures. The cost difference perception is an essential factor that was typically given for deciding on RC structures. Furthermore, experts are more familiar with the design of RC and its execution. The RC structures details appear to be simpler relatively, and concrete construction permits extra flexibility in the implementation process.

b) *Durability:* Concrete, by its origin, is quite a durable construction material. It can resist explosion, vandalism, accidental failure, and needs a little maintaining. No extra coatings are required to protecting constructed concrete from deterioration.

c) *Resistance to fire:* RC structure has intrinsic resistance to fire and therefore does not need any extra protection against fire. It can reduce the expense of protective coating to fire, which can usually account for approximately 10-15% of the frame's cost in steel structures. It also decreases the necessity for extra on-site trading.

### 1.3 Steel

In the early of twenties century, the steel become popular in structural building construction and concrete lost a considerable market contribution in the structural framed market for steel structure. With constructing steel structures, the economic outcomes involve two variables, the quantity of steel, which determines the cost of the material and the workload (bolting, welding, etc.). Steel frames can be assessed in terms of mass reduction (which contributes to little materials), connection quantity, or structural simplification (workload reduction and produced mass, etc.) (Zaveri et al., 2016).

In worldwide, the industry of steel is developed rapidly. Steel frames are more favorable than RC frames, which have a more significant earthquake response (Sangave et al., 2015). Mittal et al. (2010) determined the main features of using steel in building structures are:

a) *Implementation speed:* Structural construction by steel allows utilizing prefabricated elements that can be easily installed on-site, and it reduces substantial execution time relative to many other construction materials. In analyzing the cost efficiency, the relation of implementation time to cost mostly does not be considered. That including costs like the initial stage to get profit; the cost decreases due to a quicker execution schedule and low initial and overall costs.

b) *Lightweight**:*** Steel structures have lightweight, even if concrete floors or useful resources have been used. In a steel structure, the overall construction weight is nearly thirty percent lighter than the RC structure. The decrease in total structure weight results in reducing sizes of foundations and their costs.

c) *Integration services and longer spans:* Long distances can be realized to utilize steel members, and the distances between 12 - 18 m often are performed by using different steel structure systems. A more extended span structure enables more flexibility in use due to fewer columns and more free space. Also, utilities may be built more conveniently within lesser beam depth, thus decreasing the story height by nearly 30 cm per story. The decrease in story heights results in a considerable drop in cladding price, specifically in multi-story high-rise buildings.

d) *Safety and performance:* Within controlled situations, steel members are designed and produced off-site and result in higher quality assurance. Relative to RC building, in construction processes, using pre-fabricated elements decrease activities in the worksite. This activity reduction results in the need for much fewer on-site workers and leads to higher safety in construction (Davison, 2012).

e) *Recyclability:* The only recycled and reused materials are steel. About 95 percent of steel components might be recycled and will be reused. The construction speed and minimized site disturbance often are from environmental advantages (Davison, 2012; Mittal et al., 2010).

### 1.4 Structural Resisting Frame System

The central portion of every building is its frame. Usually, a multi-story building frame and members' material are identified as the load-bearing system that includes; columns, beams, and other building elements fixed with the foundation. The selection of a structural resisting system has a significant effect on the customer's value of the building. It presents both usability and stability and governs the cost of construction to a considerable rate. As a frame could assist the speed of project delivery, it would be a significant profit for the consumer by saving the construction cost (Blockley, 2005).

The primary requirement in efficient multi-story frame design is included according to clients' demands, and buildings work that must have a proper response. The right design considers the; enhanced strength to gravity and lateral loads, minimal cost, lighter weight, maximum construction efficiency, or a pairing of all these features. Also, architectures' decision to get the required performance of the structure is another condition that influences the structural system selection (Rathod et al., 2016).

The entire project's primary point is the correct option of a relatively lateral load-bearing system since the various systems of structures attempt to change the planned cost (Esmaili et al., 2008). As a result of a survey conducted by the RIBA Work Plan (2007), ten main points for structural frame system and materials selection were listed in Table 1.1 follows:

**Table 1.1:** Main points affecting the selection of framed structures systems and materials

| No. | subject | Description |
|---|---|---|
| 1 | Decision of Architecture | Attractive points and outcomes. |
| 2 | Usability of building | Resistance to fire, the span between columns, durability and adaptable for future changes. |
| 3 | Implementation cost | Cost of design and execution. |
| 4 | Priority | Priority for some frame system and materials. |
| 5 | Schedule | Construction duration time. |
| 6 | Execution risk | Customer requirements, prices, cost and assurance in project delivery. |
| 7 | Worksite | Site availability, conditions of ground and restriction of height. |
| 8 | Volume of building | Story numbers. |
| 9 | The capability of the supply chain | Services flexibility and simplicity in material supply. |
| 10 | Multi-story performance | Cost of the entire story life, effect of environments, recyclability, and thermal conditions. |

Constructing a multi-story building is a complex process with horizontal loads that play an important role in structural design, which required a system that can resist the imposed lateral load. Idrus and Newman (2002) argued that frame material's selection principles mainly focus on implementation cost. Also, the survey performed by Soetanto et al. (2006) demonstrated some advantages of frame system and materials in building structures as mentioned below:

- Has proper story height
- The whole building seems durable
- The construction process will be faster
- Enhancing the assurance of customers
- High efficiency of a multi-story structure
- The cumulative risks are considered to be minimum
- Will be adaptable for any future changes in the building
- The elements connections are buildable and designed well
- It designs for safely construction and maintenance
- The outcomes, architectural and structural resisting systems are entirely accommodated

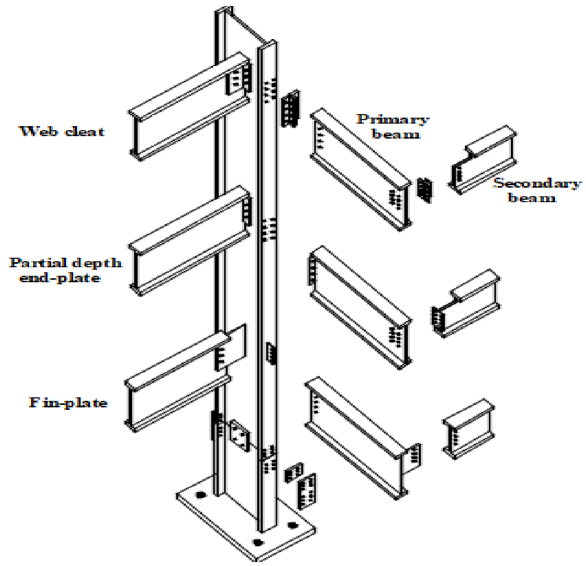



**Figure 1.2:** Connections of beam and columns used as shear type of connections

### 1.5 Construction Cost Estimation

Dysert (2006) describes cost estimation as "the analytical process of measuring the cost or pricing the resources needed by the range of investing options, activities or projects." Furthermore, Dabhade et al. (2009) identified that estimating cost as "the approximating art of predicted expenses value or cost of activities based on available information."

The cost evaluation of steel and RC frame structures is carried out by particular process and the current price in the market for labors, material, and other relevant substances or the possible difficulties of some companies producing steel structures. Therefore, the initial estimated cost plays an important role in any building construction, allowing designers and owners to assess project possibility and manage costs accurately (Feng and Li, 2013). Elhag et al. (2005) stated that estimators develop cost estimation by concerning these phases:

- Specify quantitative information required in project details for measuring.
- Evaluate the collected information.
- Create schedules.

A building construction crosses through basically two stages; the skeleton stage and finishing stage, each of them will have its significant factors that influence the overall construction project's expenses. The crucial parameters that significantly affect construction costs include story height, type of soil under foundation, the distance between columns, slab type, and situation of the construction project. Precise cost estimation will help cost saving in construction activities more productive (Kim, et al., 2004).

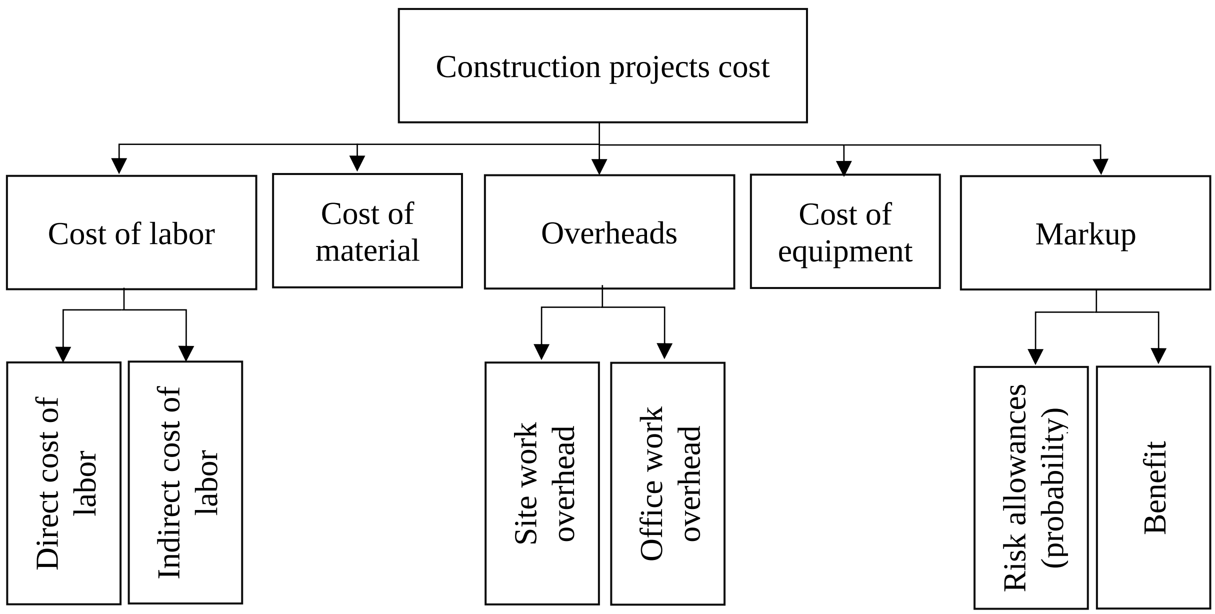



**Figure 1.3:** Analysis of projects construction costs

Antohie (2009) specified that "the primary objective of costs estimation in the projects is to determine the required finishing expense for the construction." According to Ostwald (2001), the projects' construction costs can be divided to five groups, as shown in Figure 1.5, which involves the overall project expense. Cost, duration, and performance identify the outcome of any construction project. The primary estimated construction cost is considered according to the labors and materials resource cost used in planning, installing, and implementing scheduled activities (Alzebdeh et al., 2019).

By selecting the type of concrete, the RC cost can be estimated. To estimate the cost of the RC constructions, firstly should have data on:

1. Steel price (per ton) and quantities of steel in the volume of concrete (per cubic meter)
2. Price of the ready concrete, pump and concrete transportation from the factory to the construction field
3. Wooden formworks' cost
4. Steel installation cost
5. Casting concrete and curing process cost

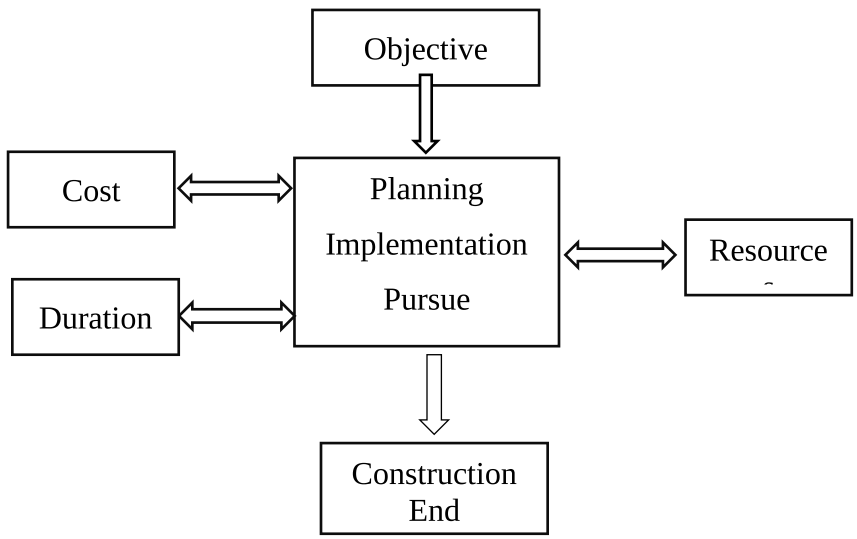



**Figure 1.4:** Project construction aims and requirements

The description of building construction stages is represented in Figure 1.6. The first step in executing structures is the objective's identification of that project for the planning, implementing, and pursuing. The three primary variables that affect the above-described process include costs, duration, and resources (El-Reedy, 2010).

The cost estimation of steel construction structures differs significantly from the estimated calculation cost for RC construction structures since particular designs are required. The connections are among the most significant portions of the building design and execution of steel frame structures. It is adapted that cost of connections nearly 50% of the overall cost of steel structural frame. Figure 1.7 shows that the percentage of the total construction cost of a steel frame structure can be determined; each part demonstrates the overall structural cost (Dagostino and Peterson, 2011).

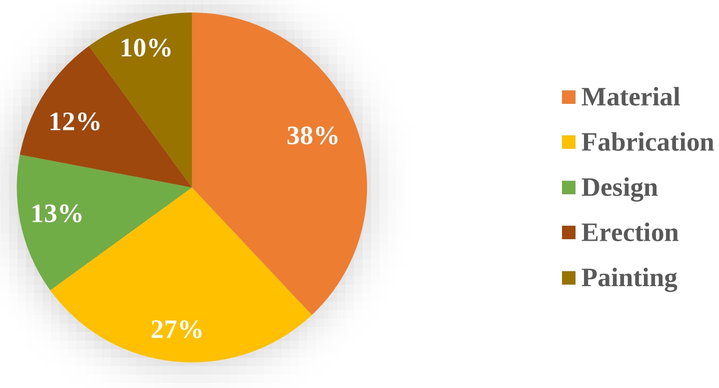



**Figure 1.5:** Percentage of resources and activities cost in the construction of steel structures

The estimated cost will involve the running costs from the constructed buildings and the uses and maintenance. The precise estimation of the cost in any building is measured with how the expected expense is corresponding the actual costs in the finished project (Alzebdeh et al., 2019). Construction economies should notice the extra costs of modification, stories number, size of the building, grid position, and project design. The models have the potential to calculate quantities and fees for these agents. Current prices must obtain the needed data at the market rather than any incorrect data (Chandanie and Kandemulla, 2014).

### 1.6 The studies' Objectives and Aims

This study considers the material and labor quantities' difference required in constructing various structural frame parameters such as different story heights, different span lengths, stories' number, and using other materials with their effect on total construction cost.

This study aims to provide recommendations or suggestions to determine an appropriate material in the construction of the multi-story structural building. The significant factor impact on choosing a system for framed structures is initial construction cost. Therefore, the proposed systems are that with the lower construction cost. This study's significance is to present a clear view about construction material and labor cost by using proper material (steel and RC) in a multi-story structural frame, which will directly affect the owner or customer spending to complete their building.

## 1.7 Thesis Limitation

The study is limited to the structural frame's construction cost (rigid structure; foundation, columns, beams, and slabs) without walls and stairs construction. So, the cost of finishing materials and labors in both RC and steel structures are the same or near each other in total cost.

## 1.8 Thesis Organization

The research includes five chapters as below:

***Chapter 1:*** It presents an introduction about the study's background and clarifies the study's objectives; also, it contains a summary of the structural frame materials and their cost estimation.

***Chapter 2:*** This chapter is derived from recent studies relevant to this thesis. Two sections explain the related literature; the first section reviewed the evaluation and compared the various framed structures. The second section discussed the estimation of quantities and cost of materials and labors.

***Chapter 3:*** In this chapter, the theories and formulations are illustrated, including the details of used materials and the modeling procedure of structures, analysis and design software, and market prices for materials.

***Chapter 4:*** The consequences quantities of the model’s analysis and design are explained and discussed to the amount and costs of the total material of multi-stories buildings.

***Chapter 5:*** The conclusions and recommendations obtained by this research are discussed in chapter five.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 General

The recent studies about the various materials and systems for constructing structural frames are reviewed in chapter two. Moreover, previous research on the quantity and cost estimate of new building construction materials is also developed in this chapter.

## 2.2 Literature Review on Structural Resisting System and Materials

The structural frames are composed of some nets which gathered elements. By filling the spaces between the members of frames as necessary, the structure's construction will be complete. Typically, this type of structure will be modified according to shape variations, layout dissymmetry, and the rate of load they carry. Various materials such as steel, concrete, or wood may be used in building construction in various sizes. The frame involves all kinds of connected beams and columns that equally carry and resist horizontal and vertical forces. The framed structure system is cost-effective and lightweight related to structures with masonry systems (Ambrose and Tripeny, 2011).

Gunel and Ilgin (2007) illustrated that with evolution in technology for construction in all types of multi-story structures (such as; RC structure, steel structure (SS), and composite structure), various load resisting frame systems arrived as follow:

- Moment-resisting (rigid) frame
- Shear wall or braced
- Braced tube frame
- Outrigger frame
- Bundled tube frame
- Framed tube

Construction materials play a significant role throughout the construction sector. In addition to cost, they have potent effects on attain sustainability objectives. In construction approaches, accurate chooses material will decrease the environment's damage and increase beneficial economic impact and public efficiency (Franzonia, 2011). There are wide alternatives of materials that can be used in multi-story structural member construction. Because of steel and concrete's natural construction features, they are extensively used by engineers and contractors around the world (Ellobody and Young, 2011).

Al Shamrani and Schierle (2007) illustrated that deciding whether to use the steel or concrete frame depends greatly on the type of construction, site conditions, project function, and many projects in regards to team member's thoughts. In general, the frame materials' selection is made by considering cost and less consideration to the performance and functionality features. In deciding on the structural resisting system, each of the architectural and structural design engineers must consider precisely all building requirements.

A structural design engineer is a member of a group working on designing a multi-story structure. An architecture engineer typically provides the necessary configuration in the team, and structural, electrical and mechanical engineers design specific systems for the building. Wight (2009) identified four primary requirements that should be fulfilled by the structure:

1. *Structural sufficiency*: Structural sufficiency includes two crucial aspects.
   a) A building structure should be strong enough which will support all expected loads.
   b) The structure should not crack, deflect, vibrate, or tilt, affecting the building's functionality.

2. *Economy*: A structure's total expenses must not exceed the budget of the client. Often, in design, teamwork can contribute to economies as a whole.

3. *Maintainability*: A system must be designed in a form that needs minimum simple maintenance methods.

4. *Appropriateness:* Regulating the spans, spaces, access, story heights, and traffic flow should supplement the desired usage. The building must suit its situation and also be aesthetically appealing.

Naik (2008) presented a guideline for the multi-story structural materials’ sustainability; they tried to figure out whether steel or concrete are more sustainable material in structural constructions? They concluded a significant subject that had been questioned mostly by architects, structural designers, and contractors. The construction professionals observe two main issues in analyzing the construction materials’ sustainability: firstly, determine the best outlines to the materials, and secondly, comparing the material with each other. Stark (2011) reported that commonly "concrete" and "steel" organized two various worlds in multi-story structural construction engineering.

In building construction, the economic point should be considered according to the required maintaining and performance. Furthermore, by using a life-cycle expense investigation system, this requirement could be evaluated. Sustainable construction materials can initially be more costly but based on long term building cost, and the economic concepts will be more explicit (Sarja, 2003).

Increasing the number of stories over ten floors will be mandatory for both economy and functionality to decrease the structure's weight. For instance, reducing 5% of wall and story weight could decrease the weight by 50 % on the ground floor. That implies that the lower stories can minimize columns' sizes, resulting in more space available and can reduce the dimensions of the foundation in the design (Jayachandran, 2009). Elhegazy et al. (2020) stated that the selection of structural systems and materials is combined with optimizing the structures. This selection process depends either on the construction sites’ ground soil or material properties, and they suggested the guidelines and procedures for choosing appropriate structural material and systems.

The frame of multi-stories comprises nearly 7% to 12% of total construction cost in a building related to the constructed building's kind and situation. Moreover, efforts were increased to decide at the design stages to reduce the cost, completion time, and the rate of defects in the building construction projects (Kolltveit and Grønhaug, 2004).

Commonly, when examining various materials for an equivalent objective, the cost is the primary concern. Designers should assess multiple variables toward successful results and optimal decisions when choosing materials. Impact of environmental efficiency, cost, execution time, safety, physical and mechanical characteristics are included within the processing. For the optimal design of framed structures, the multi-story buildings' total cost will drop significantly (Florez et al., 2013).

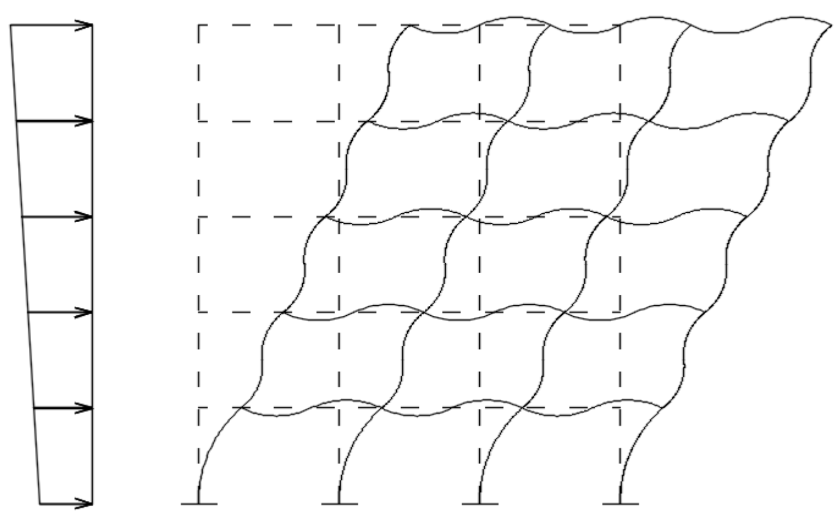
### 2.2.1 Moment-resisting frame (MRF) or rigid frame structure

MRF structures are composed of beams and columns interlocked by connections with high resistance to moments. MRFs' horizontal stability is proportioned to the deformation resistance of beams, columns, and their designed connections. Due to the intrinsic strength of RC junctions, the rigid frame is considered efficient for RC structures. Also, the form of rigid-frame will be performed for steel structures by enhancing the adequate connection rigidity. Still, moment-resisting connections in steel structures are often revealed to be expensive. The MRF reaction often resists gravity load. The negative moment in the beams near columns converts to the positive moments at mid-span that is considerably less than in simply supported spans (Smith and Coull, 1991).

In a rigid structural frame, the stiffness and strength are equivalent to the columns and beam dimensions and have an inverse proportion with the columns' distance. Special consideration must be prepared by design and drawing connections, mainly for structures built in earthquake regions. Rigid building frames are mostly ductile but less resistant to severe shaking relative to the shear wall and braced steel structures. In high rise multi-stories, the drift of frame members can be assessed by rigidity more than its strength (Azad and Chowdhury, 2019).

MRF is designed for regions with traditionally low earthquake ground motion. The lateral resistance to bending in rigid frame members is proportioned to the bending rigidity of the beams, columns, and connections in the bending layer and should have adequate rigidity to maintain the unchanged initial angles intersected members (Varghese and Borkar, 2013).

From the perspective of the multi-story structural frame engineers, a suitable structural frame system and materials for high-rise buildings beside construction cost should consider two other essential aspects: stiffness and strength. The performance of lateral rigidity depends on the distance between columns, the number of frames, the number of spans in the structure, and the gross internal story height. When the MRF is exposed to an external horizontal load, the deformation of beams and columns initially resists the structure's horizontal shears. The deformations induce a shear mode to modify the frame mechanism. The rigidity of individual frame members regulates the functionality of the frame (see Figure 1.2). The deep members have more resistance to improve the deformation rigidity (Rashid et al., 2016).



Horizontal load Side sway of MRF

**Figure 2.1:** Effect of lateral loads on rigid framed structures

The rigid frames achieve their lateral stiffness, specifically member's bending that interlocked with fixed connections. The design of connections must be in a manner that joints have sufficient rigidity, strength, and minimum deformation. The members bending should be less useful for distributing moments and internal forces in the building structure or through the entire frame bending. The unbraced rigid frame must resist horizontal loading without leaning on stability with a different system for bracing. The frame members should resist the whole designed forces, which includes gravity loads plus lateral loads. Additionally, when the frame is exposed to seismic and wind loads, its lateral stiffness must have enough resistance to side-swayed (Badami and Suresh, 2014).

### 2.2.2 Types of connections

The structure connections form significant for rigidity of structure, load resisting, the structure's strength, and the load-bearing mechanisms. By considering the form of restriction, the connections can be simple, semi-rigid, or rigid. The type of connections and their properties for RC and steel frame are explained as follow:

***1) Steel members connection***

The moment resistance connection and shear resistance connections are the most often used connections (Sadat, 2014).

a) *Moment-resisting connections:* The moment-resisting connections convey the moment through the connections. Two common forms of moment-resisting connections used in steel frames are described below:

- ❖ A moment resistance connection with full-restrained

  Transmit moment among the connected frame members by minimum rotation (see Figure 1.3). The relation can be presumed in the design of the structural frame that not permits any relevant rotation. Full restrained connections must have adequate rigidity and strength to sustain interlocked linked members (AISC Specification, 2005).

- ❖ A moment-resisting connection with partially (semi-rigid)-restrained

  Transmit moment, but rotating of connected steel members cannot be neglected. The design of the frame structures must involve the deformation reaction properties of the connection. Connections with partial-rigid moment resistance are those with the medium rate of rotation between full-restrained connections and hinge (simple) connections. Semi-rigid connections are those when the restrained rotation is nearly 20% to 90% of the required resistance to the angle changing (Salmon et al., 2008; AISC Specification, 2005). That implies that the moment transferred through the connection may be zero (or in minimum amount) even in simple structures in the case of partially restrained systems.

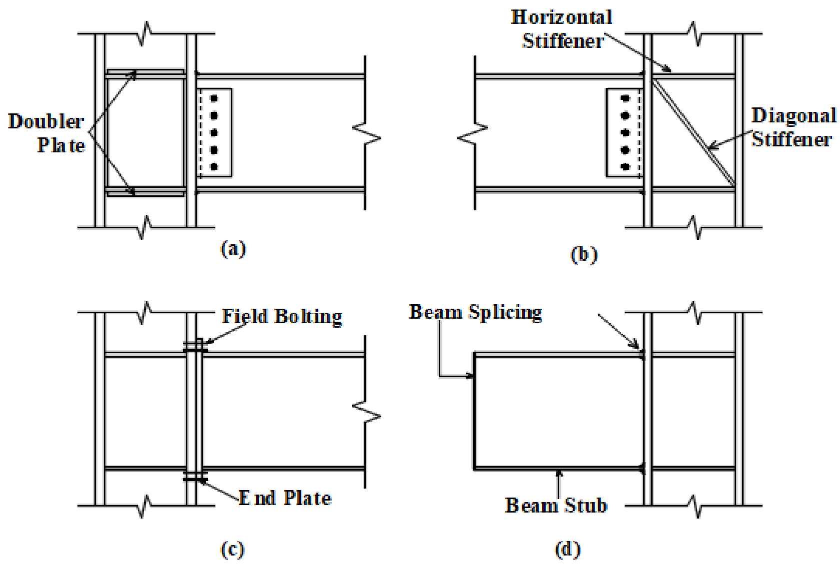



**Figure 2.2:** Full restrained connections a) Double plate welded and bolted connection. b) Diagonal stiffen welded and bolted connection. c) Endplate with bolt connections. d) Beam stub welding to the column.

*b) Simple (hinge) connections:* A hinge connection conveys a minimal moment through the connections. A simple connection can be expected in the frame structure design that permits unrestrained rotation among the connected members of the frame. The simple connections must have adequate rotation ability to handle the necessary rotation, as specified by the structure analysis (Salmon et al., 2008). Figure 1.4 identifies the common connections that will be implemented for the simple type of connections.

***2) RC members connections (joints)***

The connection of RC frame joints is generally a rigid (full restrained) connection. Typically, all connections in the column and beam member, girder and beams member, slab and beams member, etc., are poured with concrete in the monolithic form.

### 2.2.3 Reinforced concrete (RC) structure

The RC has always been utilized for structural members in multi-story buildings. Concrete is perhaps the common multi-story construction material in many countries, a default choice for such structures when choosing a members' material. Multi-story structures that use steel in structural members are few and encountered rarely. There is no traceable data able to show the market dominance of concrete and steel frame systems in constructing multi-story buildings. Currently, concrete is believed to be the prevailing option. Compared to steel, concrete materials prove to be the optimal construction material to decrease lateral sway, labor, and materials costs (Rochmanto, 2017).

Both RC and steel materials have many important properties and can be used effectively for many structural elements. With excellent results, they are mostly utilized together through the same frame member. The construction material's choice to be utilized for a specific building depends on the structure's height, column to column span, the structural system used, conditions of the soil under foundation, architectural requirements, and relevant building construction codes. Steel, RC, and wall-bearing material are efficient for building construction structures equal to or less than 4-stories. Steel and RC materials are cost-effective with high stability that utilized in multi-stories from 4 to around 20-stories. However, over 20-stories, RC becomes much competitive, and currently, many high-rise RC structures are constructed globally. The tallest multi-story building with RC is the 74-story, 261.8 m in the Chicago with the name "Water Tower Place," and the CN tower with 446.5 m in Toronto is the world's tallest tower structure built with RC (McCormac and Russell, 2015).

The construction of RC frames takes more time since they need to utilize formworks and 28 days to gain their required strength. Besides, the processing can be tedious to stepping buildings construction. Even so, steel is considered lightweight, flexible, and easier in construction and demolishing. With steel as material, construction delays become lesser and unpredicted costs often have eliminated or reduced in conventional buildings. It is revealed that labor costs associated with materials are profitable features with steel building construction over in-situ RC building construction (Mehta et al., 2008).

### 2.2.4 Steel structure

With ascending the height of multi-story structures, using new materials in building construction becomes necessary. The low production rate, high primary construction cost, and insufficient steel professionals in building and designing are the primary factors for deciding on RC to construct structures. The low construction execution time, limited activity types, and the feature of recyclability are characteristics that enhanced the probability of using steel instead of RC in framed structures. The fast implementation of construction means rapid development in the economy (Celikag and Naimi, 2011).

The design process must be assessed the lower construction cost by utilizing different materials for the multi-story structure. Not long ago, many high-rise buildings structures, like the Chicago Sears Tower, which is the higher United States tower, were constructed with steel material. Steel multi-story frames have rarely been built in non-developing countries and are often determined by the client's requirements if constructed.

By implementing tall building structures, the construction of the steel frame has taken a higher rate of total building's cost compared to other types of materials. Usually, RC frame implementation requires more extensive activities and more execution time but needs lesser cost than a steel frame. The most crucial steel structure's characteristics are that the total life-cycle cost is low, shorter construction execution time, durability, higher structural strength, flexibility in design, and recyclability features (Barrett, 2000).

By assessing the sustainability for every alternate design, construction materials often play a significant role. Poured concrete and steel both have particular features that can contribute to accomplishing a project's sustainability. Proper implementation of the applications in the steel construction sector is an important consideration. The construction of steel structures is perceived to become a cost-saving solution in multi-story structures. Also, structural steel's sustainability feature correlates with shorter execution time, higher strength, higher durability, and recyclability (Limbare and Dode, 2018).

Generally speaking, the most recyclable type of material in the construction industry is steel. Without reducing its original characteristics assets, protecting inherent resources, and minimize construction waste in worksite landfills, it will be recycled, again and again, consequently decreasing two significant problems facing the construction industry (figure 2.1). And even steel structure construction is categorized as the dry construction method; thus, the construction process's pollution will be reduced or eliminated (Simões et al., 2012).

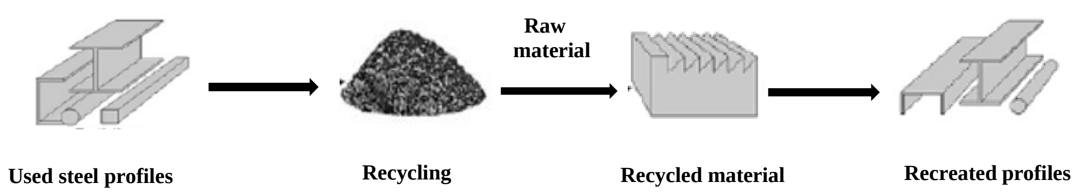



**Figure 2.3:** The process of steel recycling and reusing in the construction sector

The price of constructing columns with steel is considerably more costly relative to all other construction forms. In such situations, columns by steel are about twice the expense of columns by RC (Hasançebi, 2017). The findings revealed that bolts' connections are more favored in steel frames, and the welding system should be prohibited as possible. Besides the steel structure’s expensive construction cost compared to the construction with RC, it has a benefit for the lightness of buildings. It could be more beneficial in low-rise building structures, such as low-rise parking areas and even structures that haven’t fire hazards (Mills, 2010).

The structural steel lightness design feature leads for more favor of this material, especially for the regions with poor subgrade soil. The reaction of supports in RC frame structures will be 23% more related to steel frame structures by less in weight. The structure weights are positively correlated to the total system's performance for resisting vertical and horizontal loads (Sangave et al., 2015).

There are two critical harmful properties of using steel in constructing structures: the first is the corrosion feature by some solutions or wetted condition. The second is the quick gaining of heat that impacts strength reduction by the fire attack. But different techniques are used to restrict these problems, and both characteristics are usually must coatings to protect steel as utilizing structural constructions (Teja and Chamberlin, 2020).

Compared to steel material, the immense concrete usage in structural construction, particularly in developed countries, is mostly related to its low primary construction cost. The construction cost changes due to the regions and relies mainly on local experiences. (Mohammed, 2012). There are some advantageous and disadvantageous of RC and steel materials in construction of multi-story structures as explained in Table 2.1 and 2.2.

**Table 2.1:** Advantageous of RC and steel material in construction of multi-story building structures

| Reinforced Concrete | Steel |
|---|---|
| • RC structure is cost-effective more than its corresponding steel structure. | • By using prefabricated steel members, the structural construction can be easily installed in site. |
| • Concrete is a durable construction material, and can resist explosion, vandalism and accidental failure. | • Using pre-fabricated steel elements reduce the activities in the projects field therefore, need for fewer site workers and also higher construction safety |
| • It has a moldability properties that provide the structure and its members in various decorative configurations | • The depth of steel beams is lesser than RC beams, so the height of each story will decrease, and this results in a considerable cost saving of cladding and walls covering, specifically in tall buildings |
| • High resistance to fire and water | • Transportation expense was low |
| • Concrete has a longer serviceability life in comparison to other building materials. | • Steel has a high strength/weight ratio and can be used in areas where the sub-grade conditions under the foundation is poor. By minimizing the weight of structure, the sizes |

| | |
|---|---|
| | of foundations and their costs will be decrease. |
| • RC compared to other building materials has a high compressive strength. | • Good fatigue strength in steel structures. |
| • By moldability feature of RC to any required shape, its used in precast structural members. It yields rigid members with less apparent deflection | • In the steel structures the column sections are smaller and takes less areas in the building plan, and also can widening the span length for any length that require in the plan. |
| • The RC buildings are more durable than any other building materials. | • Steel is the only recycled and reused material. About 95 percent of steel components might be recycled and will be reused. |
| • The cost of maintenance in RC is very low. | • Prefabricated steel sections allow time saving and increases the efficiency of the entire construction process. |
| • Compared to steel structure, RC requires less skilled labor for the execution of the structure. | • Structural steel construction is classified as dry construction method; since the environment's pollution will be reduced or eliminated. |
| • With using reinforcement, RC can resist a good amount of tensile stress. | • Steel is a material with flexible and strong features, and because of its ductility feature and by considerable force it can be bent slowly. |

**Table 2.2:** Disadvantageous of RC and steel material in construction of multi-story building structures

| Reinforced Concrete | Steel |
|---|---|
| • The RC structure has a heavier weight due to its larger sections. | • The initial construction cost of steel structures is high. |
| • The RC column section is greater in size and take more areas in the building plan. | • The steel has corrosion feature as contact with some solutions or in wetted condition. |
| • The formworks' cost is relatively high. | • The strength of steel will reduce substantially when imposed to fire. |

| | |
|---|---|
| • The tensile strength of RC is about one-tenth of its compressive strength. | • Steel structure construction requires skilled labor for the installation of the structure. |
| • The compressive strength of concrete will decrease in the case of shrinkage that cause development in cracks and loss of strength. | • Due to high strength/weight ratio, steel members are in general slender and more vulnerable to buckling in compression members. |
| • The RC structural construction need to more execution time. | |

### 2.3 Literature Review on Quantities and Cost Estimation

Cost in construction management is one of the three critical issues in which the project is assessed as successful if it is finished with the determined cost, scheduled time, and required quality. Whereby, the weak strategy or inaccurate prediction of the budget could instantly transform an anticipated benefit towards loss (Cheng et al., 2010).

Unlike all other factors, cost demonstrates the structural system's choice and has a prominent role in deciding on this issue. The use or function of buildings is the primary purpose of selecting a proper type of structural material to accommodate a given behavior (Haroglu et al., 2009). The optimizing of cost decreases the total cost and provides exhaustive information about the structure for most related materials and other construction costs. All required manufacturing and installation activities are included in the expense function and represent the cost of construction and the cost of material (Pavlovčič et al., 2004).

The project becomes a series of complex, unique, and tied activities that aim and should be executed by the specified cost and requirements. Every project is going through the total life-cycle from initiation to finalization, including specifying the project's aims, scheduling the activities, executing the works, managing progress, and completing the construction project. The different project participants' requirements must be identified and adequately considered in the design process and ensuring reasonable decisions, i.e., the choice of material in frame structures (Wysocki, 2007).

The majority of recent studies have researched laborers' productivity since it is predicted that laborers' cost in the construction sector is around 33% to 50% of the entire constructed structures cost. The labor cost is unpredictable and variable, unlike other components of project cost, therefore the impact of various variables on the productivity of labors would have to be considered. The labor cost can be decreased at a proportional rate by rising productivity (Hanna, 2005).

The effects of some variables on predicting the cost could tend the estimators to achieve accurate models of cost estimation and construct better construction structures. Expense parameters have been extensively investigated, but various viewpoints and opinions are formed (Elhag and Boussabaine, 1999).

Costs are a significant issue in the comparison between RC and steel structures. Since in construction, expensive structures were typically ignored if a cheaper alternative is available for the same purpose. It's quite helpful to specify the weight of the material used in building structures, as it will influence foundation costs or the soil improvement cost (Patil and Kewate, 2015).

In every construction project, the project estimator that expect the construction quantities and determine its exact cost must be professional and has many previous experiences on project estimation. Estimation in the project includes the calculation of possible costs of construction within that project. Since the estimates are provided before the actual construction stage, it is essential to prepare detailed research and consideration include the construction implementation documents (Dagostino and Peterson, 2011).

In verification of recent research, Ujene and Idoro (2015) reported that construction costs comprise materials, labor, machinery, equipment, and overhead expenses. All the costs are grouped into two types; direct and indirect construction expenses to simplifying estimations. The direct construction costs are detectable to an operation or activity item range by approximately 65 % to 93 % of the project's overall cost. In contrast, the indirect construction costs represent a lesser rate of the entire construction costs. The direct construction costs formed a significant amount of the project's overall cost. Such costs are being budgeted, controlled, and monitored much more efficiently than the indirect construction costs.

Cost is the primary determinant in delivering projects and is perceived as the most critical project performance parameters. Researchers have been continuously searching for alternate procurement systems, construction methods, cost predictions, and monitoring methods due to the high construction costs, persistent cost failure, and some other project quality factors (Memon et al., 2010).

Morrison (2006) asserts that cost estimation is the foremost step in the cost scheduling process, selected material, and construction activities. They also argue that by effective cost estimation, the construction objectives can be achieved with cost scheduling. The first step of the evaluation is to identify the variables that contribute to achieving the estimated quality obtained in practice by surveying real quantities and evaluating all these variables' impact. The three objectives of planning for cost include:

1. Provide a better value of money for building's customer.
2. Achieving a reasonable and balanced distribution between the different sections of the construction activities with the available budget.
3. To maintain the overall spending on construction by the amount of funds that the client previously agreed to pay.

Costs of construction are often subject to variations that lead to ascending in the long period, making the pricing task more difficult. Material prices, resources of human and other expenses are continually fluctuating. The economic instability will significantly affect the firms, particularly on long-term construction projects and mega construction projects. Special considerations are needed to minimize possible financial risks (Elfahham, 2019).

Furthermore, precise scheduling and planning are significant steps to ensure that building construction can be completed with its determined budgets. Cost estimation is an attribute that will helps managers and supervisors to identify potential risks and provide an effective solution. Several research types have been conducted to provide an accurate cost prediction model and technique that can complement conventional cost estimation approaches (Vahdani, 2016). The ultimate decision is of particular significance since the frame of structure interacts with some other building components that could be influencing their standard and feasibility (Soetanto et al., 2007).

The construction of projects goes per two main stages: the skeleton frame and the finishing stage, each of which impacts the overall cost of the project. There are several variables for choosing the skeleton, where all of the stakeholders perceive that stories number and the average area of floors will be the most effective construction cost variables. They think that the project's cost is less affected by the span length, the column numbers, room number, and the project's place (Kestner et al., 2010). A successful constructed project shall not satisfy just the performance requirements but even should consider expense objectives. Westhuizen and Fitzgerald (2005) reported that “proper cost," "proper execution time," and "proper performance" are the crucial targets to complete a construction project successfully.

### 2.3.1 Controlling construction cost

In the construction outcome, appropriate controlling of cost is a crucial aspect. The primary stage in cost management is to define the variables that influence project construction costs. It can classify current factors into two main groups: quantitative and qualitative factors. The industry investigators have made several attempts to extend methods that only quantitative agents can consider (Elchaig et al., 2005). According to a wide range of variables that have to be assessed, the accurate cost of constructed projects is hard to predict. Usually, the real finished cost of the completed structure is greater than the costs that are budgeted. Gould (2005) illustrated that the initial construction stage's imprecise estimation is the most significant source of extra costs.

The estimation is the broad calculation of the future cost within the construction project, and also budget indicates the rate of stakeholders expending money. The most precise estimated cost is that which can be administered the real cost with the determined budget and ensured to the contractors for their specified profit.

# CHAPTER 3
# METHOD OF ANALYSIS

## 3.1 Research Strategy

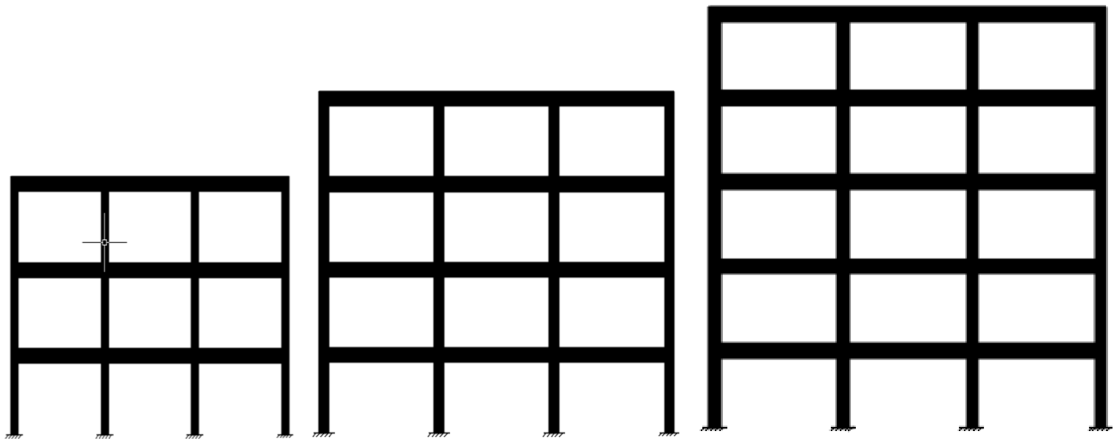
In this chapter, a quantitative approach is chosen to determine the quantities and prices for different materials of steel and RC building structures. To fulfill the study's objective, various models have been designed, analyzed according to different parameters including story heights, span lengths, number of stories, and usage of the steel and RC materials. Afterward, the quantities and costs of building structures were estimated and compared based on the different structural frame materials.

## 3.2 Used Parameters for Frame Analyzing and Design

Distinctive kinds of 3D steel and RC frames are thought about and exposed to the analysis and designing. For the resistance system of horizontal loads, only MRF is considered. Other parameters have been changed for the structural systems that include; the span length (L) of 4, 5, 5.5, 6 and 7 m, the number of stories (S) of 3- and 4-story for (Low-rise), 5-story for (Med-rise) have been considered, the number of spans (N) of 3 spans and the height of stories (H) of 3.3 and 3.6 meters are applied. As a result, this research database contains 60 models of buildings for two different materials (steel and RC) that are analyzed and designed.

## 3.3 Illustrating Structural Frame Models by Figures

- *The number of stories (S):* Low-rise (3-story) and (4-story), med-rise (5-story) RC and steel structures with MRF are investigated and modeled in ideCAD software (Figure 3.1 illustrated the number of stories of the evaluated models).



3-Story (Low-rise) 4-story (Low-rise) 5-story (Med-rise)

**Figure 3.1:** Number of stories of the evaluated models

- *Number of spans(N):* 3-span

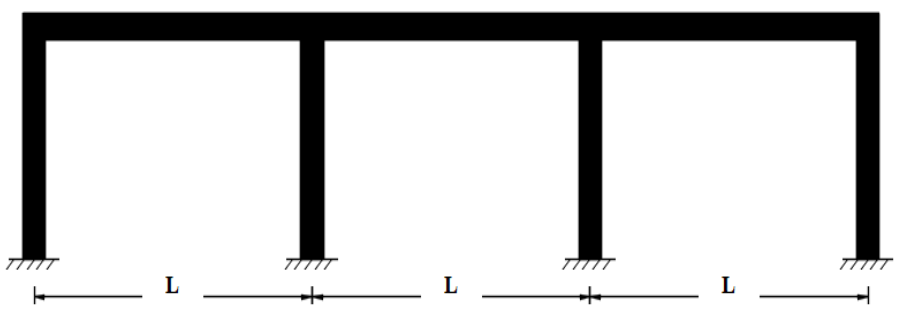



**Figure 3.2:** Number of spans

- *Height of stories (H):* 3.3 m and 3.6 m

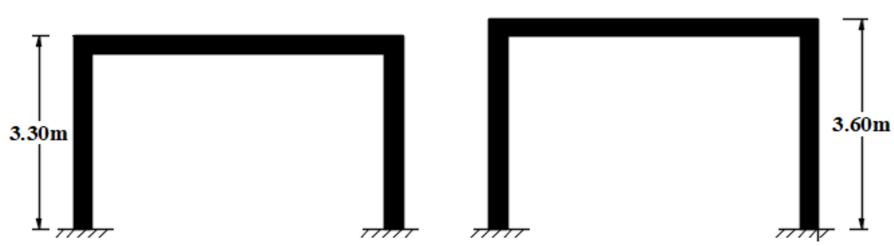



**Figure 3.3:** Stories’ heights

- *Span length(L):* 4 m, 5 m, 5.5 m, 6 m and 7 m

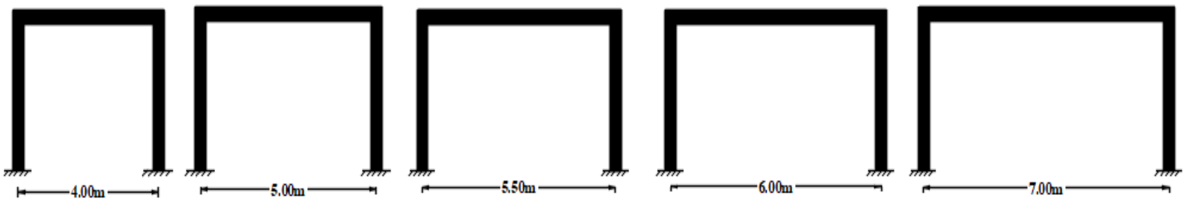



**Figure 3.4:** Different span lengths

- *Number of analyzed and designed models:* 3(S) ×5 (L) ×2 (H) ×2 (material types) = 60 models
- *Location:* Erbil, Kurdistan Region, Iraq
- *Materials prices:* All materials prices are in USD ($) according to Gulan construction company (10/8/2020). The wage for installing steel bars (steel fixers) is 100 $ per ton, and installation of steel sections (welding and bolting) in steel structures is 80 $ per ton.

**Table 3.1:** Materials' price in Erbil-Iraq

| No. | Materials | Unit | Amount | Price ($) |
|---|---|---|---|---|
| 1 | Formwork | $m^2$ | 1 | 8 |
| 2 | Reinforcement bar | ton | 1 | 570 |
| 3 | Concrete | $m^3$ | 1 | 42 |
| 4 | Steel sections | ton | 1 | 640 |

- *Used materials:* Steel and RC material were used. Designing models with different materials is the most crucial parameter in this comparative study.

### 3.4 Modeling and Analyzing Software

The ideCAD structural computer software program was used to model, analyze, and design building structures. It was developed by ideYAPI Inc., and contains useful features to analyze and design models for both steel and RC frames and give the precise amount of all member's material quantities (concrete, formwork, steel bar, steel sections). The specific version of the software is ideCAD structural 10.

### 3.5 Materials Properties

Concrete and steel are two materials that were used in this study. Table 3.2 represents the properties of the materials and applied gravity loads on the framed structures.

**Table 3.2:** Material properties and loads on the structure

| Parameter | Value |
|---|---|
| Fy of steel sections | 420 N/mm$^2$ |
| Fu of steel sections | 448 N/mm$^2$ |
| F'c for concrete | 30 N/mm$^2$ |
| Elastic modulus of steel | 200,000 N/mm$^2$ |
| Fy in reinforcement bar | 420 N/mm$^2$ |
| Concrete unit weight | 24 kN/m$^3$ |
| Elastic modulus of concrete | 25,743 N/mm$^2$ |
| Live load | 2.5 kN/m$^2$ |
| Super dead load | 2 kN/m$^2$ |
| Soil bearing capacity | 15 t/m$^3$ |
| Soil unit weight | 2.1 t/m$^3$ |

#### 3.5.1 Concrete

Concrete probably is a construction material, having an essential role through all engineering structures. The most significant characteristics of concrete are its compression strength and low construction cost. Typically, the amount of concrete strength is determined by testing cube specimens' strength in the 28 days. Formability is from the significance of concrete, i.e., can molding the required shapes in different structural types.

Concrete has a longer serviceability life in comparison to other building materials. Concrete structures could be utilized indefinitely by reasonable conditions without decreasing their ability to carrying loads. It can be related to that, due to the lengthy stage of cement mix solidification, the concrete strength will not reduce over time, and it rises over a longer time, determined by years.

When standards and execution are in the correct processes, concrete is extremely durable, water and fire-resistant. Actually, for regions with water damage, it will be the best available materials for building structures. In average fire intensity, it will damage the concrete surface without failure of members, in case of adequate concrete cover to protect steel bars.

For this research, the grade of 30 Mpa in 28 days compression strength RC is used. All variables used in the ideCAD software for the structural model design are illustrated in Table 3.2. The columns' section dimensions have been altered in various stories, as the vertical forces are less in the upper stories of tall buildings. In the higher stories, loads will decrease on columns. So, the sizes of columns and beams depend on the stories' numbers and the span length. Some examples of RC columns and beam sizes for standard low- and med-rise structures for L= 6 m and H= 3.6 m are shown in Table 3.3.

**Table 3.3:** Beams and columns dimensions (mm) for L= 6 m and H= 3.6 m

| **Floor** | **3-Story** | | **4-Story** | | **5-Story** | |
|---|---|---|---|---|---|---|
| | Column | Beam | Column | Beam | Column | Beam |
| 0 | 400x400 | 300x400 | 500x500 | 300x400 | 600x600 | 300x400 |
| 1 | 400x400 | 300x400 | 400x400 | 300x400 | 500x500 | 300x400 |
| 2 | 400x400 | 300x400 | 400x400 | 300x400 | 500x500 | 300x400 |
| 3 | --------- | --------- | 400x400 | 300x400 | 400x400 | 300x400 |
| 4 | --------- | --------- | --------- | --------- | 400x400 | 300x400 |

### 3.5.2 Steel

In structural constructions, steel is a lightweight material and provides a high strength ratio related to its weight. The advantages of steel structures are lighter in building weight, wider spans, and less column space than the other traditional building materials, without a decline in performance and engineering requirements. It is also the preferred material for wide span industrial projects, in which framed structures may be applied.

In steel constructions, the essential elements of steel include plates and standard profiles and can make numerous sections and compound forms by these crucial elements. It has been widely thought that steel is a type of innovative material with features to provide various needs. Regarding high efficiency, consideration will be given to load-related properties (toughness, ductility, and strength), environmental condition, execution time, fabrications (drawing and welding), etc., to maintain the efficiency and safety of steel components.

Steel is a material with strong and flexible features, and it can be bent slowly by considerable force because of its ductility attribute. The use of steel bars in the RC members resulting in an effective behavior of structures by properly strengthening members in tension zones, which compression force resisted by concrete itself. It also can be used to offer cost-effective construction that combines concrete. Some examples of columns and beam sizes for standard low- and med-rise structures with L= 6 m and H= 3.6 m are shown in Table 3.4.

**Table 3.4:** Beams and columns dimensions (mm) for L= 6 m and H= 3.6 m

| **Floor** | **3-Story** | | **4-Story** | | **4-Story** | |
|---|---|---|---|---|---|---|
| | Column | Beam | Column | Beam | Column | Beam |
| 0 | W360×410×216 | W250×250×167 | W360×410×216 | W250×250×167 | W360×410×287 | W250×250×167 |
| 1 | W360×370×179 | W250×250×131 | W360×410×216 | W250×250×167 | W360×410×216 | W250×250×167 |
| 2 | W360×370×179 | W250×250×131 | W360×370×179 | W250×250×131 | W360×410×216 | W250×250×167 |
| 3 | --------- | --------- | W360×370×179 | W250×250×131 | W360×370×179 | W250×250×131 |
| 4 | --------- | --------- | --------- | --------- | W360×370×179 | W250×250×131 |

### 3.5.3 Concrete formwork

Formworks become temporal structures used to carrying concrete mixture till it will maintain itself and hardens. Formworks must be a structure designed because many loads like concrete mixture, equipment, building materials, and workers will be moving.

Moreover, the formworks should have a desired surface, shape, and dimension to mold the required concrete. In construction, the formwork components and supports are produced from different materials like plywood, steel, plastic, timber, and aluminum. The formwork cost is effective since it typically takes 40 % to 60 % of an RC's cost. The economy in the formwork design partly depends on the experience and ingenuity of the formwork designer, either an engineer or a contractor. Deciding on the correct selection of a formwork system can always expedite the construction and minimize its costs. Steel forms have altered wooden forms to the extent of numerous reuse cases. However, using wood seems to be significant due to its accessibility and easy installation. For the economy purpose by formworks, it is needed:

1. *Simple:* It should be configured for simple installation and removing and usable for common dimensions.
2. *Standardized:* The ability to quickly assemble and reuse can minimize formwork cost by standardized the sizes.
3. *Easy handling:* The formworks unit and panels' dimension must be in a form that not heavy for use.
4. *Re-usable:* Formworks that are aiming for multiple re-uses must be organized with simple removal.

### 3.6 Consideration of Loads

Wight and MacGregor (2009) revealed that loads of gravity include live and dead loads acting vertically and lateral loads (wind and earthquake loads) acting horizontally. For building structure design, these fundamental loads must be taken into consideration.

#### 3.6.1 Dead loads

Dead loads are vertically acted loads according to the permanent weight of building components such as beams, columns, floors, walls, ceilings, fixed equipment, partitions, etc. The structural elements loads are determined in term of the weights of:

- Members weight,
- The construction material's weight that constitutes the permanently supported members,
- All wall partition's weight,
- The weight of all installed servicing tools,
- Net pre-stressing effects.

### 3.6.2 Live loads

These load types are the imposed loads with the building's usage and occupation, not environmental impacts like seismic, rain, or wind loads. These loads used in designing supporting elements and floors must be the maximum loads applied resulting from the intending of building's usage or occupation or by the materials storing and tools within construction, which should equal or greater than the lowest design loads specified within specific standard codes. The live load reduction upon the main structural element is obtained from multiplying the equivalent live loads distributed uniformly with an adequate reduction factor of that load (Bungale, 2016).

### 3.6.3 Lateral loads

The wind and earthquake loads are specified in terms of lateral loads (or horizontal loads). And the optimum designed wind loads on structures and elements shall be defined in terms of the wind speed, the form, and height of the structures or the state of the project's surface exposure.

Furthermore, the lateral loads are generally resisted only by the outer frames, but the outer frames and the inner frames together resist gravity loads. Through the outcomes, it could be noted that the internal frames resist gravity loads commonly (Gupta, 2014).

### 3.6.4 Used loads in this study

In all models, loads of gravity like; dead loads (weight of frames members), live loads, and super dead loads are fixed and considered the same for all models. The self-weight was automatically calculated by ideCAD software, but super dead load and live load are defined and allocated to the ideCAD software. But live load and super dead load are defined and assigned to the program as follows.

The loading parameters were as follows:

a) Live load (LL)= 2.5 kN/$m^2$

b) Dead load (DL)= Frame members' weight

c) Super dead loads (SDL)= 2 kN/$m^2$

d) Earthquake load (SL):  I (Importance factor) = 1, Zone = 3, Z=0.36

e) Wind load (WL): Category= C, Vb = 38 m/sec

### 3.6 Illustration of Models Through IdeCAD Software

In this section, the RC and steel models analyzed and designed by the ideCAD software for the three different story heights (3-story, 4-story, and 5-story) are shown with 3D and 2D for further illustration.

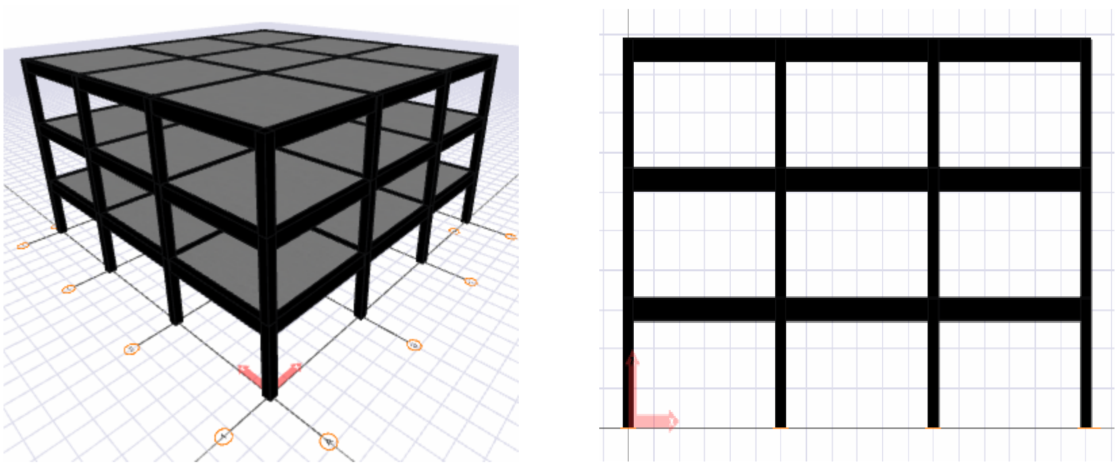


**Figure 3.5:** Low rise (3-Story) RC building model

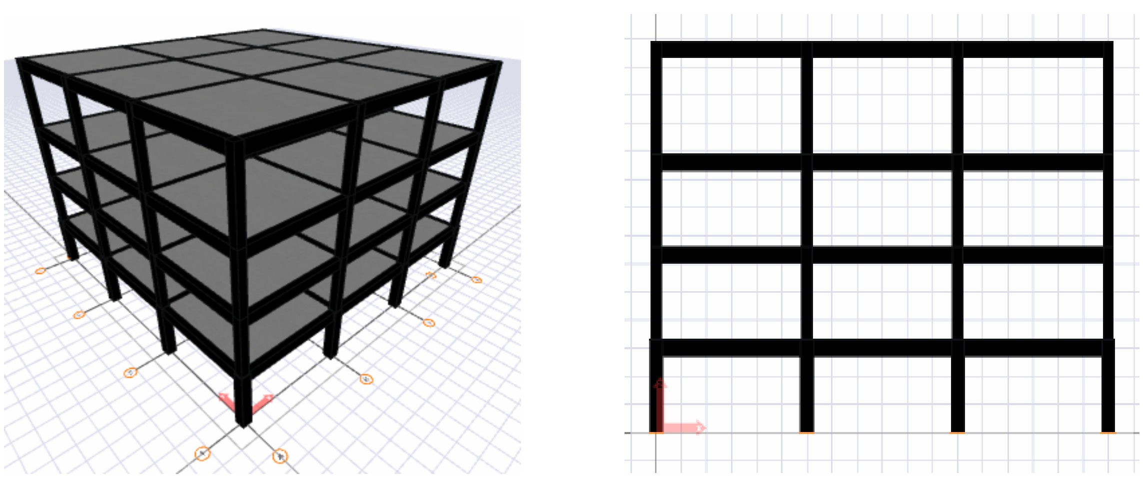


**Figure 3.6:** Low rise (4-Story) RC building model

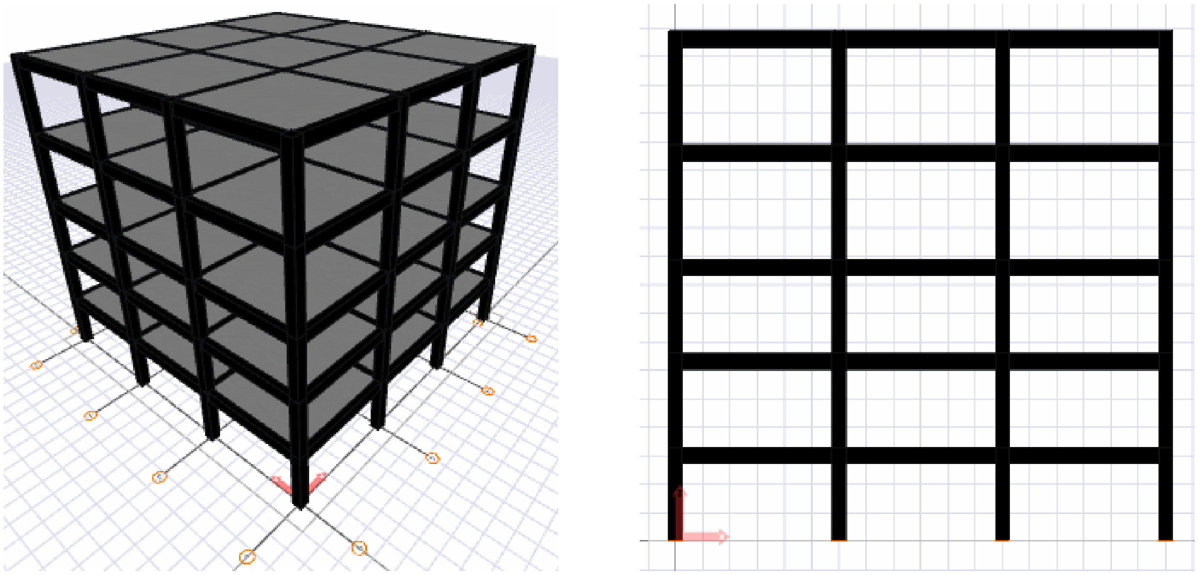


**Figure 3.7:** Med-rise (5-Story) RC building models

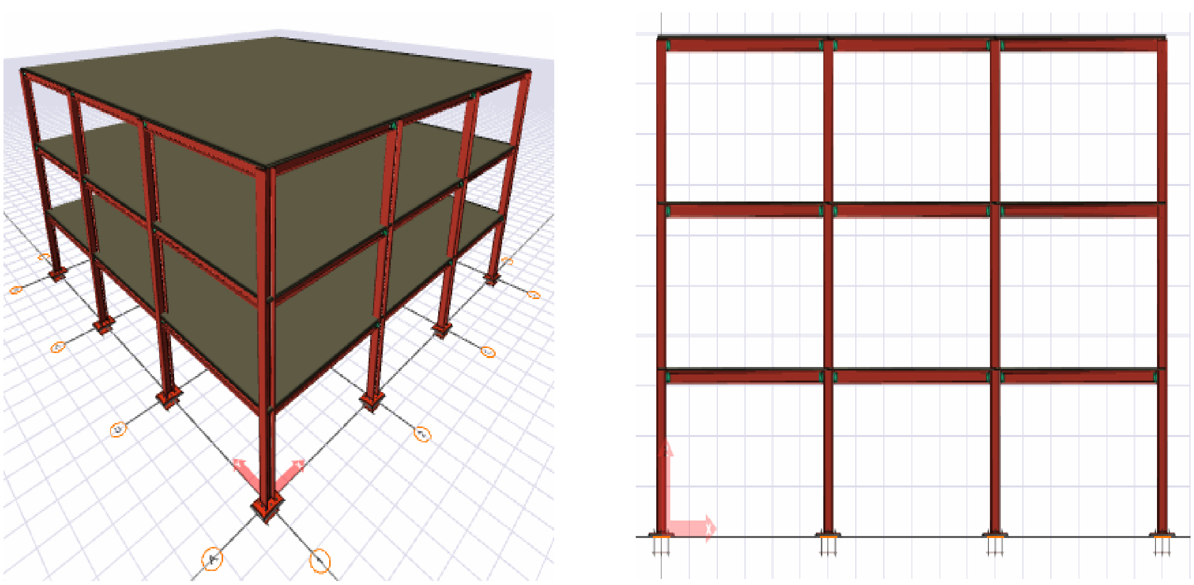


**Figure 3.8:** Low rise (3-Story) steel building models

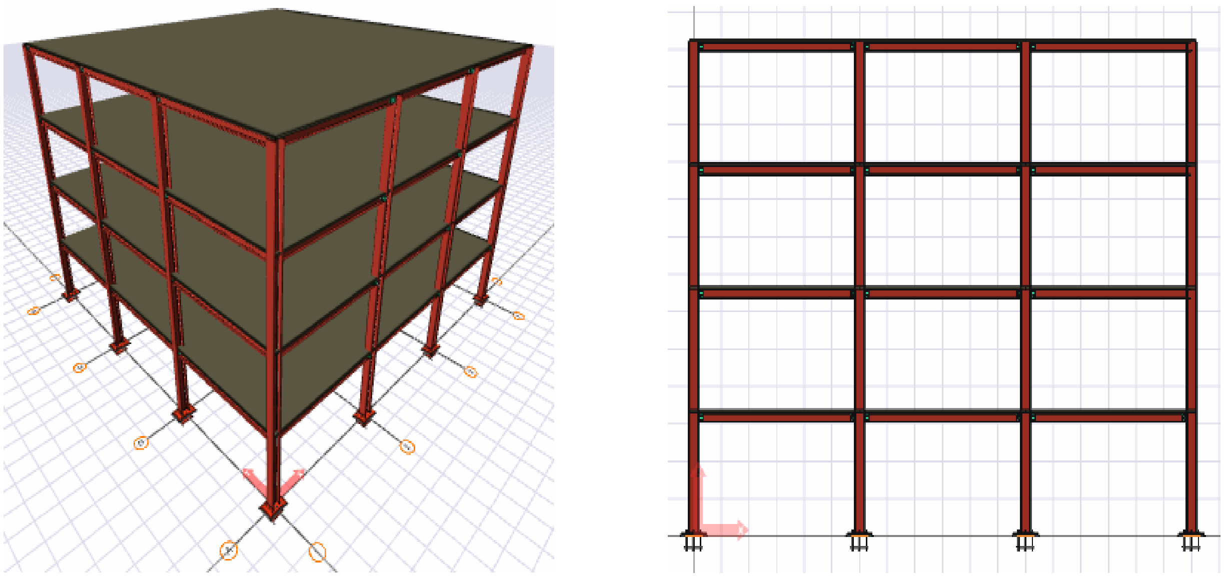


**Figure 3.9:** Low rise (4-Story) steel building models

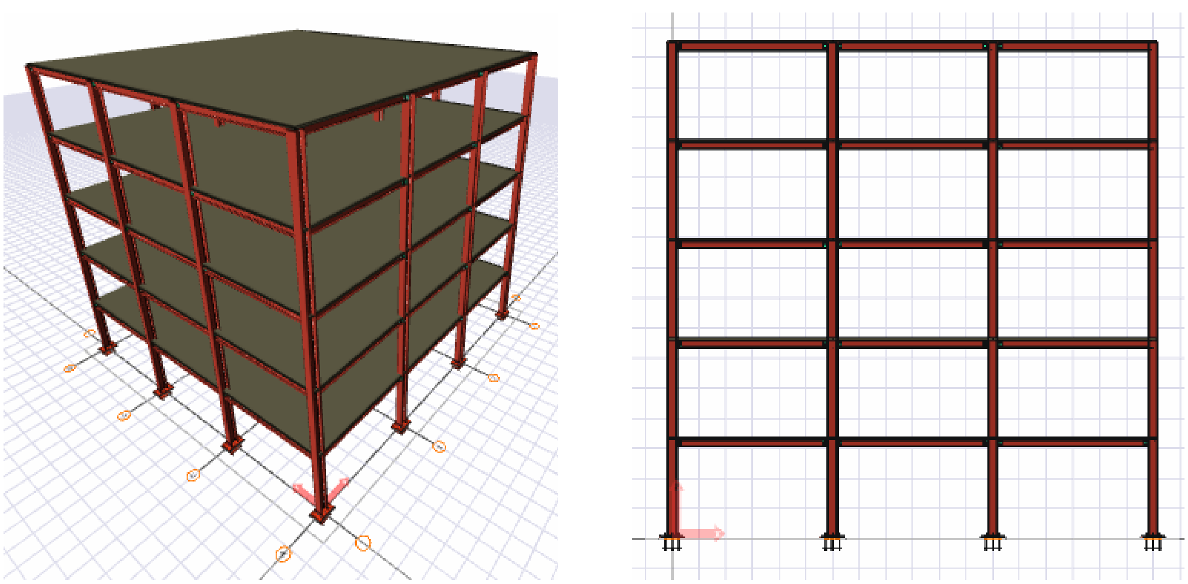


**Figure 3.10:** Med-rise (5-Story) steel building models

# CHAPTER 4
# RESULTS AND DISCUSSION

Chapter four contains the comparisons and explaining the discussion on the resulting quantities and cost of steel and RC framed structures by different parameters such as various lengths of spans, story height, number of stories, and different materials. Also, presenting table and charts demonstrate the effect of the parameters on the quantities and cost of structures. This evaluation and comparisons of the framed structures rely on the materials and labors needed for construction projects. The chapter is distributed into two sections. Section one illustrates the consequences of the parameter's effect on the rate of used materials quantities. Section two demonstrates the impact of various parameters on the total cost of constructed structures.

To simplified the tables and figures, some symbols and abbreviation are used as follow:

L: The length of the span

H: Story height of the structure

RCS: Reinforced concrete structure

SS: Steel structure

## 4.1. Quantity of Materials Used in Framed Structures

This part includes the amount of the primary materials (formwork, concrete, steel) were calculated for all structural models. The calculation of quantities achieved by using the ideCAD computer software and prepared as a detailed report. These quantity estimations can give reliable data to schedule future projects managing and deciding on resources. By utilizing the analysis and design computer software, the calculation and prediction of material quantities will be more precise and reduce errors.

In this section, the comparison is done between each RC and steel structure materials separately by the effects of different parameters. In the RC structures, columns, beams, and thicker slabs were built using formwork, concrete, and steel bar; therefore, the quantities of these materials are more than in steel structures. And reversely, in steel structures, the columns and beams are built by steel sections, so it is needed to the high rate of steel quantities, while in RC structures, there is no need for steel sections.

### 4.1.1 Formwork quantity in RC structures

The quantity of formwork has effective impact on the RC structures' total cost since it typically constitutes 40 % to 60 % of the RC's construction cost. The economy in the design of formwork partly depends on the experience and type of formwork designer. Deciding on the correct selection of a formwork system can always expedite the construction and minimize its costs. Table 4.1 presents the quantity of concrete formwork for the whole framed building and per square meter of the constructed structure.

**Table 4.1:** Concrete formwork quantity ($m^2$) of the entire structure and per square meter of RCS

| | | 3-story | | 4-story | | 5-story | |
|---|---|---|---|---|---|---|---|
| **L (m)** | **H (m)** | **Total RCS Formwork ($m^2$)** | **Formwork per $m^2$** | **Total RCS Formwork ($m^2$)** | **Formwork per $m^2$** | **Total RCS Formwork ($m^2$)** | **Formwork per $m^2$** |
| **4** | **3.3** | 853.07 | 1.85 | 1159.55 | 1.89 | 1486.22 | 1.93 |
| **5** | **3.3** | 1251.80 | 1.76 | 1692.91 | 1.78 | 2150.42 | 1.81 |
| **5.5** | **3.3** | 1430.47 | 1.67 | 1928.05 | 1.69 | 2433.43 | 1.70 |
| **6** | **3.3** | 1633.95 | 1.59 | 2203.45 | 1.61 | 2784.70 | 1.63 |
| **7** | **3.3** | 2137.61 | 1.54 | 2887.67 | 1.56 | 3633.00 | 1.57 |
| **4** | **3.6** | 896.68 | 1.94 | 1207.21 | 1.96 | 1536.06 | 2.00 |
| **5** | **3.6** | 1279.84 | 1.80 | 1735.87 | 1.83 | 2207.30 | 1.86 |
| **5.5** | **3.6** | 1453.51 | 1.70 | 1968.57 | 1.72 | 2481.20 | 1.74 |
| **6** | **3.6** | 1659.39 | 1.62 | 2242.17 | 1.64 | 2827.90 | 1.65 |
| **7** | **3.6** | 2183.05 | 1.57 | 2928.47 | 1.58 | 3690.15 | 1.60 |

***1) Effects of the increasing number of stories on the quantity of formwork in RC structures***

By observing figures 4.1 and 4.2, it is clear that the graph lines direction is towards up by increasing the number of stories. This quantity incrementation in the higher story-rises' building is due to their needs for a wider and thicker foundation and greater columns section in the lower stories.

The data in Table 4.2 demonstrate the quantity of concrete formwork per square meter of RCS and the percentage of their increase by rising the model's height. The maximum percentage of quantity increase in 3- to 4-story is 1.95% for H= 3.3 m and 1.72% for H= 3.6 m. While these rates are higher in 4- to 5-story that include: 2.54% and 1.79% for H= 3.3 m and 3.6 m respectively.

**Table 4.2:** Percentage of formwork quantity increase per square meter by increasing the number of stories in RCS

| **L (m)** | **H (m)** | **Quantity of concrete formwork per $m^2$** | | | **% Formwork increase from 3- to 4-story** | **% Formwork increase from 4- to 5-story** |
|---|---|---|---|---|---|---|
| | | **3-story** | **4-story** | **5-story** | | |
| **4** | **3.3** | 1.85 | 1.89 | 1.93 | 1.95 | 2.54 |
| **5** | **3.3** | 1.76 | 1.78 | 1.81 | 1.43 | 1.62 |
| **5.5** | **3.3** | 1.67 | 1.69 | 1.70 | 1.09 | 0.97 |
| **6** | **3.3** | 1.59 | 1.61 | 1.63 | 1.14 | 1.10 |
| **7** | **3.3** | 1.54 | 1.56 | 1.57 | 1.32 | 0.65 |
| **4** | **3.6** | 1.94 | 1.96 | 2.00 | 0.97 | 1.79 |
| **5** | **3.6** | 1.80 | 1.83 | 1.86 | 1.72 | 1.73 |
| **5.5** | **3.6** | 1.70 | 1.72 | 1.74 | 1.58 | 0.83 |
| **6** | **3.6** | 1.62 | 1.64 | 1.65 | 1.34 | 0.90 |
| **7** | **3.6** | 1.57 | 1.58 | 1.60 | 0.61 | 0.81 |

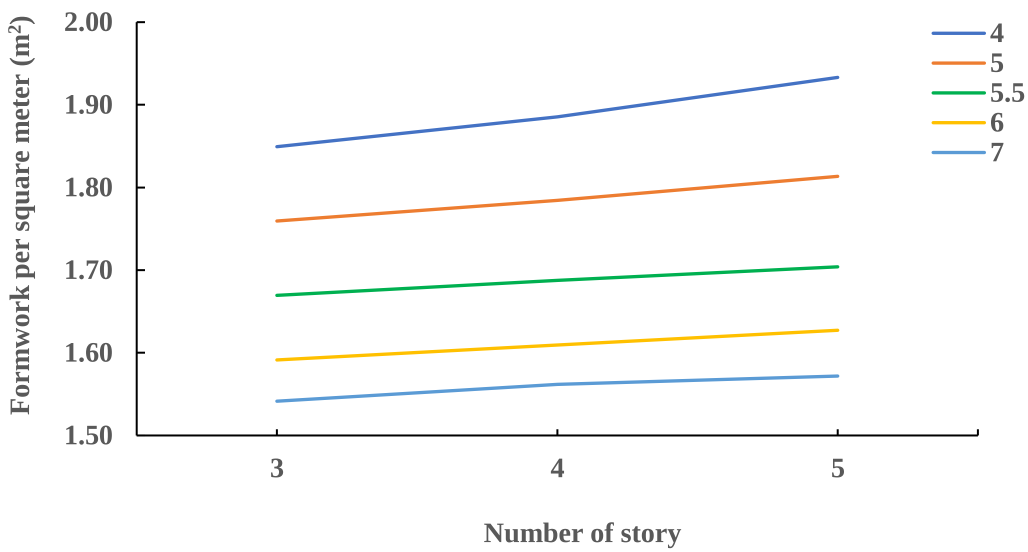



**Figure 4.1:** Influence of increasing number of stories on the formwork quantity per square meter of RCS with H=3.3 m

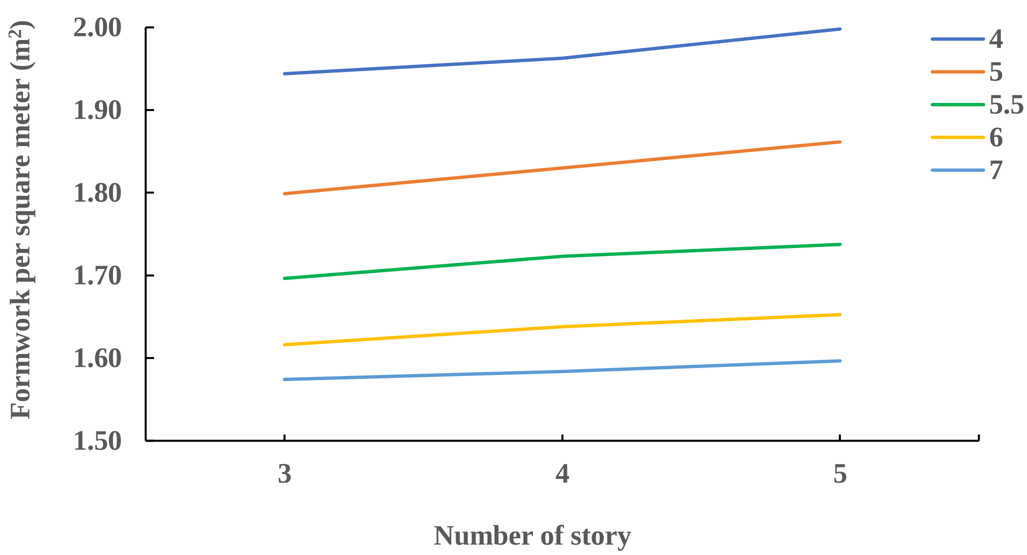



**Figure 4.2:** Influence of increasing number of stories on the formwork quantity per square meter of RCS with H=3.6 m

***2) Effects of increasing span length on the quantity of formwork in RC structures***

Increasing span length directly affects reducing formwork quantity, and these changes are clearly shown in figures 4.3 and 4.4. The percentage of formwork reduction by extending distances between columns in structural construction was listed in Table 4.3 (the negative signs mean reduction in quantities).

The quantity of formwork per square meter of structure with L= 4 m is higher than the structure with L= 5 m or 5.5 m or 6 m or 7 m. For example, in 4-story with H= 3.3 m by increasing 3 m length (from 4 m to 7 m), the formwork quantity decreases by 17.16% (from 1.89 $m^2$ in 4 m to 1.56 $m^2$ in 7 m per 1 $m^2$ of RCS; Table 4.1). This reduction in quantity is related to the lesser number of columns in the lengthy span building structures. The maximum decrease rate in formwork quantities is 20.09% in the 5-story with H= 3.6 m between 4 m and 7 m span length.

**Table 4.3:** Percentage of formwork quantity reduction by increasing span length per square meter in the RCS

| **Increasing span length (m)** | **H (m)** | **%Decrease in formwork quantity** | | |
|---|---|---|---|---|
| | | **3-story** | **4-story** | **5-story** |
| 1m (From 4 m to 5 m) | **3.3** | -4.86 | -5.34 | -6.19 |
| 1.5m (From 4 m to 5.5 m) | **3.3** | -9.73 | -10.48 | -11.85 |
| 2m (From 4 m to 6 m) | **3.3** | -13.95 | -14.63 | -15.82 |
| 3m (From 4m to 7 m) | **3.3** | -16.65 | -17.16 | -18.69 |
| 1m (From 4 m to 5 m) | **3.6** | -7.46 | -6.77 | -6.83 |
| 1.5m (From 4 m to 5.5 m) | **3.6** | -12.73 | -12.21 | -13.04 |
| 2m (From 4 m to 6 m) | **3.6** | -16.86 | -16.56 | -17.29 |
| 3m (From 4 m to 7 m) | **3.6** | -19.02 | -19.31 | -20.09 |

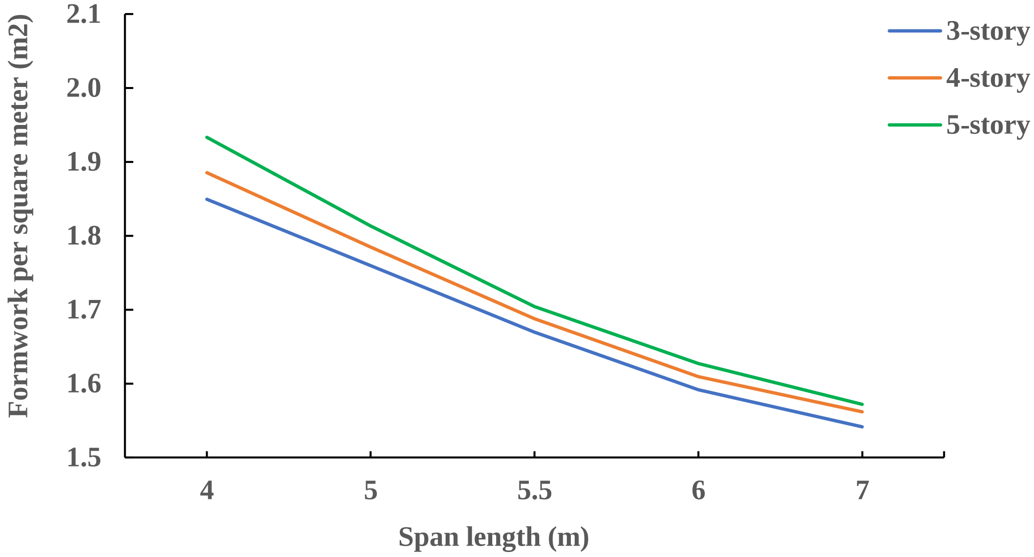



**Figure 4.3:** Influence of increasing span length on the formwork quantity per square meter of RCS with H=3.3 m

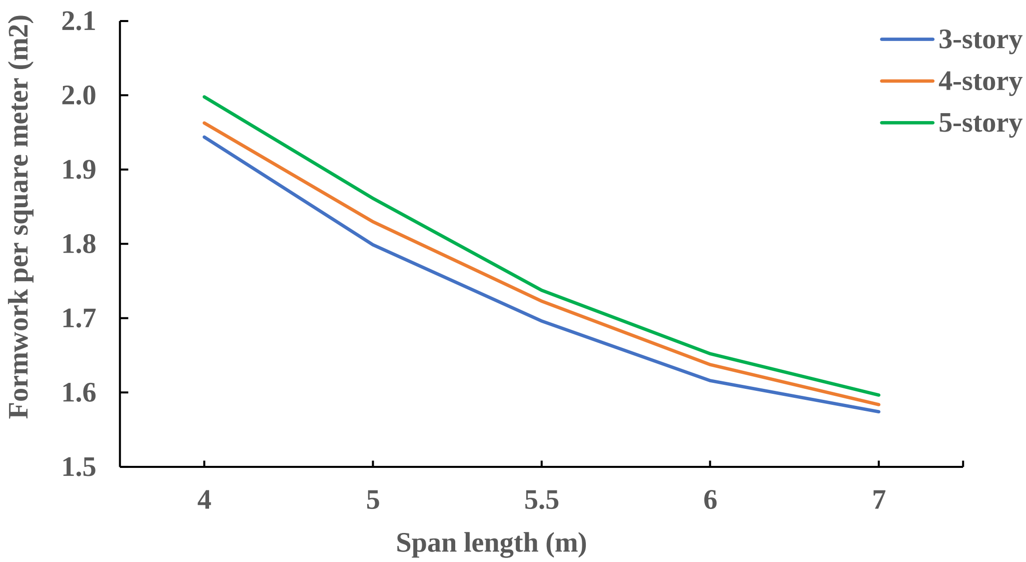



**Figure 4.4:** Influence of increasing span length on the formwork quantity per square meter of RCS with H= 3.6 m

***3) Effects of rising story height on the quantity of formwork in RC structures***

Rising the story height by the amount of 30 cm (from 3.3 m to 3.6 m) will increase the quantity of formwork per square meter of RCS at various rates, as illustrated in figures 4.5, 4.6, and 4.7.

And Table 4.4 shows the amount of increasing quantity by percentage. The table shows that in 3-story buildings, this increasing rate is between 1.56% to 5.11% and for 4-story structures is 1.41% to 4.89%, while these values in 5-story buildings reduce to 1.53% to 3.35%. The increasing amount is proportional to the number, height, and dimension of columns in all stories. As the height of columns and partition walls increase, the structural and covering materials also increase. Hence, it needs stronger and wider structural members to support these extra gravity loads.

**Table 4.4:** Percentage of formwork quantity increase ($m^2$) by rising story height per square meter in RCS

| **L (m)** | **H (m)** | **3-story** | | **4-story** | | **5-story** | |
|---|---|---|---|---|---|---|---|
| | | **Formwork per $m^2$** | **% Formwork increase** | **Formwork per $m^2$** | **% Formwork increase** | **Formwork per $m^2$** | **% Formwork increase** |
| **4** | **3.3** | 1.85 | 5.11 | 1.92 | 4.89 | 1.93 | 3.35 |
| | **3.6** | 1.94 | | 2.01 | | 2.00 | |
| **5** | **3.3** | 1.76 | 2.24 | 1.76 | 2.57 | 1.78 | 2.70 |
| | **3.6** | 1.80 | | 1.81 | | 1.83 | |
| **5.5** | **3.3** | 1.67 | 1.61 | 1.67 | 3.17 | 1.68 | 2.00 |
| | **3.6** | 1.70 | | 1.72 | | 1.71 | |
| **6** | **3.3** | 1.59 | 1.56 | 1.60 | 1.77 | 1.65 | 1.53 |
| | **3.6** | 1.62 | | 1.63 | | 1.68 | |
| **7** | **3.3** | 1.54 | 2.13 | 1.56 | 1.41 | 1.57 | 1.57 |
| | **3.6** | 1.57 | | 1.58 | | 1.60 | |

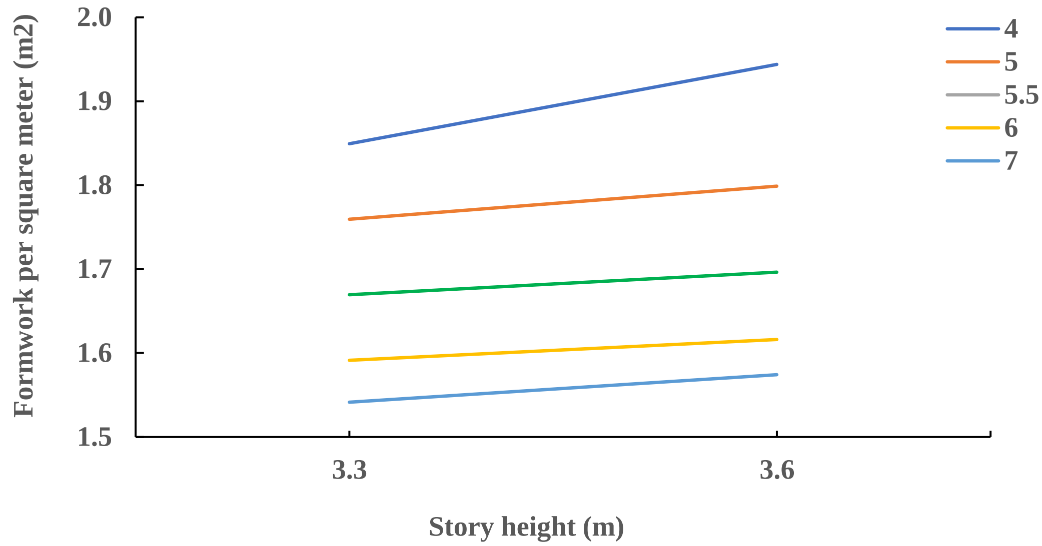



**Figure 4.5:** Effect of rising story height on the formwork quantity per square meter of 3-story RCS

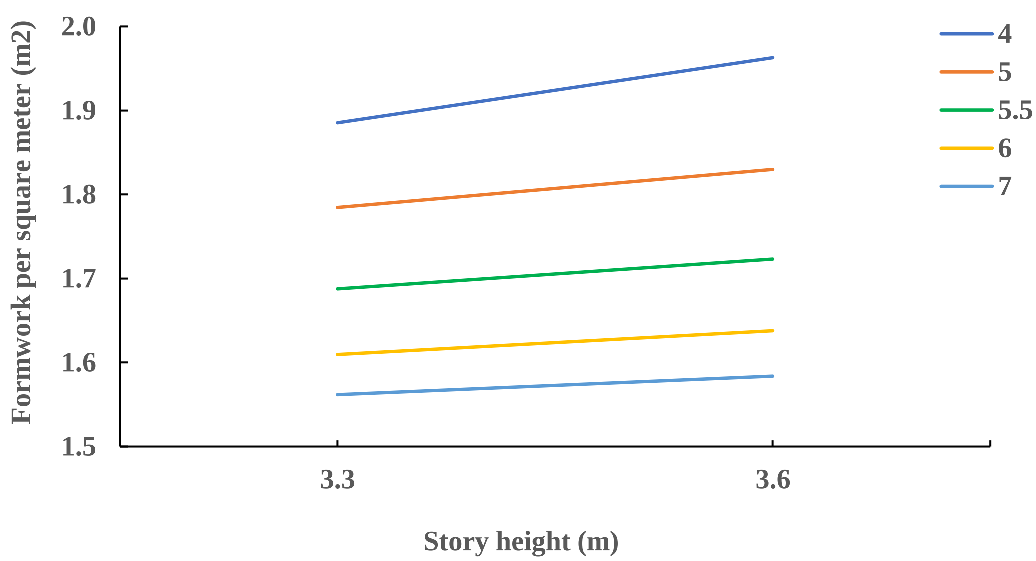



**Figure 4.6:** Effect of rising story height on the formwork quantity per square meter of 4-story RCS

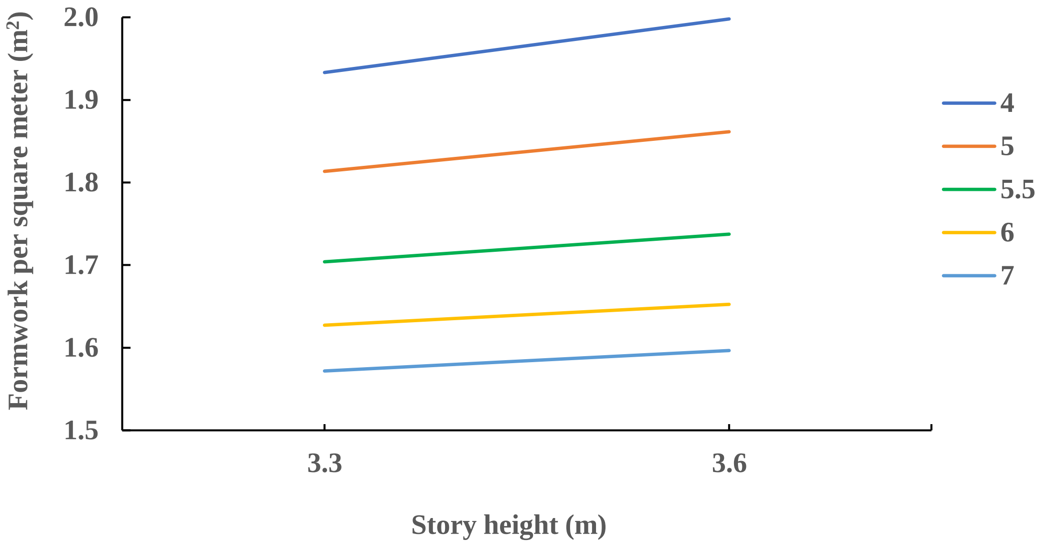



**Figure 4.7:** Effect of rising story height on the formwork quantity per square meter of 5-story RCS

### 4.1.2 Concrete quantity in RC structures

Concrete is the primary material in the construction of the RC framed structures. All building members consist of a higher amount of concrete in comparison to other structural materials. The amount of concrete need for a member depends on the imposed loads that the member should support them. The columns and beams will alter in various stories; for instance, loads will decrease in columns and need to smaller sections in the higher stories. Therefore, columns and beams' sizes depend on the stories' numbers, the length of the spans, and story height. Table 4.5 shows the quantity of concrete for the whole framed and per square meter of RC structures.

**Table 4.5:** Concrete quantity ($m^3$) of entire structure and per square meter of RCS

| L (m) | H (m) | 3-story | | 4-story | | 5-story | |
|---|---|---|---|---|---|---|---|
| | | Total concrete ($m^3$) | Concrete per $m^2$ | Total concrete ($m^3$) | Concrete per $m^2$ | Total concrete ($m^3$) | Concrete per $m^2$ |
| **4** | **3.3** | 135.7 | 0.294 | 227.3 | 0.370 | 297.1 | 0.386 |
| **5** | **3.3** | 205.6 | 0.289 | 336.0 | 0.354 | 437.0 | 0.369 |
| **5.5** | **3.3** | 238.8 | 0.279 | 395.5 | 0.346 | 506.0 | 0.354 |
| **6** | **3.3** | 319.9 | 0.312 | 533.9 | 0.390 | 689.3 | 0.403 |
| **7** | **3.3** | 468.8 | 0.338 | 821.5 | 0.444 | 1069.6 | 0.463 |
| **4** | **3.6** | 141.3 | 0.306 | 235.8 | 0.383 | 304.5 | 0.396 |
| **5** | **3.6** | 210.6 | 0.296 | 343.3 | 0.362 | 445.2 | 0.375 |
| **5.5** | **3.6** | 243.1 | 0.284 | 402.4 | 0.352 | 513.6 | 0.360 |
| **6** | **3.6** | 324.0 | 0.316 | 539.6 | 0.394 | 695.7 | 0.407 |
| **7** | **3.6** | 472.3 | 0.341 | 826.6 | 0.447 | 1075.5 | 0.465 |

***1) Effects of the increasing number of stories on the quantity of concrete in RC structures***

Table 4.6 the quantity of concrete per square meter of RC structures and the percentage of their increase by increasing the number of stories illustrated. The percentage of increased quantities by rising the structure from 3- to 4-story is in the range of 22.54% to 31.44% for H= 3.3 m and 22.28% to 31.27% for H= 3.6 m. While this percentage is lesser for 4- to 5-story which include: 2.36% to 4.56% for H= 3.3 m and 2.11% to 4.09% for H= 3.6 m.

The higher percentage of the concrete difference between 3- and 4-story is due to the difference in their foundation type. In 3-story, the single footing has been used with less amount of concrete, but in 4- and 5-story, the raft foundation has used that need more concrete amount. These ascending of concrete quantity by increasing the number of stories are shown clearer in Figure 4.8 and 4.9 lines.

**Table 4.6:** Percentage of concrete quantity increase by increasing the number of stories per square meter in RCS

| L (m) | H (m) | Concrete ($m^3$) square meter of RCS | | | % Concrete increase from 3- to 4-story | % Concrete increase from 4- to 5-story |
|---|---|---|---|---|---|---|
| | | 3-Story | 4-Story | 5-Story | | |
| **4** | **3.3** | 0.29 | 0.37 | 0.39 | 25.64 | 4.56 |
| **5** | **3.3** | 0.29 | 0.35 | 0.37 | 22.54 | 4.05 |
| **5.5** | **3.3** | 0.28 | 0.35 | 0.35 | 24.22 | 2.36 |
| **6** | **3.3** | 0.31 | 0.39 | 0.40 | 25.15 | 3.29 |
| **7** | **3.3** | 0.34 | 0.44 | 0.46 | 31.44 | 4.16 |
| **4** | **3.6** | 0.31 | 0.38 | 0.40 | 25.20 | 3.31 |
| **5** | **3.6** | 0.30 | 0.36 | 0.38 | 22.28 | 3.75 |
| **5.5** | **3.6** | 0.28 | 0.35 | 0.36 | 24.15 | 2.11 |
| **6** | **3.6** | 0.32 | 0.39 | 0.41 | 24.93 | 3.14 |
| **7** | **3.6** | 0.34 | 0.45 | 0.47 | 31.27 | 4.09 |

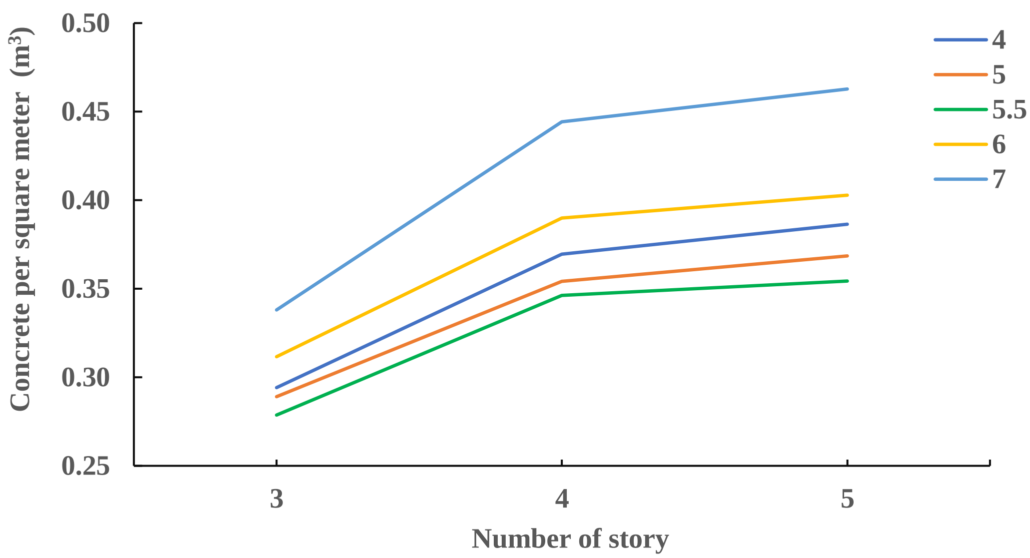



**Figure 4.8:** Influence of number of stories on the concrete quantity per square meter of RCS with H=3.3 m

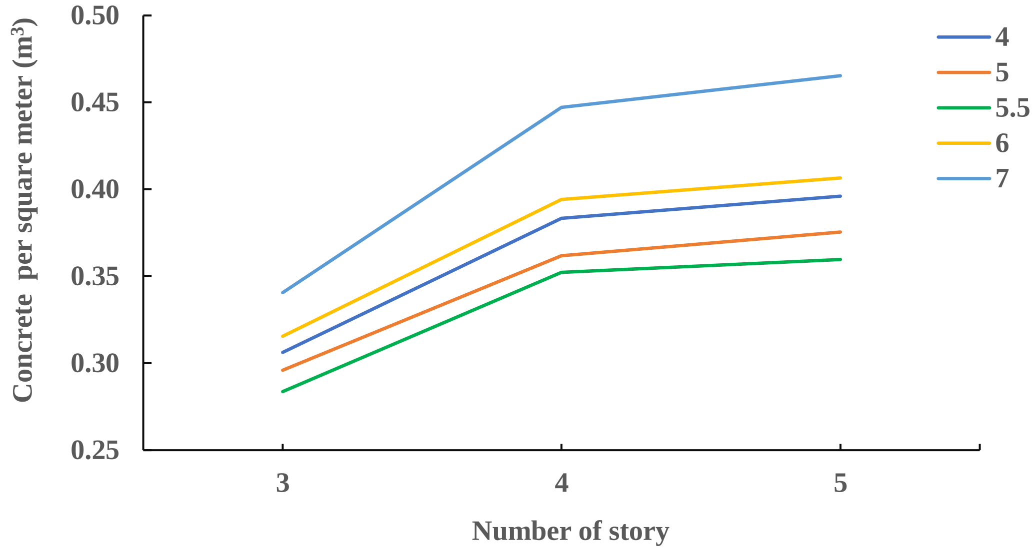



**Figure 4.9:** Influence of number of stories on the concrete quantity per square meter of RCS with H=3.6 m

***2) Effects of increasing span length on the quantity of concrete in RC structures***

The rate of concrete quantities required for structural construction, as shown in Table 4.7, is decreased gradually by extending the length of spans from 4 m till 5.5 m compared to the same multi-story and story height, but in 6 m and 7 m, it will increase again. The amount of concrete needed in constructing a structure with L= 4 m is higher than the same structure with L= 5 m or 5.5 m and less than in 6 m and 7 m. For example, in 5-story with H= 3.3 m, increasing 1.5 m span length (from 4 m to 5.5 m) will decrease the rate of concrete quantity by 8.3% (from 0.39 $m^3$ in 4m to 0.35 $m^3$ in 5.5 m per square meter of RCS; Table 4.6).

The maximum percentage of decrease in concrete quantities is 9.2% in the 5-story by increasing 1.5 m span length with H= 3.6 m, and the top rate of the concrete quantity increase is 20.2% in the 4-story by increasing the 3 m span length (from 4 m to 7 m) with H= 3.3 m. This change in the amount of concrete is illustrated by graph lines in Figure 4.10 and Figure 4.11.

**Table 4.7:** Percentage of change in concrete quantity by increasing span length per square meter in the RCS

| **Increasing span length (m)** | **H (m)** | **% Change in concrete quantity** | | |
|---|---|---|---|---|
| | | **3-story** | **4-story** | **5-story** |
| 1 m (From 4 m to 5 m) | **3.3** | -1.7 | -4.2 | -4.6 |
| 1.5 m (From 4 m to 5.5 m) | **3.3** | -5.3 | -6.3 | -8.3 |
| 2 m (From 4 m to 6 m) | **3.3** | 5.9 | 5.5 | 4.2 |
| 3 m (From 4 m to 7 m) | **3.3** | 14.9 | 20.2 | 19.8 |
| 1 m (From 4 m to 5 m) | **3.6** | -3.3 | -5.6 | -5.2 |
| 1.5 m (From 4 m to 5.5 m) | **3.6** | -7.4 | -8.1 | -9.2 |
| 2 m (From 4 m to 6 m) | **3.6** | 3.0 | 2.8 | 2.6 |
| 3 m (From 4 m to 7m) | **3.6** | 11.2 | 16.6 | 17.5 |

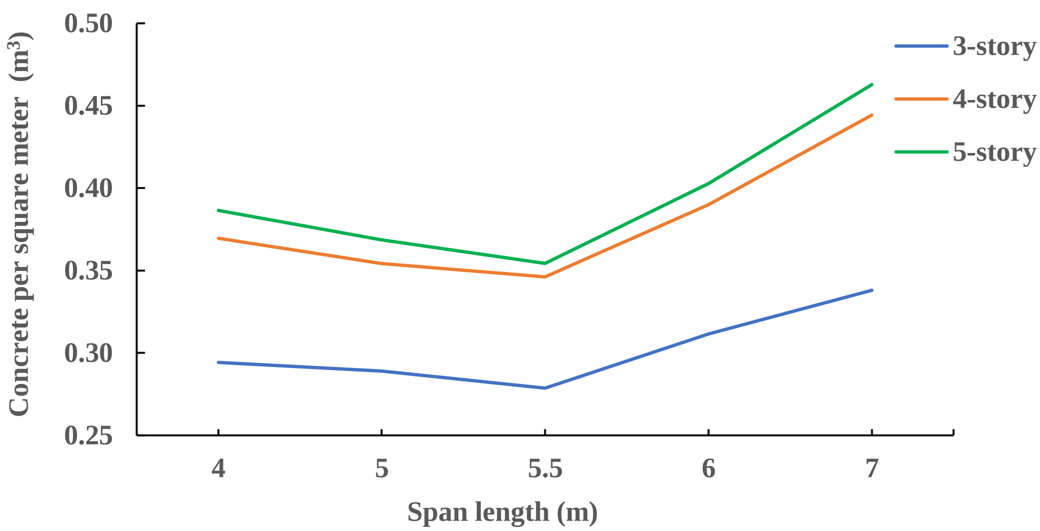



**Figure 4.10:** Influence of increasing span length on the concrete quantity per square meter of RCS with H=3.3 m

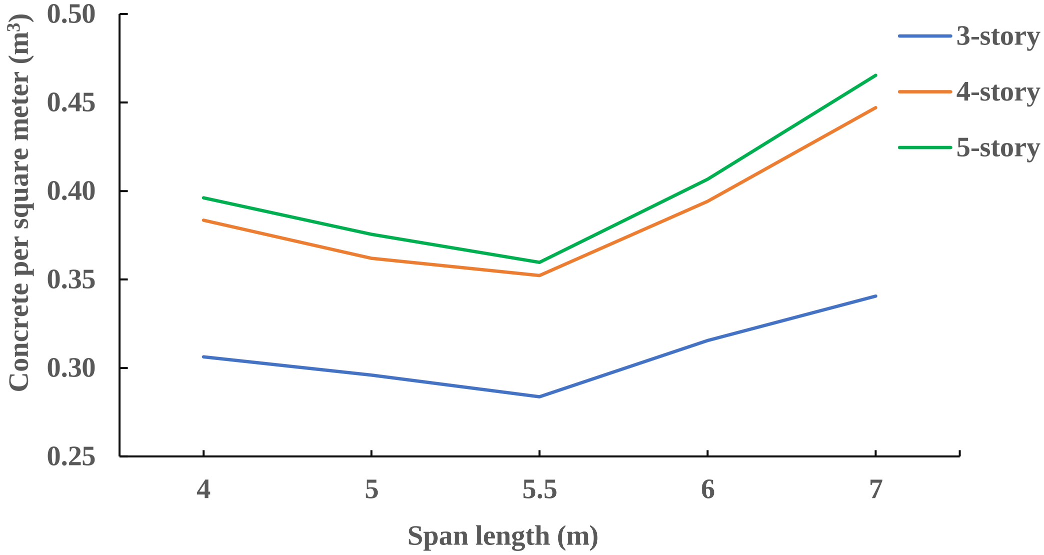



**Figure 4.11:** Influence of increasing span length on the concrete quantity per square meter of RCS with H=3.6 m

***3) Effects of rising story height on the quantity of concrete in RC structures***

Rising the height of the story will increase the quantity of concrete per square meter of RCS at various rates, as demonstrated in Table 4.8 below. The maximum increase rate in 3-story is 4.10%, but these rates in 4-story structures receive 3.70%, and in 5-story it will be decreased to 2.50%.

These incrementations of quantities are more observed in figures 4.12, 4.13, and 4.14. This change has a relation to the dimension and heights of columns in all stories. By rising the height of columns and partition walls, the amount of structural and covering materials should increase, which needs to the bigger dimensions of all structural members for carrying these imposed loads.

**Table 4.8:** Percentage of concrete quantity increase ($m^3$) by rising story height per square meter of RCS

| L (m) | H (m) | 3-story Concrete per $m^2$ | 3-story % Concrete increase | 4-story Concrete per $m^2$ | 4-story %Concrete increase | 5-story Concrete per $m^2$ | 5-story % Concrete increase |
|---|---|---|---|---|---|---|---|
| **4** | **3.3** | 0.294 | 4.1 | 0.370 | 3.7 | 0.386 | 2.5 |
| | **3.6** | 0.306 | | 0.383 | | 0.396 | |
| **5** | **3.3** | 0.289 | 2.4 | 0.354 | 2.2 | 0.369 | 1.9 |
| | **3.6** | 0.296 | | 0.362 | | 0.375 | |
| **5.5** | **3.3** | 0.279 | 1.8 | 0.346 | 1.7 | 0.354 | 1.5 |
| | **3.6** | 0.284 | | 0.352 | | 0.360 | |
| **6** | **3.3** | 0.312 | 1.3 | 0.390 | 1.1 | 0.403 | 0.9 |
| | **3.6** | 0.316 | | 0.394 | | 0.407 | |
| **7** | **3.3** | 0.338 | 0.8 | 0.444 | 0.6 | 0.463 | 0.6 |
| | **3.6** | 0.341 | | 0.447 | | 0.465 | |

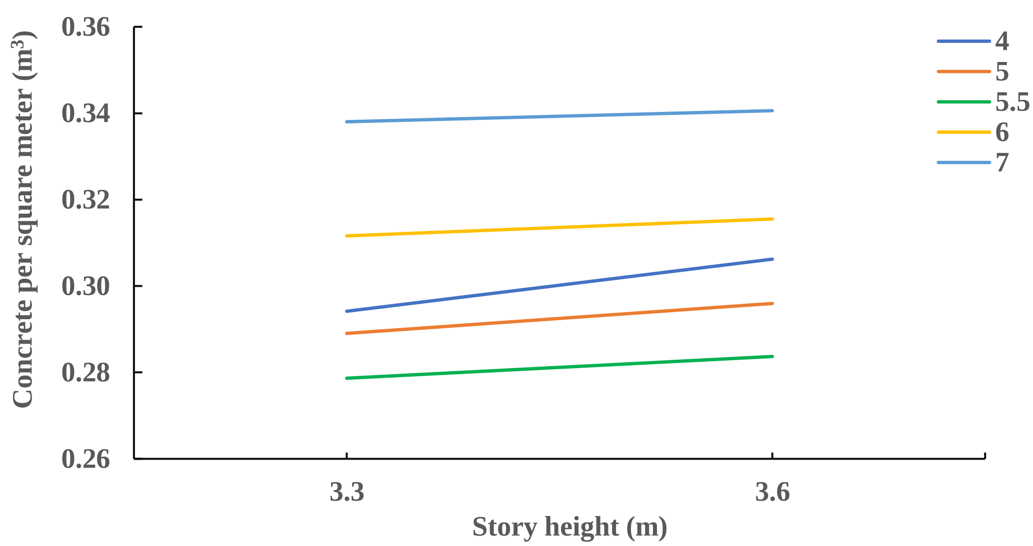



**Figure 4.12:** Influence of rising story height on the concrete quantity per square meter of 3-story RCS

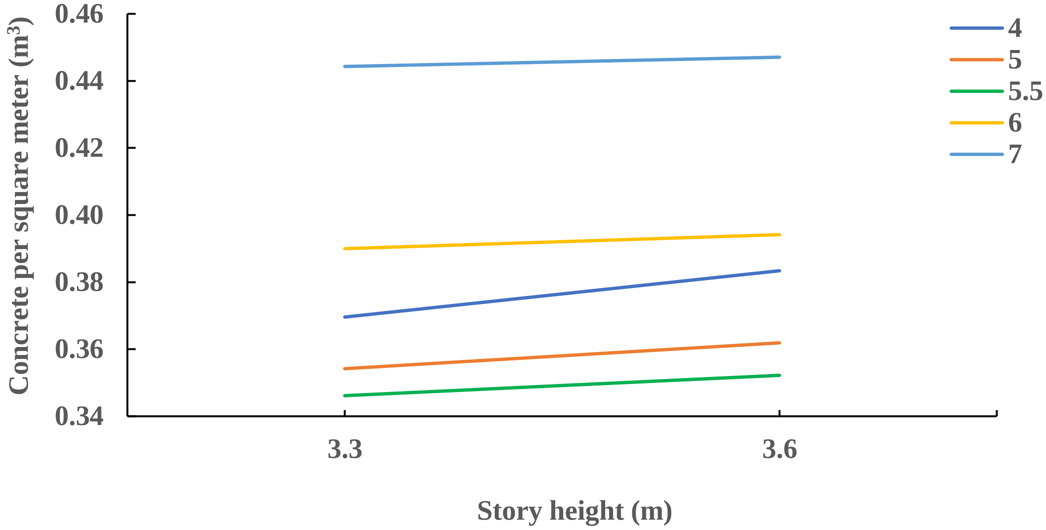



**Figure 4.13:** Influence of rising story height on the concrete quantity per square meter of 4-story RCS

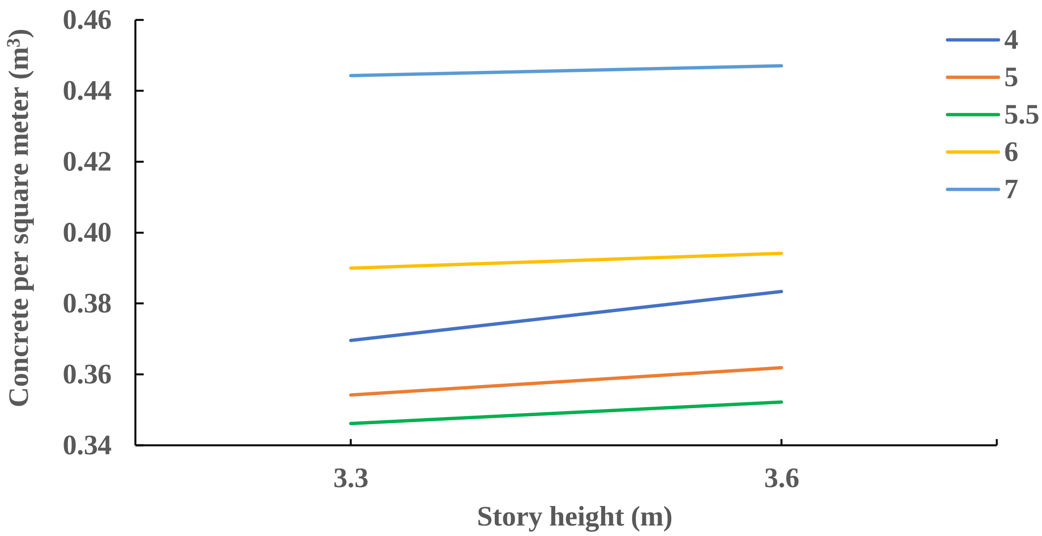



**Figure 4.14:** Influence of rising story height on the concrete quantity per square meter of 5-story RCS

### 4.1.3 Steel bar quantity in RC structures

Steel bar is an essential material in RC structure that equivalent to concrete resist the imposed vertical and horizontal loads and protect structures from failure in the members' tension zones. According to the position and rate of loads acted on the member, its quantity must be in the standard range, which should not be too more (over reinforced) or too less (under reinforced) than the required quantities in the design. Table 4.9 illustrates the steel bar quantity in the whole RC structures and per square meter of models, obtained as a detailed report from the analyzed and designed models by the ideCAD software.

**Table 4.9:** Steel bar quantity of the whole structure and per square meter of RCS

| L (m) | H (m) | 3-story | | 4-story | | 5-story | |
|---|---|---|---|---|---|---|---|
| | | Total steel bar (kg) | Steel bar (kg) per $m^2$ | Total steel bar (kg) | Steel bar (kg) per $m^2$ | Total steel bar (kg) | Steel bar (kg) per $m^2$ |
| **4** | **3.3** | 16,027 | 34.74 | 25,276 | 41.10 | 33,085 | 43.03 |
| **5** | **3.3** | 22,348 | 31.41 | 34,758 | 36.64 | 44,749 | 37.74 |
| **5.5** | **3.3** | 26,546 | 30.98 | 39,931 | 34.95 | 51,773 | 36.25 |
| **6** | **3.3** | 32,113 | 31.28 | 48,185 | 35.20 | 63,793 | 37.28 |
| **7** | **3.3** | 46,579 | 33.59 | 70,794 | 38.29 | 92,222 | 39.90 |
| **4** | **3.6** | 16,745 | 36.30 | 27,410 | 44.57 | 36,415 | 47.37 |
| **5** | **3.6** | 24,142 | 33.93 | 37,827 | 39.87 | 50,246 | 42.37 |
| **5.5** | **3.6** | 27,461 | 32.05 | 41,088 | 35.97 | 56,145 | 39.32 |
| **6** | **3.6** | 33,743 | 32.86 | 50,969 | 37.23 | 69,096 | 40.38 |
| **7** | **3.6** | 48,952 | 35.30 | 74,933 | 40.53 | 99,836 | 43.20 |

***1) Effects of the increasing number of stories on the quantity of steel bars in RC structures***

The quantity of steel bar per square meter of RC structures and the percentage of their increase by rising the number of stories is illustrated in Table 4.10 below. The rate of quantity increases by rising the structure from 3- to 4-story is in the limit of 12.54% to 18.28% for H= 3.3 m and 12.22% to 22.77% for H= 3.6 m. While this percentage has a lesser rate between 4- and 5-story, including 3.00% to 5.91% for H= 3.3 m and 6.27% to 9.32% for H= 3.6 m.

The higher rate of difference in 3- and 4-story is due to their foundation form difference. In 3-story, the single footing was used, which needs less quantity of steel bar in compare to the 4- and 5-story with the raft foundation and higher amount of steel bars. These ascending steel bar quantity in different multi-story types are seen better with the graph lines in figures 4.15 and 4.16.

**Table 4.10:** Effects of the increasing number of stories on the quantity of steel bar per square meter of RCS

| L (m) | H (m) | Steel bar (kg) per square meter of RCS 3-story | 4-story | 5-story | % Steel bar increase from 3- to 4-story | % Steel bar increase from 4- to 5-story |
|---|---|---|---|---|---|---|
| **4** | **3.3** | 34.74 | 41.10 | 43.03 | 18.28 | 4.72 |
| **5** | **3.3** | 31.41 | 36.64 | 37.74 | 16.65 | 3.00 |
| **5.5** | **3.3** | 30.98 | 34.95 | 36.25 | 12.82 | 3.72 |
| **6** | **3.3** | 31.28 | 35.20 | 37.28 | 12.54 | 5.91 |
| **7** | **3.3** | 33.59 | 38.29 | 39.90 | 13.99 | 4.21 |
| **4** | **3.6** | 36.30 | 44.57 | 47.37 | 22.77 | 6.28 |
| **5** | **3.6** | 33.93 | 39.87 | 42.37 | 17.51 | 6.27 |
| **5.5** | **3.6** | 32.05 | 35.97 | 39.32 | 12.22 | 9.32 |
| **6** | **3.6** | 32.86 | 37.23 | 40.38 | 13.29 | 8.45 |
| **7** | **3.6** | 35.30 | 40.53 | 43.20 | 14.81 | 6.59 |

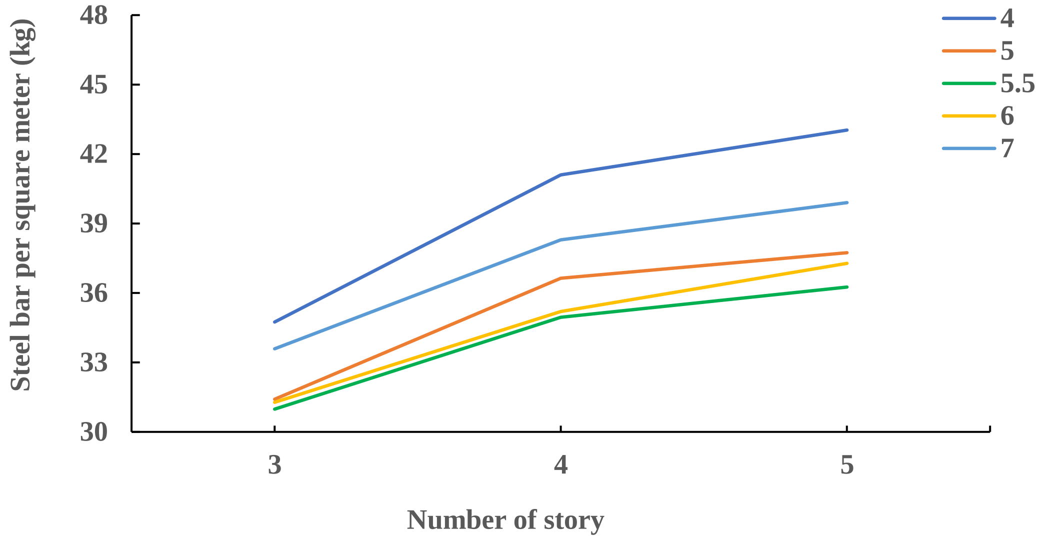



**Figure 4.15:** Influence of number of stories on the steel bars quantity per square meter of RCS with H=3.3 m

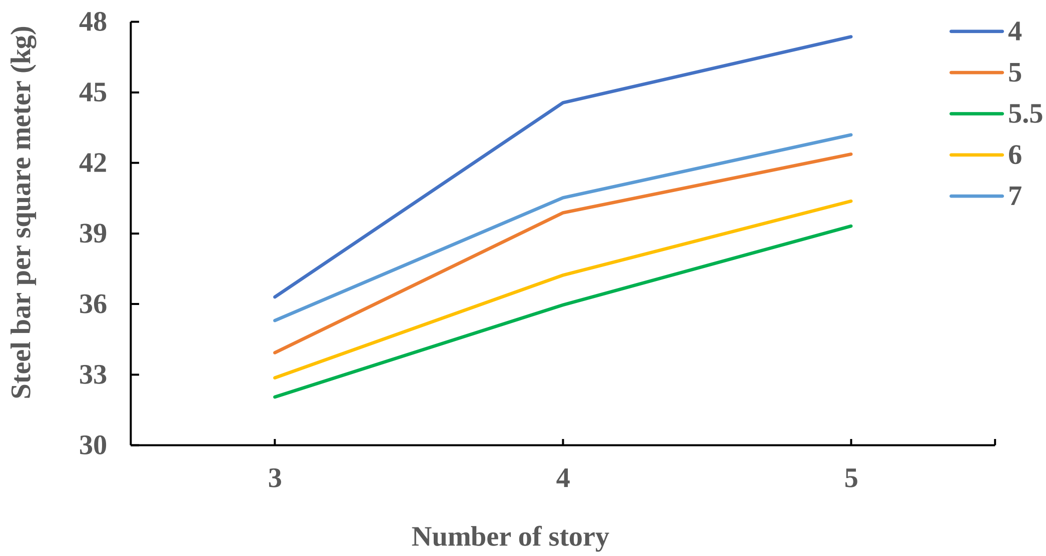



**Figure 4.16:** Influence of number of stories on the steel bars quantity per square meter of RCS with H=3.6 m

*2) Effects of increasing span length on the quantity of steel bar in RC structures*

The descending of graph lines in figures 4.17 and 4.18 explain the influence of extending span lengths on the quantity of steel bars in RC structures for three types of stories.

Also, Table 4.11 shows that the rate of steel bar quantities decreases gradually by increasing the length of the spans from 4 m till 5.5 m compared to the same multi-story and story height but in 6 m and 7 m increasing again. The minimum percentage of decrease in steel bar quantities is 2.76% in the 3-story with H= 3.6 m and by increasing 3 m span length, and the maximum rate of the reinforcement quantity decrease is 19.3% in the 4-story by increasing the 1.5 m span length (from 4 m to 5.5 m) with H= 3.6 m.

**Table 4.11:** Percentage of decreasing steel bar quantity per square meter by increasing span length in the RCS

| **Increasing span length (m)** | **H (m)** | **% Decrease in steel bar** | | |
|---|---|---|---|---|
| | | **3-story** | **4-story** | **5-story** |
| 1 m (From 4 m to 5 m) | **3.3** | -9.60 | -10.84 | -12.31 |
| 1.5 m (From 4 m to 5.5 m) | **3.3** | -10.83 | -14.95 | -15.76 |
| 2 m (From 4 m to 6 m) | **3.3** | -9.98 | -14.35 | -13.38 |
| 3 m (From 4 m to 7 m) | **3.3** | -3.33 | -6.83 | -7.28 |
| 1 m (From 4 m to 5 m) | **3.6** | -6.53 | -10.53 | -10.54 |
| 1.5 m (From 4 m to 5.5 m) | **3.6** | -11.71 | -19.30 | -17.00 |
| 2 m (From 4 m to 6 m) | **3.6** | -9.47 | -16.46 | -14.75 |
| 3 m (From 4 m to 7 m) | **3.6** | -2.76 | -9.07 | -8.80 |

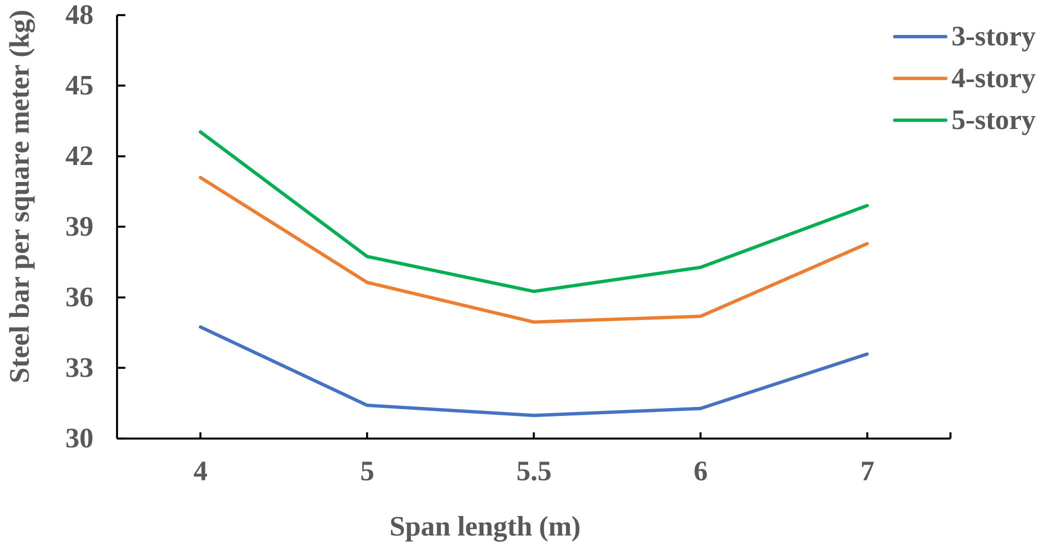



**Figure 4.17:** Influence of increasing span length on the steel bar quantity per square meter of RCS with H=3.3 m

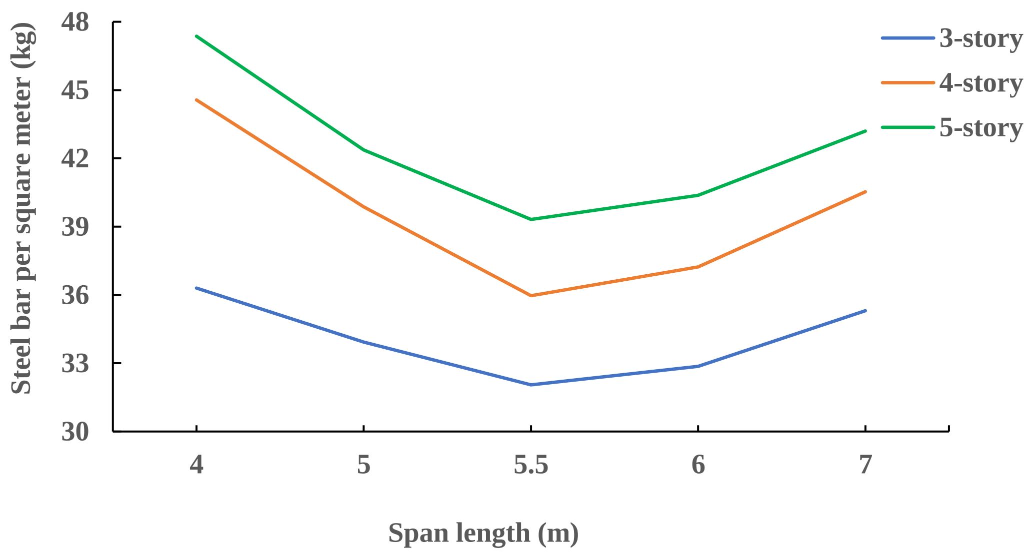



**Figure 4.18:** Influence of increasing span length on the steel bar quantity per square meter of RCS with H=3.6 m

### *3) Effects of rising story height on the quantity of steel bar in RC structures*

Rising the height of the building story by the amount of 30 cm (from 3.3 m to 3.6 m) will increase the quantity of steel bar per square meter of RCS at a different rate, as demonstrated in Table 4.12. The higher rate of increase in 3-story structures is 8.03% and in 4-story models is 8.83%, while this rate will be more in 5-story, which is 12.28%.

The figures 4.19, 4.20, and 4.21 shown better these changes in quantities by the effect of rising story height. As the columns and walls are raised more, the amount of materials for structural and finishing will increase; consequently, the greater section of columns, beams, and foundation must be built to carry these extra gravity loads.

**Table 4.12:** Percentage of steel bar increase by rising the story height per square meter of RCS

| L (m) | H (m) | 3-story | | 4-story | | 5-story | |
|---|---|---|---|---|---|---|---|
| | | Steel bar (kg) per $m^2$ | % Steel bar increase | Steel bar (kg) per $m^2$ | % Steel bar increase | Steel bar (kg) per $m^2$ | % Steel bar increase |
| **4** | **3.3** | 34.74 | 4.48 | 41.10 | 8.44 | 43.03 | 10.06 |
| | **3.6** | 36.30 | | 44.57 | | 47.37 | |
| **5** | **3.3** | 31.41 | 8.03 | 36.64 | 8.83 | 37.74 | 12.28 |
| | **3.6** | 33.93 | | 39.87 | | 42.37 | |
| **5.5** | **3.3** | 30.98 | 3.45 | 34.95 | 2.90 | 36.25 | 8.44 |
| | **3.6** | 32.05 | | 35.97 | | 39.32 | |
| **6** | **3.3** | 31.28 | 5.08 | 35.20 | 5.78 | 37.28 | 8.31 |
| | **3.6** | 32.86 | | 37.23 | | 40.38 | |
| **7** | **3.3** | 33.59 | 5.09 | 38.29 | 5.85 | 39.90 | 8.26 |
| | **3.6** | 35.30 | | 40.53 | | 43.20 | |

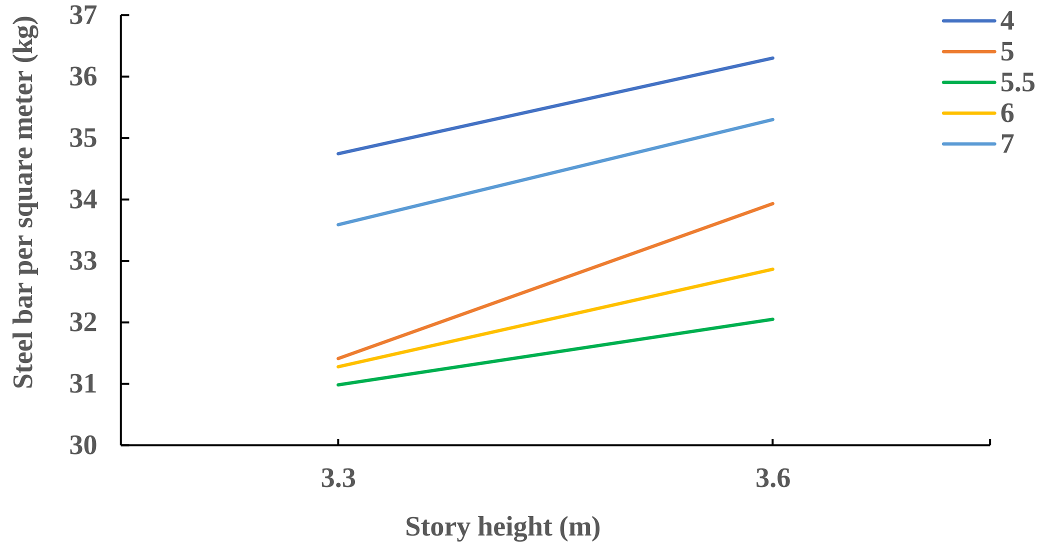



**Figure 4.19:** Influence of rising story height on the steel bars quantity per square meter of 3-story RCS

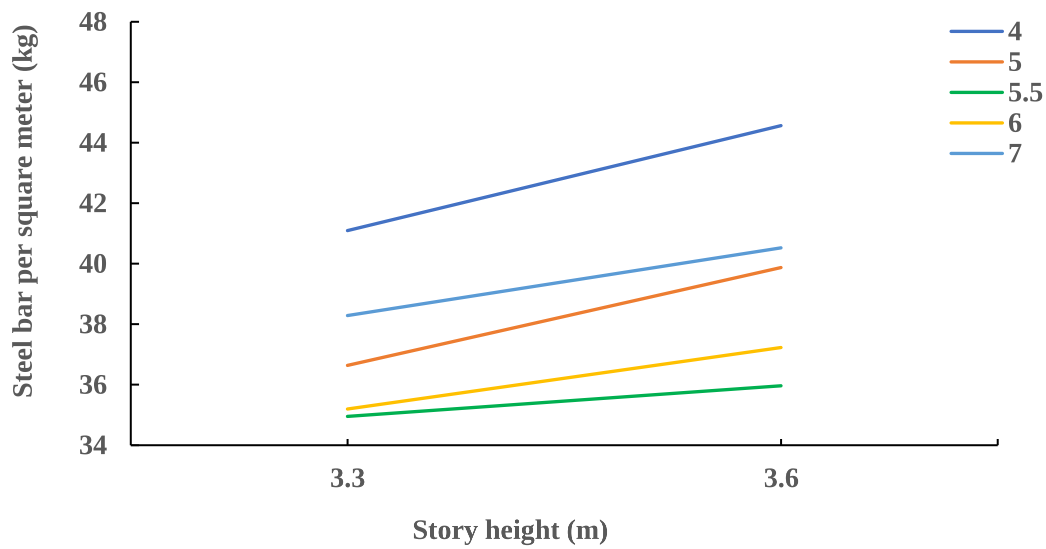



**Figure 4.20:** Influence of rising story height on the steel bars quantity per square meter of 4-story RCS

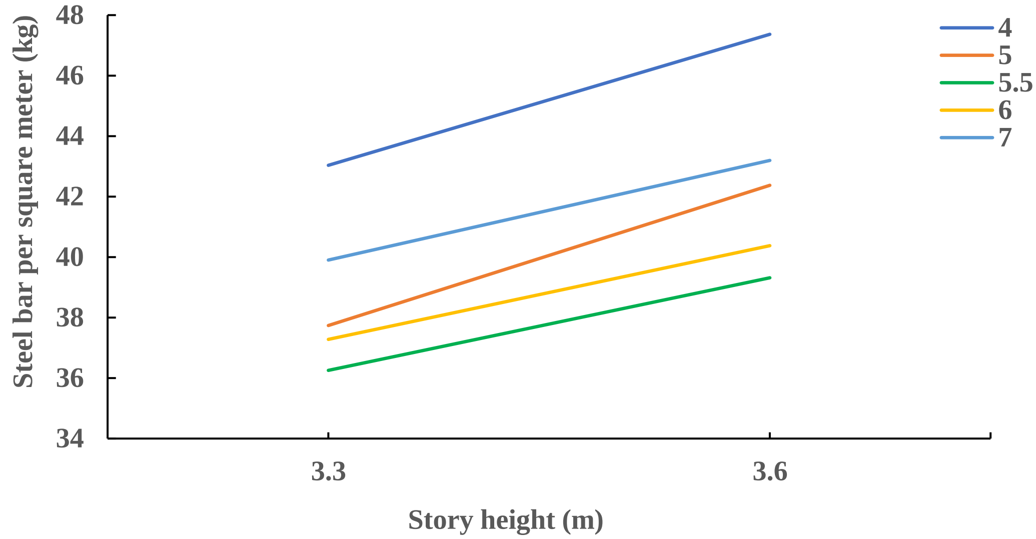



**Figure 4.21:** Influence of rising story height on the steel bars quantity per square meter of 5-story RCS

### 4.1.4 Steel quantity in steel structures

A considerable alternative material in the construction of multi-story buildings is steel. Besides using as reinforcing material in RC structures, it is utilized individually in many high-rise framed structures with many simplifications and advantageous in execution and functionality. The quantity of required steel, like all other alternatives, depends on the span length, number of stories, and story height. The whole steel sections and steel bars quantity used in columns, beams, foundations, and slabs of the structural steel models in this research under all the mentioned parameters are revealed in Table 4.13.

**Table 4.13:** Quantity of steel for the whole and per square meter of steel structure

| L (m) | H (m) | 3-story | | 4-story | | 5-story | |
|---|---|---|---|---|---|---|---|
| | | **Total steel (kg)** | **Steel (kg) per m$^2$** | **Total steel (kg)** | **Steel (kg) per m$^2$** | **Total steel (kg)** | **Steel (kg) per m$^2$** |
| **4** | **3.3** | 43,071 | 93.37 | 58,369 | 94.90 | 77,807 | 101.21 |
| **5** | **3.3** | 67,070 | 94.27 | 90,757 | 95.67 | 123,025 | 103.75 |
| **5.5** | **3.3** | 82,843 | 96.69 | 113,706 | 99.53 | 153,078 | 107.19 |
| **6** | **3.3** | 105,620 | 102.87 | 143,688 | 104.96 | 193,540 | 113.10 |
| **7** | **3.3** | 157,714 | 113.73 | 213,096 | 115.25 | 279,750 | 121.04 |
| **4** | **3.6** | 43,794 | 94.94 | 60,094 | 97.71 | 80,738 | 105.02 |
| **5** | **3.6** | 69,104 | 97.13 | 95,371 | 100.53 | 126,974 | 107.08 |
| **5.5** | **3.6** | 86,056 | 100.44 | 118,314 | 103.56 | 157,612 | 110.37 |
| **6** | **3.6** | 111,141 | 108.25 | 153,006 | 111.76 | 198,432 | 115.96 |
| **7** | **3.6** | 164,454 | 118.59 | 222,084 | 120.11 | 283,409 | 122.62 |

***1) Effects of the increasing number of stories on the quantity of steel in steel structures***

The increasing number of stories directly influences the increasing steel quantity in steel structures; as seen in figures 4.22 and 4.23, the direction of quantity graph lines is continually increasing by rising multi-stories from 3- to 4- and 5-story.

Table 4.14 listed the quantity of steel per square meter of structure and the difference in quantities between various stories. The quantity of steel per square meter in 5-story structures is more than in low-rise buildings.  An increase in the number of stories needs to more steel per square meter; for example, in a structure with L= 5 m and H=3.6 m, the required construction steel is 97.13 kg, 100.53 kg and 107.08 kg for 3-, 4- and 5-story respectively. The higher percentage of steel difference between 3- and 4-story is 3.51% in L=5 m and H=3.6 m, while the higher percentage in between 4-and 5-story was 8.44% for L=5 m and H=3.3 m. This increase in steel quantity for riser framed buildings is due to the higher rate of loads in the lower stories, which need the wider dimension of columns and foundation.

**Table 4.14:** Effects of the increasing number of stories on the quantity of steel per square meter in the SS

| L (m) | H (m) | Steel (kg) per square meter of SS | | | % Steel increase from 3- to 4-story | % Steel increase from 4- to 5-story |
|---|---|---|---|---|---|---|
| | | 3-story | 4-story | 5-story | | |
| **4** | **3.3** | 93.37 | 94.90 | 101.21 | 1.64 | 6.64 |
| **5** | **3.3** | 94.27 | 95.67 | 103.75 | 1.49 | 8.44 |
| **5.5** | **3.3** | 96.69 | 99.53 | 107.19 | 2.94 | 7.70 |
| **6** | **3.3** | 102.87 | 104.96 | 113.10 | 2.03 | 7.76 |
| **7** | **3.3** | 113.73 | 115.25 | 121.04 | 1.34 | 5.02 |
| **4** | **3.6** | 94.94 | 97.71 | 105.02 | 2.91 | 7.48 |
| **5** | **3.6** | 97.13 | 100.53 | 107.08 | 3.51 | 6.51 |
| **5.5** | **3.6** | 100.44 | 103.56 | 110.37 | 3.11 | 6.57 |
| **6** | **3.6** | 108.25 | 111.76 | 115.96 | 3.25 | 3.75 |
| **7** | **3.6** | 118.59 | 120.11 | 122.62 | 1.28 | 2.09 |

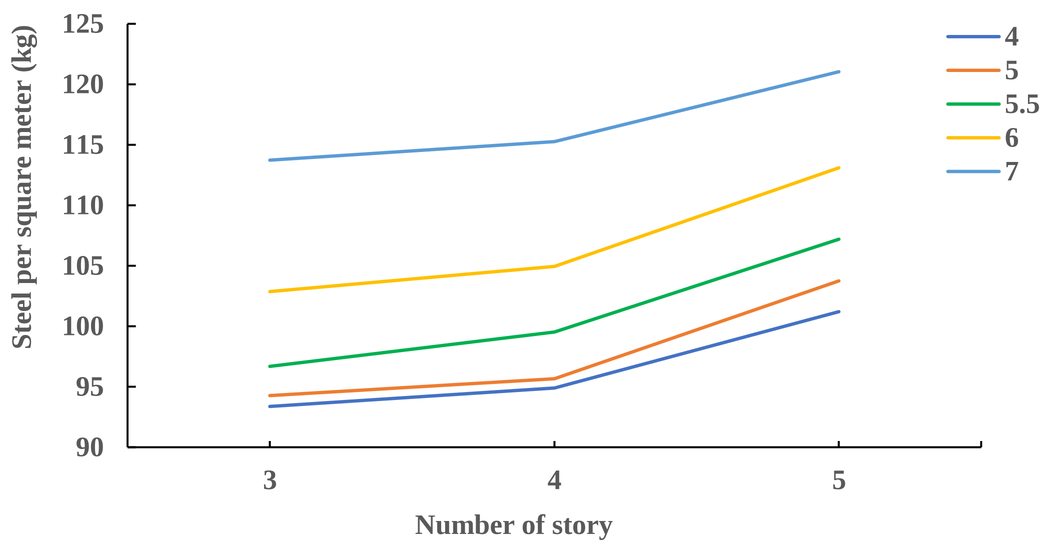



**Figure 4.22:** Influence of number of stories on the steel quantity per square meter of SS with H=3.3 m

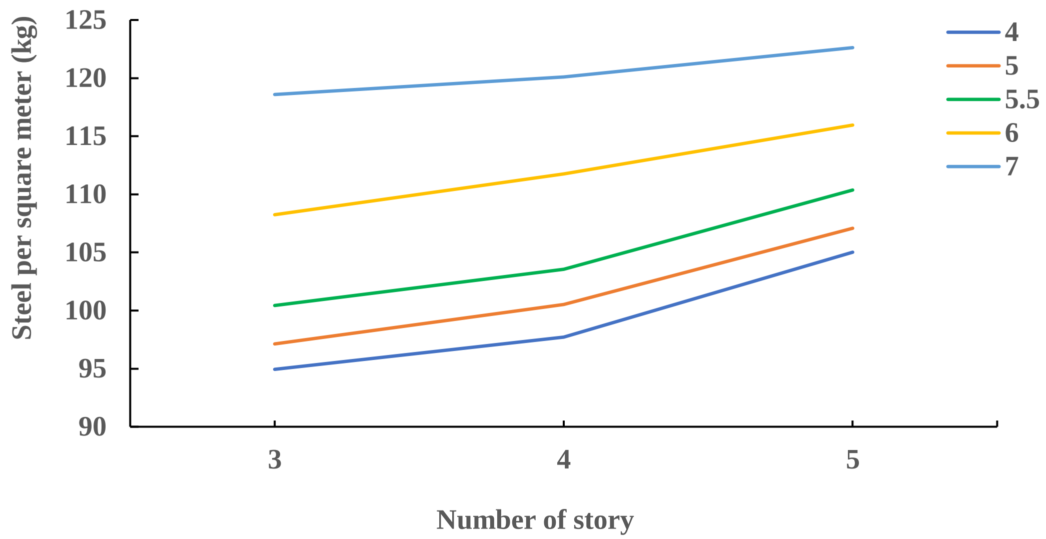



**Figure 4.23:** Influence of number of stories on the steel quantity per square meter of SS with H=3.6 m

***2) Effects of increasing span length on the quantity of steel in steel structures***

Increasing span length is the second parameter for increment the quantity of steel per square meter of steel structures in all multi-story types. The increased percentage of steel quantities by stretch out the spans from 4 m is shown in Table 4.15 below. For instance, in a 3-story structure with H=3.6 m, the percentage increasing length with 1 m, 1.5 m, 2 m, and 3 m is 2.3%, 5.79%, 14.01%, and 24.91%, respectively. That means a greater amount of steel quantity (kg) per square meter of the constructed structure is with the longer span used in this study, 7 m.

The quantity of steel in kg for 4 m and 7 m with constant H=3.6 m is 94.94 kg - 118.59 kg in 3-story, 97.71 kg – 120.11 kg in 4-story, and 105.02 kg – 122.62 kg in 5-story (Table 4.14). This increase in the amount of steel in longer spans is due to a greater section of steel beams used with the higher weight that require a wider section of steel columns and foundation reinforcement to support the extra dead loads. The incrementation of steel quantities in three types of multi-stories and all used spans and story heights is more obvious in figures 4.24 and 4.25, which continually graph lines ascend toward the upper level by lengthening the spans.

**Table 4.15:** Percentage of increasing steel quantity by extending span length per square meter of the SS

| Increasing span length (m) | H (m) | % Increase in steel quantity | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| 1 m (From 4 m to 5 m) | **3.3** | 0.96 | 0.81 | 2.51 |
| 1.5 m (From 4 m to 5.5 m) | **3.3** | 3.55 | 4.87 | 5.92 |
| 2 m (From 4 m to 6 m) | **3.3** | 10.17 | 10.60 | 11.75 |
| 3 m (From 4 m to 7m) | **3.3** | 21.80 | 21.44 | 19.60 |
| 1 m (From 4 m to 5 m) | **3.6** | 2.30 | 2.89 | 1.96 |
| 1.5 m (From 4 m to 5.5 m) | **3.6** | 5.79 | 5.99 | 5.09 |
| 2 m (From 4 m to 6 m) | **3.6** | 14.01 | 14.39 | 10.42 |
| 3 m (From 4 m to 7 m) | **3.6** | 24.91 | 22.93 | 16.76 |

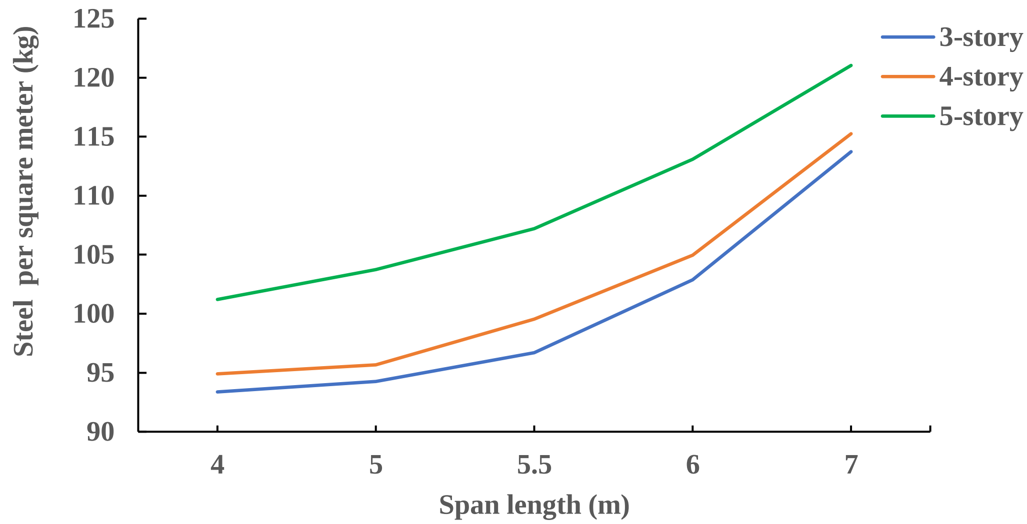



**Figure 4.24:** Influence of increasing span length on the steel quantity per square meter of SS with H=3.3 m

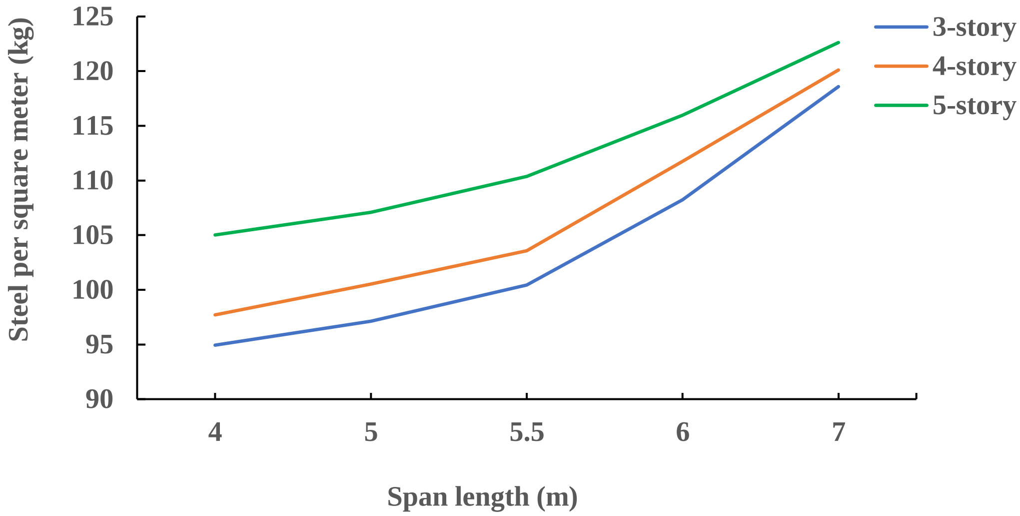



**Figure 4.25:** Influence of increasing span length on the steel quantity per square meter of SS with H=3.6 m

***3) Effects of rising story height on the quantity of steel in steel structures***

Rising the height of stories in framed construction affects the increasing steel quantities of structures because, in the same building area, all stories must use more steel quantities. Rising story height means increasing the building's weight totally, that transport heavy loads to the lower stories and foundation.

The difference in steel quantities per square meter of the building by percentage is explained in Table 4.16. The percentage of increase in 3-story is between 1.68% to 5.23%, in 4-story structures is between 2.96% to 6.48%, but this value is lesser in 5-story that is 1.31% to 3.77%. The effect of rising story height on the steel quantity is presented by the figures 4.26 for 3-story, 4.27 for 4-story, and 4.28 for 5-story structures.

**Table 4.16:** Percentage of steel quantity increase by increasing story height per square meter of SS

| L (m) | H (m) | 3-story | | 4-story | | 5-story | |
|---|---|---|---|---|---|---|---|
| | | **Steel (kg) per m$^2$** | **% Steel increase** | **Steel (kg) per m$^2$** | **% Steel increase** | **Steel (kg) per m$^2$** | **% Steel increase** |
| **4** | **3.3** | 93.37 | 1.68 | 94.90 | 2.96 | 101.21 | 3.77 |
| | **3.6** | 94.94 | | 97.71 | | 105.02 | |
| **5** | **3.3** | 94.27 | 3.03 | 95.67 | 5.08 | 103.75 | 3.21 |
| | **3.6** | 97.13 | | 100.53 | | 107.08 | |
| **5.5** | **3.3** | 96.69 | 3.88 | 99.53 | 4.05 | 107.19 | 2.96 |
| | **3.6** | 100.44 | | 103.56 | | 110.37 | |
| **6** | **3.3** | 102.87 | 5.23 | 104.96 | 6.48 | 113.10 | 2.53 |
| | **3.6** | 108.25 | | 111.76 | | 115.96 | |
| **7** | **3.3** | 113.73 | 4.27 | 115.25 | 4.22 | 121.04 | 1.31 |
| | **3.6** | 118.59 | | 120.11 | | 122.62 | |

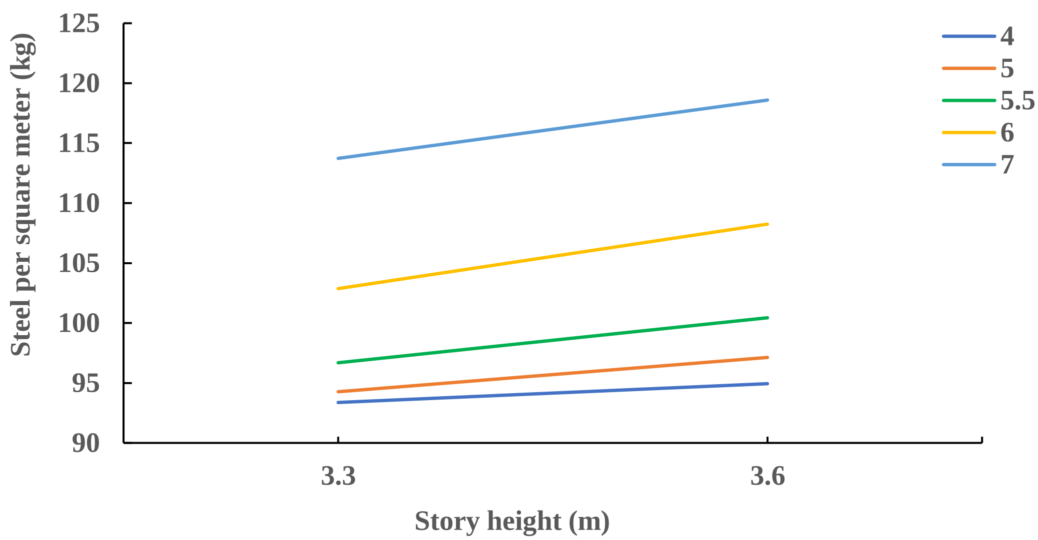



**Figure 4.26:** Influence of rising story height on the steel quantity per square meter of 3-story SS

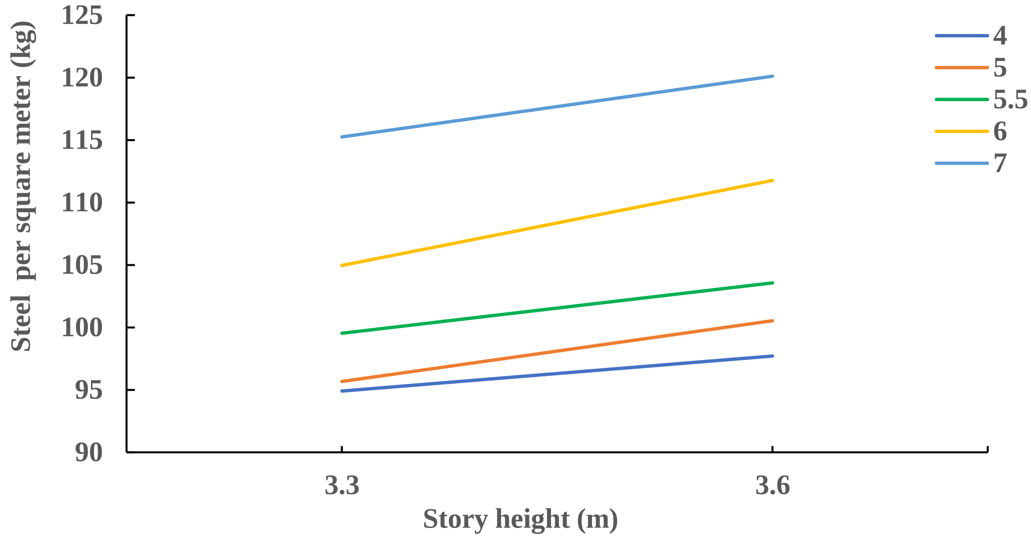



**Figure 4.27:** Influence of rising story height on the steel quantity per square meter of 4-story SS

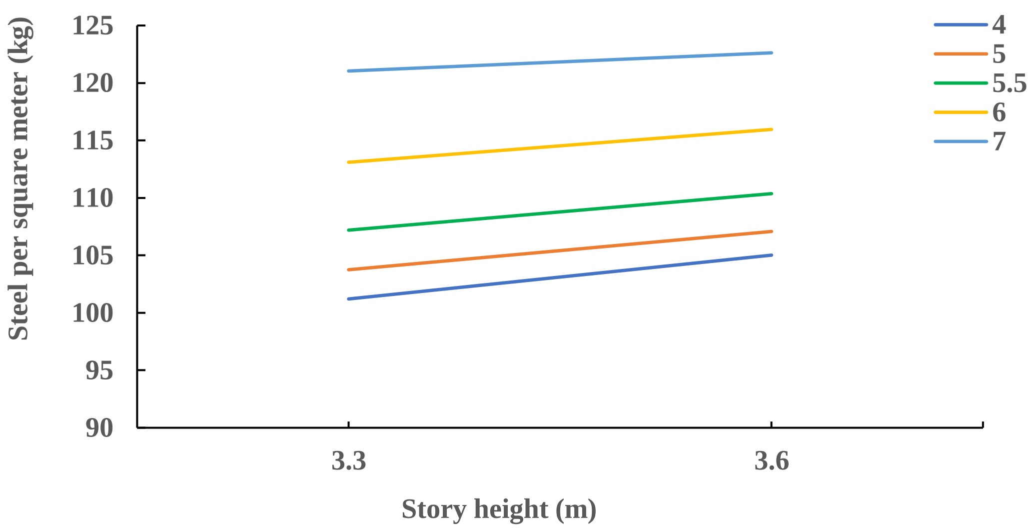



**Figure 4.28:** Influence of rising story height on the steel quantity per square meter of 5-story SS

## 4.2. Total Cost of Structural Construction

The main objective of materials quantity prediction is to estimate the project's total construction cost and provide the determined budget to start project implementation. This section will demonstrate the cost of structural construction by considering the quantities listed and explained in the previous section of this chapter. That will be a process of converting the materials quantity measurement (units) to the currency measurement rate (like US dollar), which will present the structural construction budget and the detail of each material and activities cost to the owners, contractors, and non-engineers.

### 4.2.1 Impacts of the increasing stories number on the total cost of RC and steel structures

Rising story height has a different effect on RC and steel structures construction costs. Figures 4.29, 4.30 illustrate the costs per square meter of structures by the impact of rising stories from 3- to 4- and 5-story. As seen in the figures, adding one story to structure from 3- to 4-story in RC structures greatly increases the structural cost by comparing to the steel structure in the same span lengths and story heights. And these changes are inversely between 4- to 5-story; the steel structures have a higher cost increase in this stage relative to RC structures. That is because in 3- to 4-story, the foundation type is changed (single footing to raft foundation), and since the weight of RC is heavier than steel structure, by increasing one story, it needs to the thicker and wider foundation and columns sections. The type of 4- to 5-stories foundation is the same, but increasing steel column sections need more expenses than RC columns, and the cost of steel columns is near twice the cost of RC columns in some cases.

The percentage of cost increase due to adding stories is explained by numbers in Table 4.17, for example, the rate of cost increase in 3- to 4-story for L=5 m and H=3.3 m is 13.6% in RC and 2.1% in steel structures, but with the same parameters in the 4- to 5-story this rate is reversed to 3.0% for RC and 6.9% for steel structures.

**Table 4.17:** Percentage of total cost increase by increasing the number of stories per square meter of RCS and SS

| L (m) | H (m) | Cost of RCS ($) per m² | | | %Cost increase from 3- to 4-story | %Cost increase from 4- to 5-story | Cost of SS ($) per m² | | | %Cost increase from 3- to 4-story | %Cost increase from 4- to 5-story |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3-story | 4-story | 5-story | | | 3-story | 4-story | 5-story | | |
| **4** | **3.3** | 50.4 | 58.1 | 60.5 | 15.2 | 4.1 | 81.1 | 82.9 | 87.1 | 2.2 | 5.1 |
| **5** | **3.3** | 47.3 | 53.7 | 55.3 | 13.6 | 3.0 | 82.0 | 83.7 | 89.5 | 2.1 | 6.9 |
| **5.5** | **3.3** | 45.8 | 51.5 | 52.8 | 12.4 | 2.5 | 83.6 | 86.9 | 91.9 | 3.9 | 5.8 |
| **6** | **3.3** | 46.8 | 52.8 | 54.9 | 12.9 | 4.0 | 87.9 | 91.6 | 96.8 | 4.2 | 5.7 |
| **7** | **3.3** | 49.0 | 56.8 | 58.7 | 15.8 | 3.3 | 96.6 | 99.3 | 104.2 | 2.8 | 4.9 |
| **4** | **3.6** | 52.7 | 61.7 | 64.4 | 17.0 | 4.4 | 82.3 | 85.4 | 89.8 | 3.8 | 5.2 |
| **5** | **3.6** | 49.6 | 56.6 | 58.4 | 14.2 | 3.2 | 84.1 | 87.2 | 91.9 | 3.7 | 5.4 |
| **5.5** | **3.6** | 47.0 | 52.7 | 55.3 | 12.2 | 4.9 | 86.3 | 89.8 | 94.6 | 4.1 | 5.3 |
| **6** | **3.6** | 48.2 | 54.6 | 57.3 | 13.3 | 4.9 | 91.8 | 96.5 | 98.9 | 5.1 | 2.4 |
| **7** | **3.6** | 50.5 | 58.6 | 61.3 | 15.9 | 4.6 | 100.1 | 102.8 | 105.7 | 2.7 | 2.8 |

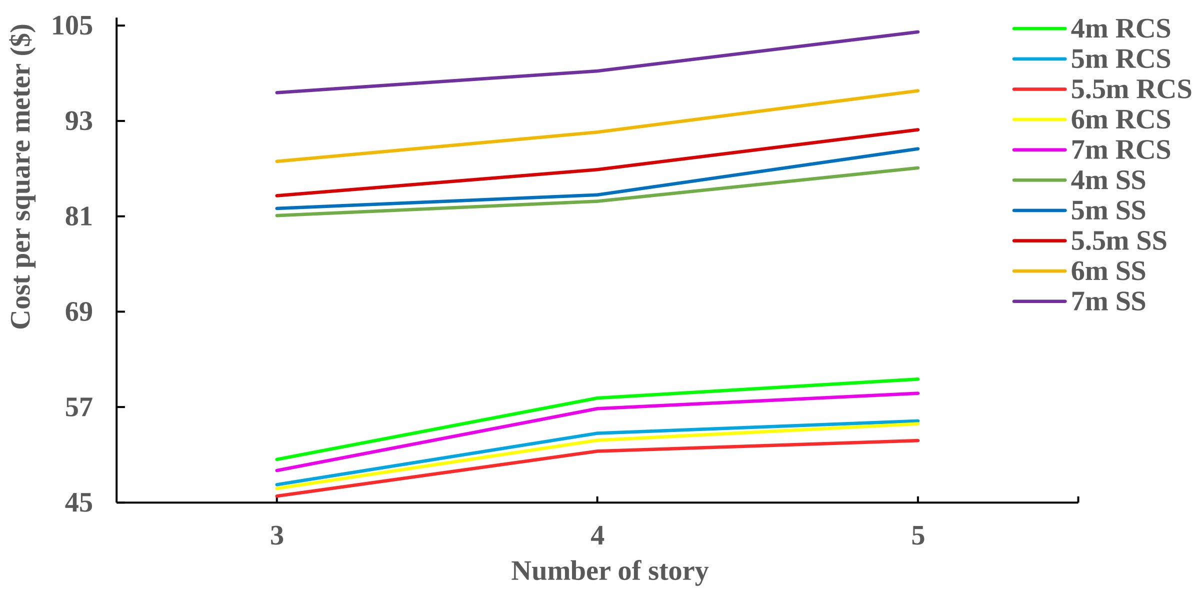



**Figure 4.29:** Influence of number of stories on the total cost of square meter of RC and steel structures with H= 3.3 m

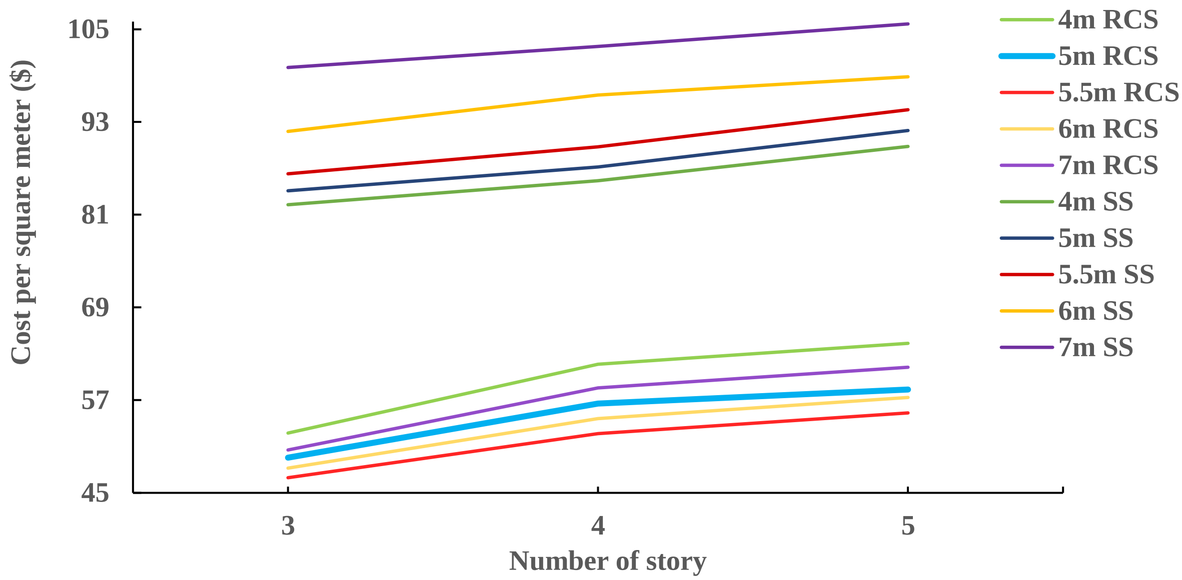



**Figure 4.30:** Influence of number of stories on the total cost of square meter of RC and steel structures with H= 3.6 m

### 4.2.2 Effects of increasing span length on the total cost of RC and steel structures

The span length is multiple parameters in structural building construction since this parameter must hold the balance between architectural plan, construction expense, and structural stability and safety.

Figures 4.31 and 4.32 shows a clear influence of increasing span length on the structural RC and steel construction cost. These figures showed that by extending span lengths in each RC and steel structure, the graph lines take a different direction (steel goes upward and RC goes downward). The cost of RC structures will gradually decrease by extending the span, while steel structures' cost continually increases in the same conditions. For example, by increasing 2 m of span length from (4 m to 6 m) with H=3.3 m, the cost of RC structures is decreased by the rate 7.2%, 9.1%, and 9.3% for 3-, 4- and 5-story respectively, but inversely the qualities of steel structures cost are increased by 8.4%, 10.5% and 11.1% for 3-, 4- and 5-story structures respectively (Table 4.18). These numbers specify that extending span length by any rate directly increases the construction cost of steel structures and oppositely decreases the cost of RC structures in all types of multi-stories and story heights in this study.

**Table 4.18:** Percentage of total cost change per square meter by increasing span length in the RCS and SS

| Increasing span length (m) | H (m) | %RCS cost decrease | | | %SS cost increase | | |
|---|---|---|---|---|---|---|---|
| | | 3-story | 4-story | 5-story | 3-story | 4-story | 5-story |
| 1 m (From 4 m to 5 m) | **3.3** | -6.3 | -7.6 | -8.7 | 1.1 | 1.0 | 2.8 |
| 1.5 m (From 4 m to 5.5 m) | **3.3** | -9.1 | -11.5 | -12.8 | 3.1 | 4.8 | 5.5 |
| 2 m (From 4 m to 6 m) | **3.3** | -7.2 | -9.1 | -9.3 | 8.4 | 10.5 | 11.1 |
| 3 m (From 4 m to 7 m) | **3.3** | -2.8 | -2.3 | -2.9 | 19.1 | 19.8 | 19.6 |
| 1 m (From 4 m to 5 m) | **3.6** | -6.0 | -8.3 | -9.3 | 2.2 | 2.1 | 2.3 |
| 1.5 m (From 4 m to 5.5 m) | **3.6** | -11.0 | -14.6 | -14.0 | 4.9 | 5.2 | 5.3 |
| 2 m (From 4 m to 6 m) | **3.6** | -8.6 | -11.5 | -10.9 | 11.5 | 13.0 | 10.0 |
| 3 m (From 4 m to 7 m) | **3.6** | -4.2 | -5.0 | -4.8 | 21.6 | 20.4 | 17.6 |

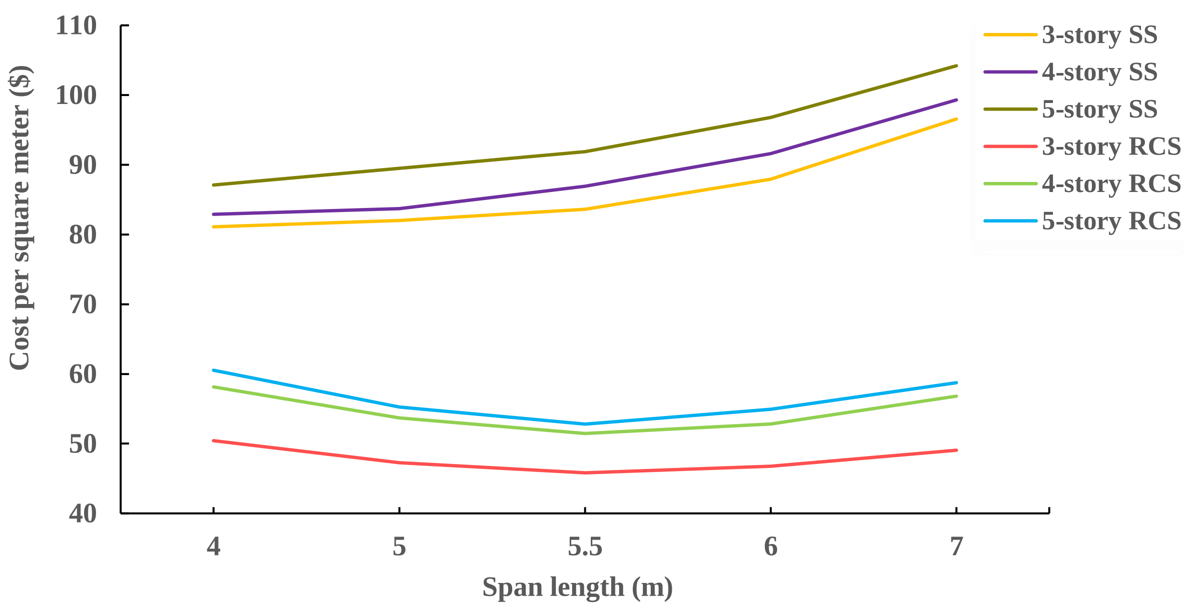



**Figure 4.31:** Influence of increasing span length on the total cost in square meter of RC and steel structures with H=3.3 m

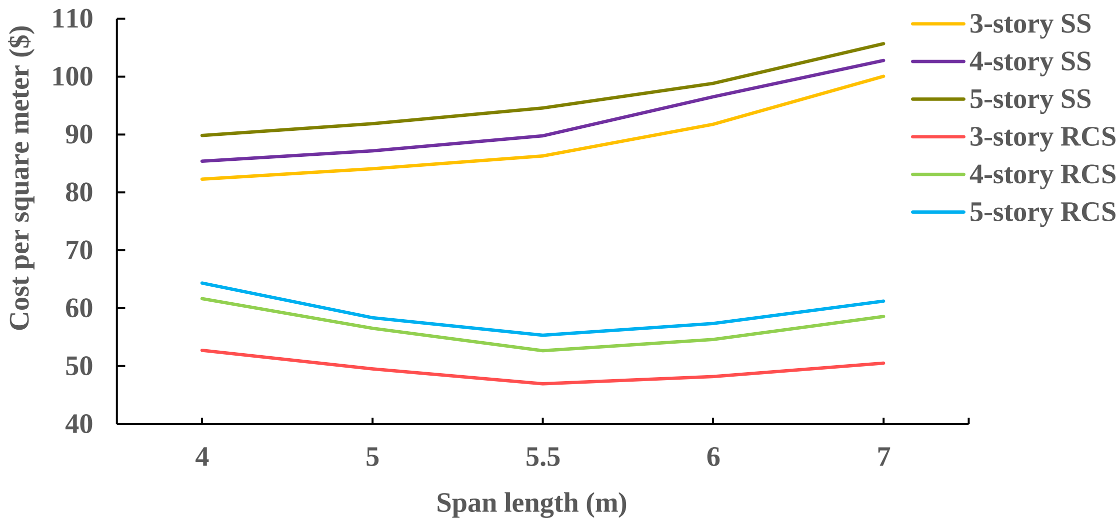



**Figure 4. 32:** Influence of increasing span length on the total cost in square meter of RC and steel structures with H=3.6 m

### 4.2.3 Impacts of rising story height on the total cost of RC and steel structures

By increasing the story height in the building structures (RC and steel), the construction cost will be increased. Figures 4.33, 4.34, and 4.35 illustrate that in all types of multi-stories and span lengths, the direction of cost graph lines by rising story height is going upward.

The maximum rate of cost increase by the effect of 30 cm story rising in RC structures is 6.32% in the 5-story with L= 4 m, and the higher cost increasing rate in steel structures is in 4-story with L= 6 m by the amount of 5.35% (Table 4.19). This increasing cost is because by rising story height, the quantity of material and their installation activities will increase in the same building area.

**Table 4.19:** Amount of total cost increase per square meter by rising story height in the RCS and SS

| L (m) | H (m) | 3-story RCS Cost per $m^2$ ($) | 3-story RCS % Increase in cost | 3-story SS Cost per $m^2$ ($) | 3-story SS % Increase in cost | 4-story RCS Cost per $m^2$ ($) | 4-story RCS % Increase in cost | 4-story SS Cost per $m^2$ ($) | 4-story SS % Increase in cost | 5-story RCS Cost per $m^2$ ($) | 5-story RCS % Increase in cost | 5-story SS Cost per $m^2$ ($) | 5-story SS % Increase in cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 3.3 | 50.4 | 4.58 | 81.1 | 1.48 | 58.1 | 6.06 | 82.9 | 3.02 | 60.5 | 6.32 | 87.1 | 3.15 |
| | 3.6 | 52.7 | | 82.3 | | 61.7 | | 85.4 | | 64.4 | | 89.8 | |
| 5 | 3.3 | 47.3 | 4.86 | 82.0 | 2.56 | 53.7 | 5.31 | 83.7 | 4.18 | 55.3 | 5.62 | 89.5 | 2.68 |
| | 3.6 | 49.6 | | 84.1 | | 56.6 | | 87.2 | | 58.4 | | 91.9 | |
| 5.5 | 3.3 | 45.8 | 2.49 | 83.6 | 3.23 | 51.5 | 2.36 | 86.9 | 3.34 | 52.8 | 4.81 | 91.9 | 2.93 |
| | 3.6 | 47.0 | | 86.3 | | 52.7 | | 89.8 | | 55.3 | | 94.6 | |
| 6 | 3.3 | 46.8 | 3.05 | 87.9 | 4.40 | 52.8 | 3.34 | 91.6 | 5.35 | 54.9 | 4.43 | 96.8 | 2.13 |
| | 3.6 | 48.2 | | 91.8 | | 54.6 | | 96.5 | | 57.3 | | 98.9 | |
| 7 | 3.3 | 49.0 | 3.09 | 96.6 | 3.62 | 56.8 | 3.16 | 99.3 | 3.52 | 58.7 | 4.28 | 104.2 | 1.44 |
| | 3.6 | 50.5 | | 100.1 | | 58.6 | | 102.8 | | 61.3 | | 105.7 | |

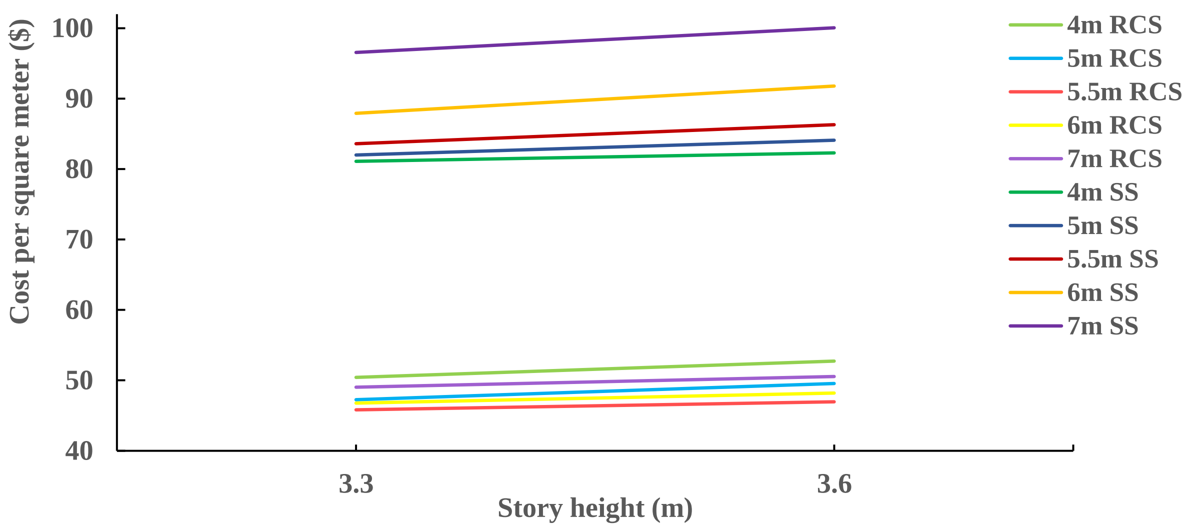



**Figure 4.33:** Influence of rising 30 cm story height on the total cost per square meter of 3-story RCS and SS

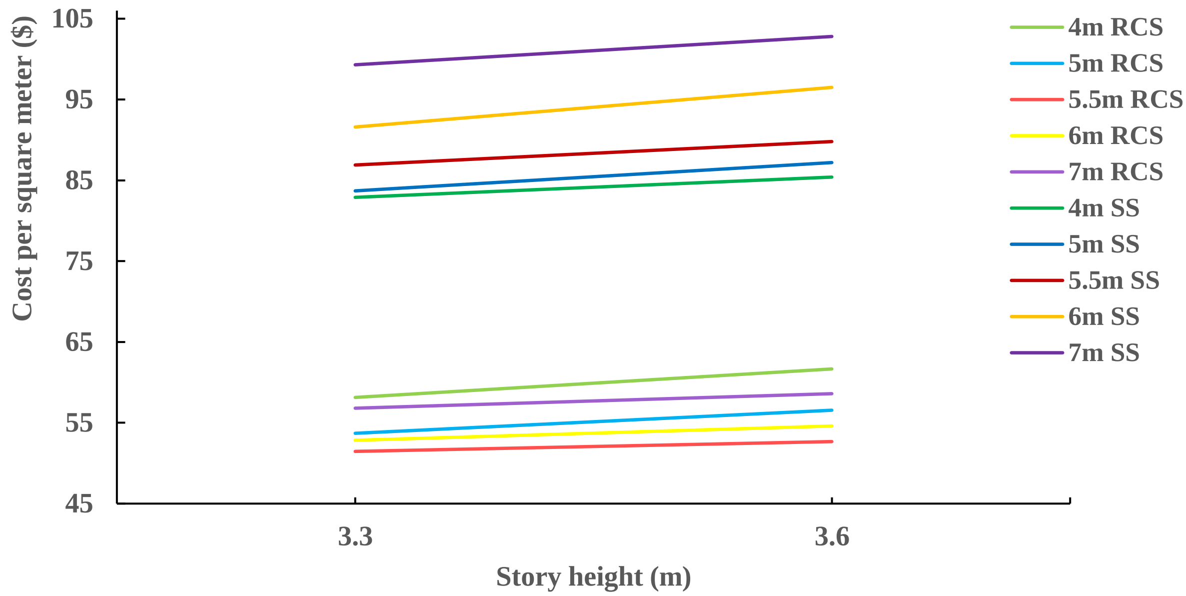



**Figure 4.34:** Influence of rising 30 cm story height on the total cost per square meter of 4-story RC and SS

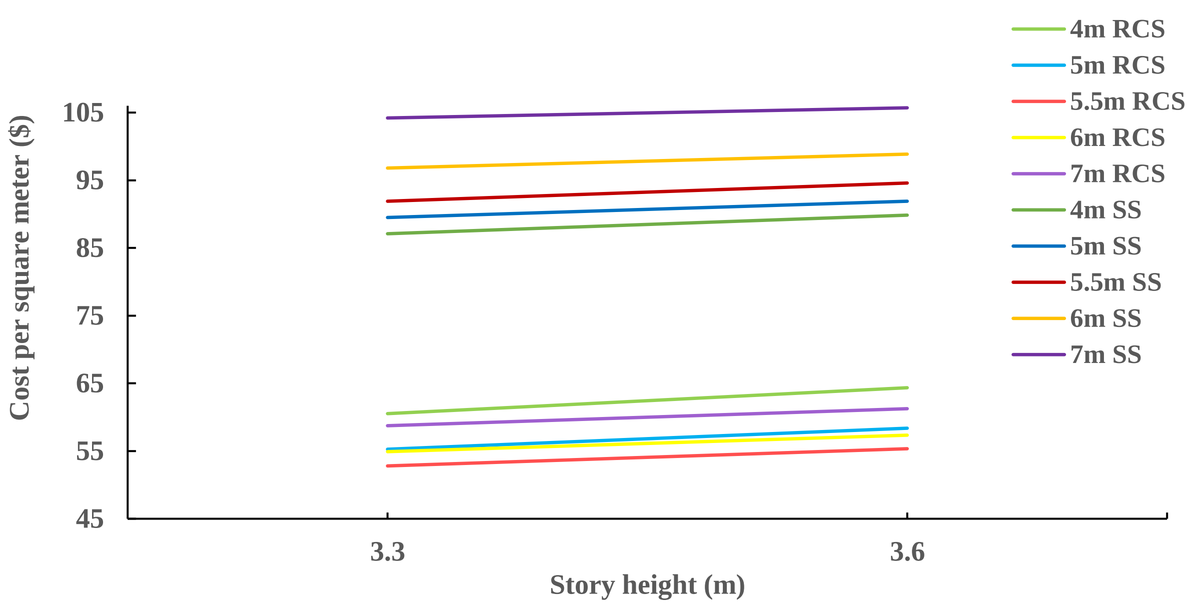



**Figure 4.35:** Influence of rising 30 cm story height on the total cost per square meter of 5-story RC and SS

### 4.2.4 Effect of using different materials (RC and steel) on the total structural construction cost

The total cost of multi-story structural construction utilizing various alternatives (RC and steel) per square meter and their differences in percent is clearly explained by Table 4.20 below. As obviously shown, the prices by using steel in structures are more costly than RC in different stories, span length, and story heights. The cost of constructing one square meter building structure by steel is more than 1.5 square meter of structures cost built by RC (the percentage of extra cost is more than 50%) in all cases except for 4 m span length in 4- and 5-story buildings with both H= 3.3 m and 3.6 m.

By figures 4.36 and 4.37, the percentage of the cost difference is illustrated simpler. The rate of the cost increase in the 3-story building is higher compare to 4- and 5- stories, and especially in 7 m span lengths, this rate gets a higher level among its equivalent indicator bars. The maximum percentage of the cost difference is 97.9% in the 3-story structures with L= 7 m, H= 3.6 m.
As a result, increasing all parameters (span length, number of stories, and rising story height) directly influences the rising cost of steel structure construction by a rate more than using RC materials. The high price of constructing a structure by steel is also related to the expensive supplying steel material price in Erbil-Iraq and its installation compared to concrete and formwork materials.

**Table 4.20:** Percentage of extra structural construction cost by steel related to RC per square meter

| L (m) | H (m) | 3-story Cost of RCS ($) per m$^2$ | 3-story Cost of SS ($) per m$^2$ | 3-story % Extra cost of SS | 4-story Cost of RCS ($) per m$^2$ | 4-story Cost of SS ($) per m$^2$ | 4-story % Extra cost of SS | 5-story Cost of RCS ($) per m$^2$ | 5-story Cost of SS ($) per m$^2$ | 5-story % Extra cost of SS |
|---|---|---|---|---|---|---|---|---|---|---|
| **4** | **3.3** | 50.4 | 81.1 | 60.8 | 58.1 | 82.9 | 42.6 | 60.5 | 87.1 | 43.9 |
| **5** | **3.3** | 47.3 | 82.0 | 73.5 | 53.7 | 83.7 | 55.9 | 55.3 | 89.5 | 61.9 |
| **5.5** | **3.3** | 45.8 | 83.6 | 82.5 | 51.5 | 86.9 | 68.9 | 52.8 | 91.9 | 74.0 |
| **6** | **3.3** | 46.8 | 87.9 | 88.0 | 52.8 | 91.6 | 73.4 | 54.9 | 96.8 | 76.3 |
| **7** | **3.3** | 49.0 | 96.6 | 96.9 | 56.8 | 99.3 | 74.8 | 58.7 | 104.2 | 77.4 |
| **4** | **3.6** | 52.7 | 82.3 | 56.1 | 61.7 | 85.4 | 38.5 | 64.4 | 89.8 | 39.6 |
| **5** | **3.6** | 49.6 | 84.1 | 69.7 | 56.6 | 87.2 | 54.2 | 58.4 | 91.9 | 57.4 |
| **5.5** | **3.6** | 47.0 | 86.3 | 83.8 | 52.7 | 89.8 | 70.5 | 55.3 | 94.6 | 70.9 |
| **6** | **3.6** | 48.2 | 91.8 | 90.4 | 54.6 | 96.5 | 76.7 | 57.3 | 98.9 | 72.4 |
| **7** | **3.6** | 50.5 | 100.1 | 97.9 | 58.6 | 102.8 | 75.4 | 61.3 | 105.7 | 72.5 |

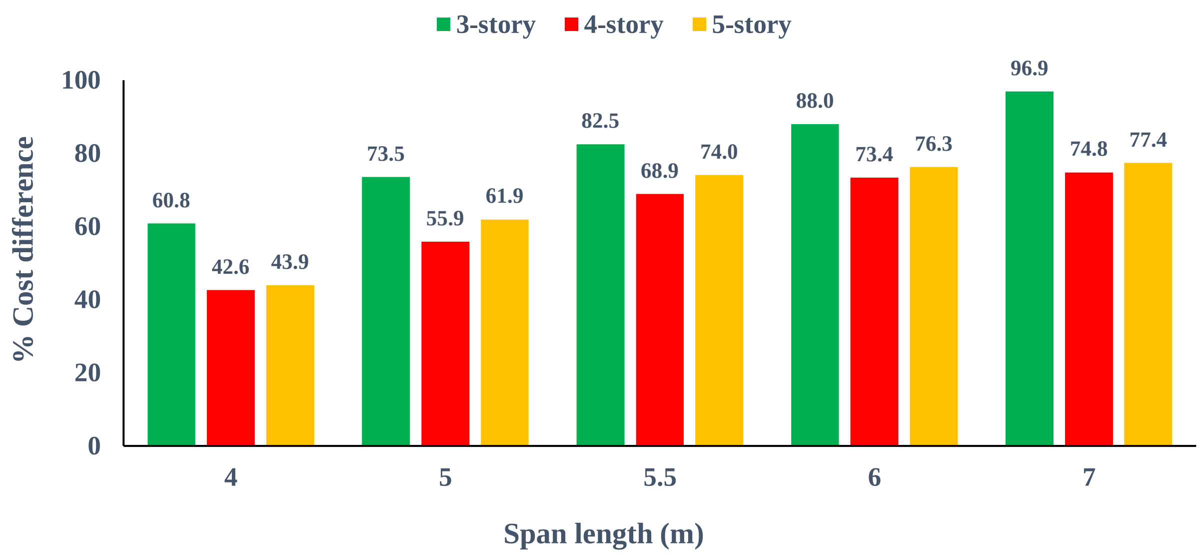


**Figure 4.36:** Percentage of extra construction cost of SS related to RCS with H=3.3 m

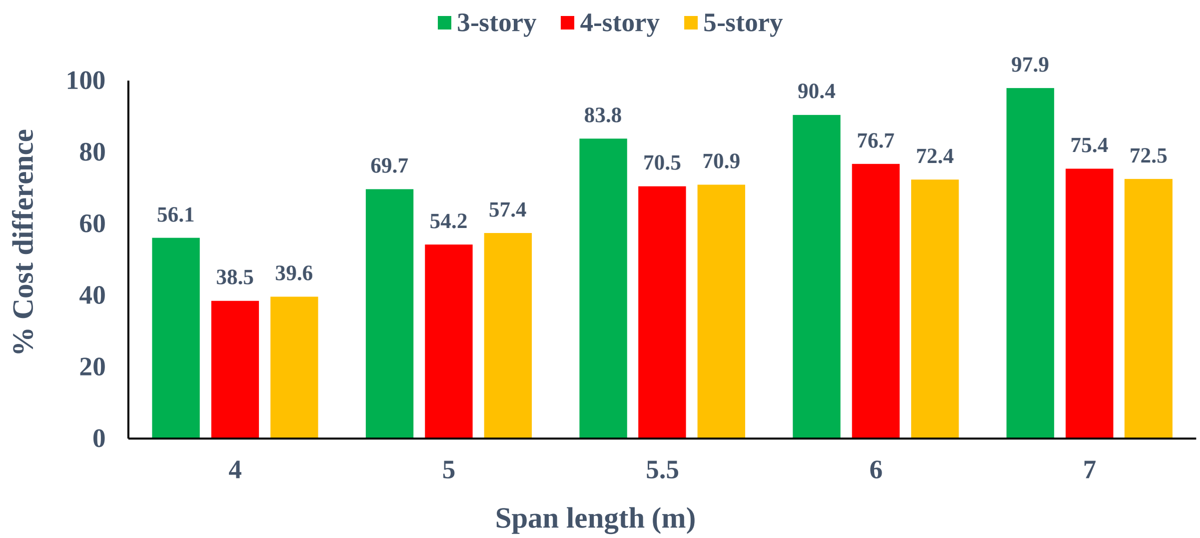



**Figure 4.37:** Percentage of extra construction cost of SS related to RCS with H=3.6 m

# CHAPTER 5
# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

This study evaluates the effects of four different parameters (span length, number of stories, story height, and different materials) on the cost of structural building construction. The various cost prediction approaches for low-rise and med-rise RC and multi-story steel buildings have been performed under the effects of different mentioned parameters. The study's broad validation was built by comparing cost-effective parameter alternatives with detailed data of the designed building's construction. In addition to specifying cost-effective parameters of building construction, the research would help assess the different types of structures with the effect of various parameters.

The results of cost comparisons in this study demonstrate that RC material is a more economical choice in constructing multi-story structures than steel material in all cases of different used parameters. From the results obtained in the quantities of construction materials and total cost of structures can conclude the effects of various parameters on the quantities and cost of models as bellows:

An abbreviated conclusion about the consequences of formwork quantity under the effect of different parameters in the RC structure

1- The quantity of concrete formwork is increase by adding the number of stories. This quantity increment in the higher story buildings is due to their needs for a wider and thicker foundation and greater columns section in the lower stories. The maximum percentage of quantity increase by rising the structure from 3-story to 4-story is 1.95%. While this maximum percentage is higher in between 4-story and 5-story that include: 2.54%.

2- Increasing span length directly affect decreasing the quantity of formwork. The amount of formwork in structures with L= 4 m is higher than the structure with L= 5 m or 5.5 m or 6 m or 7 m. For example, in 4-story framed structures, by increasing span length from 4 m to 7 m, the quantity of formwork will decrease by 17.16%. This decrease in quantity is because of the lesser number of columns in the building.

3- By rising story height from 3.3 m to 3.6 m, the quantity of formwork in RC structures will increase at various rates. The maximum increasing rate of quantity for 3-story buildings is 5.11% and for 4-story is 4.89%, while this rate in 5-story buildings is received to 3.35%. These rates are proportional to the number and dimension of columns in all stories. As the height of columns and partition walls increase, it needs more structural and covering materials. As a result, the gravity loads will increase, which requires greater dimensions of all structural members.

An abbreviated conclusion about the consequences of the concrete quantity under the effect of different parameters in the RC structure

1- Increasing the number of stories is proportional to the increasing quantity of concrete. The maximum percentage of concrete quantity increased by rising the structure from 3-story to 4-story is 31.44%, while this percentage is lesser in between 4- and 5-story that is 4.56%. The higher rate of concrete difference between 3- and 4-story is due to the difference in their foundation's type. In 3-story, the single footing was used with less concrete, but in 4- and 5-story, the raft foundation needed more concrete amount.

2- The rate of concrete quantities required for construction is decreased gradually by increasing the span from 4 m till 5.5 m compared to the same multi-story and story height, but it is increasing again in 6 m and 7 m. It means the amount of concrete needed in the construction of framed structures with a 4 m span is higher than the same structure with a 5 m or 5.5 m span and less than 6 m and 7 m span lengths. For example, in 5-story buildings increasing span length from 4 m to 5.5 m will decrease the rate of concrete quantity by 8.3%. The maximum percentage of decrease in concrete quantities is 9.2% in the 5-story model by increasing 1.5 m span length, and the maximum rate of the concrete quantity increase is 20.2% in the 4-story and by increasing the span from 4 m to 7 m.

3- Rising the building's height will increase the quantity of concrete in RCS by various per cents. The maximum increase rate in 3-story structures is 4.10%, in 4-story structures is 3.70%, and in 5-story structures, it will be decreased to 2.50%. The reduction in quantities has a relation to the dimension of columns in all stories. By rising the height of columns and partition walls, it needs to more structural and covering materials. As a result, the gravity loads increase, which needs the bigger dimensions of all structural members.

An abbreviated conclusion about the consequences of steel bar quantity under the effect of different parameters in the RC structure

1- The quantity of steel bars in RC structures increases by increasing the number of stories. The maximum percentage of increase from 3- to 4-story is 22.77%. While this percentage is lesser in between 4- and 5-story, which is 9.32%. The higher rate of difference in 3- and 4-story is related to the difference in their foundation form. In 3-story, the single footing was used with less steel bar amount, but in 4- and 5-story, the raft foundation was used that need more steel bars.

2- By extending span lengths, the quantity of steel bars in RC structures will decrease in all three types of multi-stories buildings. As the span length increases from 4 m to 5.5 m for the same multi-story and story height, the steel bar will decrease, but in 6 m and 7 m, it increases. The minimum percentage of decrease in steel bar quantities is 2.76% in the 3-story model by increasing 3m span length. In comparison, the maximum rate of the reinforcement quantity decrease is 19.3% in the 4-story model by increasing the span length from 4 m to 5.5 m.

3- With rising the height of building stories from 3.3 m to 3.6 m, the quantity of steel bar will increase in RC structures at various rates. The range of increase is between 3.45% to 8.03% for 3-story building structures, and for 4-story models are between 2.90% to 8.83%, while the rate will be higher in 5-story by the range of 8.26% to 12.28%. Total increasing amounts are depending on the dimension and height of columns in all stories. As the height of columns and walls increases, it needs more structural and covering materials which require the greater dimension of framed members to carry these extra gravity loads.

An abbreviated conclusion about the consequences of steel quantity under the effect of different parameters in the steel structure

1- Increasing number of stories directly influences increasing steel quantity in steel structures; the quantity of steel in 5-story structures is more than low- rise buildings. An increase in the number of stories needs to more quantity of steel; for example, for a structure with a span of 5 m and 3.6 m story height, the required construction steel per square meter of the structure is 97.13 kg, 100.53 kg, and 107.08 kg for 3-, 4- and 5-story respectively. The higher percentage of steel difference between 3- and 4-story is 3.51% in 5 m span length, while the higher percentage rate between 4-and 5-story is 8.44% for 5 m span length. This increase in steel quantity for riser framed buildings is due to the higher rate of loads in the lower stories, which need the wider dimension of columns and foundation reinforcement.

2- Increasing span length is the second parameter for increment the quantity of steel in steel structures and all multi-story types. In a 3-story structure with a 3.6 m story height, the percentage increasing length with 1 m, 1.5 m, 2 m, and 3 m is 2.3%, 5.79%, 14.01%, and 24.91%, respectively. A greater amount of steel quantity (kg) in the constructed structure is with the longer span used in this study, 7 m in all story-rise types. As an example, the quantity of steel in kg per square meter of steel structure for 4 m and 7 m with a constant story height of 3.6 m is as follows 94.94 kg - 118.59 kg in 3-story, 97.71 kg – 120.11 kg in 4-story, and 105.02 kg – 122.62 kg in 5-story. This increase in the amount of steel in longer spans is due to a greater section of steel beams used with the higher weight that require wider section of steel columns and foundation reinforcement to support the extra dead loads.

3- Rising the story heights directly affects the increasing steel quantities of structures, because in the same building area for all stories must use more steel quantities. Rising story height means increasing the building's weight totally, which transports heavy loads to the lower stories and foundation. The maximum percentage of increase in 3-story is 5.23%, in 4-story structures is 6.48% and in 5-story is 3.77%.

An abbreviated conclusion about the consequences of total construction cost under the effect of different parameters in the RC and steel structure

1- The main objective of materials quantity prediction is to estimate the project's total construction cost and provide the determined budget to start project implementation. That will be a process of converting the materials quantity measurement rate (units) to the currency measurement rate (like US dollar), which will present the structural construction budget and the detail of each material and activities cost to the owners, contractors, and non-engineers.

2- Increasing number of stories has a different impact on RC and steel structures construction cost. By rising the structure from 3- to 4-story with 5 m span length and 3.3 m story height, the cost increase in RC structures is 13.6%, which is more than steel structures (2.1%). And these percentages reversed between 4- to 5-story building with the same conditions, the steel structures have higher cost increase (6.9%) related to RC structures (3.0%). In 3- to 4-story, the foundation type was changed, and since the weight of RC is heaver related to steel structure, increasing one story needs to the thicker and wider foundation and columns sections. The types of foundation in 4- to 5-stories are the same, but increasing steel columns sections need more expenses than RC columns since the cost of steel columns is near twice the RC columns' cost in some cases.

3- The span length is a considerable parameter in structural building construction because it must balance architectural plan, construction expense, and structural stability. Extending span lengths will decrease RC structures' cost while increasing the cost of steel structures by the same conditions. By increasing the span length from 4 m to 6 m with 3.3 m floor height, the cost of RC structures is decreased by the rate 7.2%, 9.1%, and 9.3% for 3-, 4- and 5-story respectively, but inversely the rates of steel structures cost are increased by 8.4%, 10.5% and 11.1% for 3-, 4- and 5-story structures respectively. These amounts specify that increasing span length by any rate will increase the construction cost of steel structures and, conversely, decrease RC structures' cost in all types of multi-story and story heights in this research.

4- By increasing the story height in RC and steel structures, the construction cost will be increased. The maximum rate of cost increase by rising 30 cm story height in RC structures is 6.32% in the 5-story with 4 m span length, and the higher cost increasing rate in steel structures is in 4-story with 6 m span length by the rate of 5.35%. The cause of this increased cost by rising story height is related to the incrementation of materials quantity and their installation activities for the same building area.

5- The total cost of steel structures is more costly than RC structures in all cases of different stories, span length, and story heights. The cost of constructing one square meter building structure by steel is more than 1.5 square meters of structures cost built by RC in all cases except for 4 m span length in 4- and 5-story buildings. The cost increase in the 3-story building is more compared to 4- and 5- stories, especially in 7 m span lengths. The maximum percentage of the cost difference is 97.9% in the 3-story structures with 7 m span length and 3.6 m story height. As a result, increasing all parameters (span length, number of stories, and rising story height) directly influences the rising cost of steel structure construction by a rate more than using RC materials.

## 5.2 Recommendations

In this research, only the effect of the number of stories, steel and RC materials, story height, and span length is considered. But can be prepared several studies on more parameters and factors which have a significant effect on the cost of building construction, such as types of slabs (flat slab, waffle slabs, etc.), the composite material of steel and RC, precast concrete elements, and can be considered the total life-cycle cost of the building.

More studies can also be done to quantify and estimate the impact of different systems of structures, occupancy, types of sub-grade soil, and foundations on the cost of construction.

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# APPENDICES

# APPENDIX 1

# MATERIALS QUANTITY IN STRUCTURAL CONSTRUCTION

## A.1.1 Concrete Formwork Quantity in RC Structures

**Table A.1.1:** Concrete formwork quantity of the whole RC structures

| L (m) | H (m) | Total RCS formwork ($m^2$) | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| 4 | 3.3 | 853 | 1,159 | 1,486 |
| 5 | 3.3 | 1,251 | 1,693 | 2,150 |
| 5.5 | 3.3 | 1,430 | 1,928 | 2,433 |
| 6 | 3.3 | 1,634 | 2,203 | 2,785 |
| 7 | 3.3 | 2,137 | 2,887 | 3,633 |
| 4 | 3.6 | 896 | 1,207 | 1,536 |
| 5 | 3.6 | 1,279 | 1,736 | 2,207 |
| 5.5 | 3.6 | 1,453 | 1,968 | 2,481 |
| 6 | 3.6 | 1,659 | 2,242 | 2,828 |
| 7 | 3.6 | 2,183 | 2,928 | 3,690 |

**Table A.1.2:** Formwork quantity per square meter of RC structures

| L (m) | H (m) | Quantity of concrete formwork ($m^2$) per square meter | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| 4 | 3.3 | 1.85 | 1.89 | 1.93 |
| 5 | 3.3 | 1.76 | 1.78 | 1.81 |
| 5.5 | 3.3 | 1.67 | 1.69 | 1.70 |
| 6 | 3.3 | 1.59 | 1.61 | 1.63 |
| 7 | 3.3 | 1.54 | 1.56 | 1.57 |
| 4 | 3.6 | 1.94 | 1.96 | 2.00 |
| 5 | 3.6 | 1.80 | 1.83 | 1.86 |
| 5.5 | 3.6 | 1.70 | 1.72 | 1.74 |
| 6 | 3.6 | 1.62 | 1.64 | 1.65 |
| 7 | 3.6 | 1.57 | 1.58 | 1.60 |

### A.1.1.1 Formwork quantity in low- and med-rise RC structures

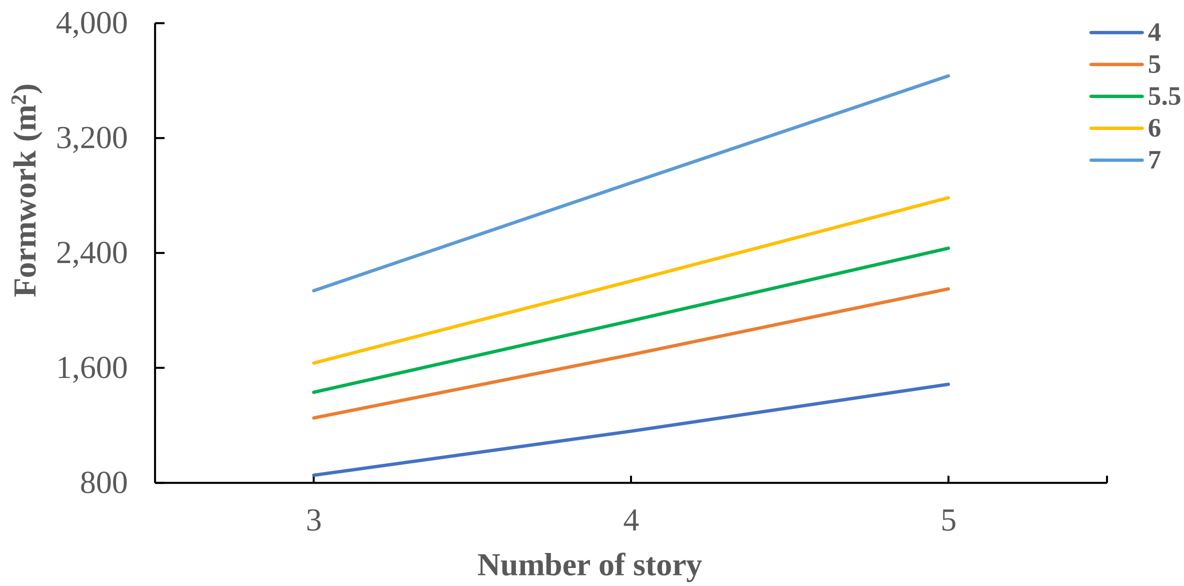


**Figure A.1.1:** Formwork quantity versus number of stories in RC multi-story structure with H=3.3 m

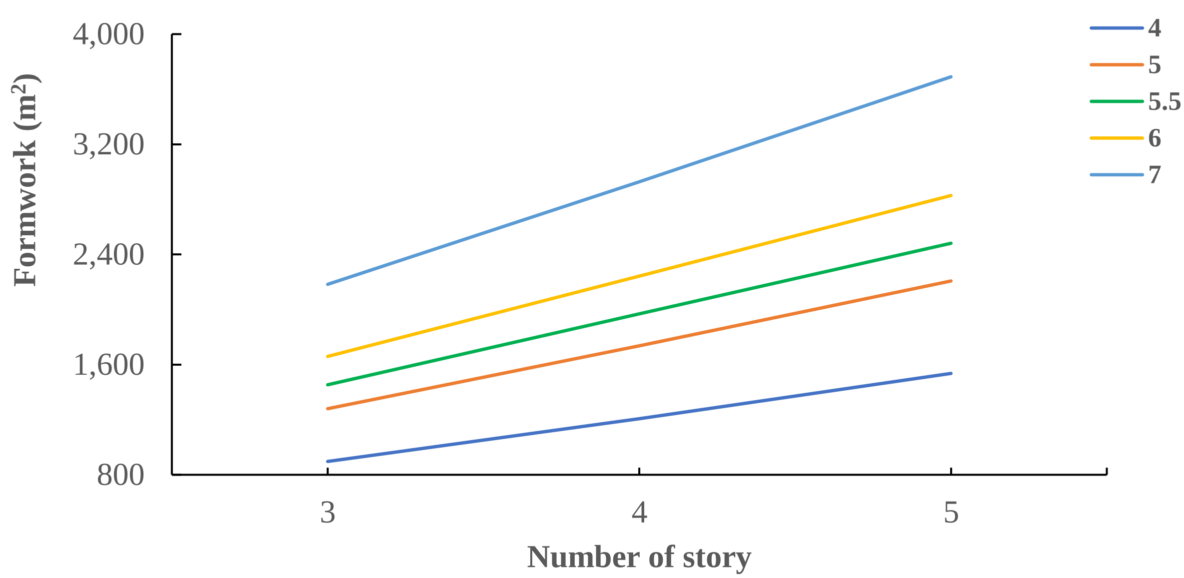


**Figure A.1.2:** Formwork quantity versus number of stories in RC multi-story structures with H=3.6 m

**A.1.1.2 Formwork quantity in various span lengths of RC structures**

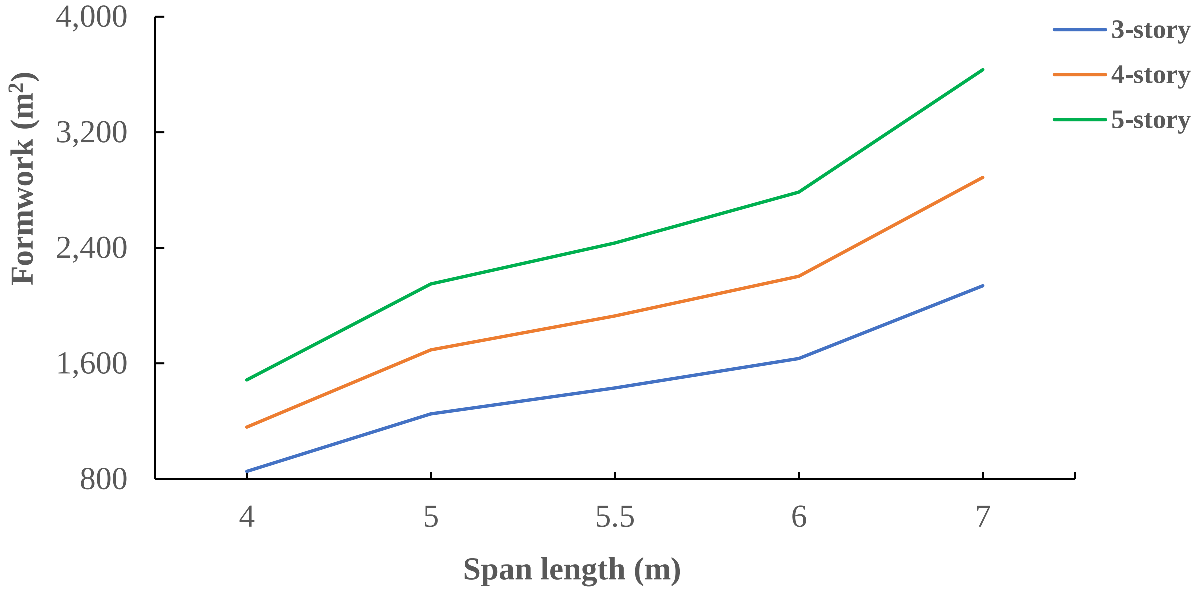


**Figure A.1.3:** Formwork quantity versus various span lengths in the RCS with H=3.3 m

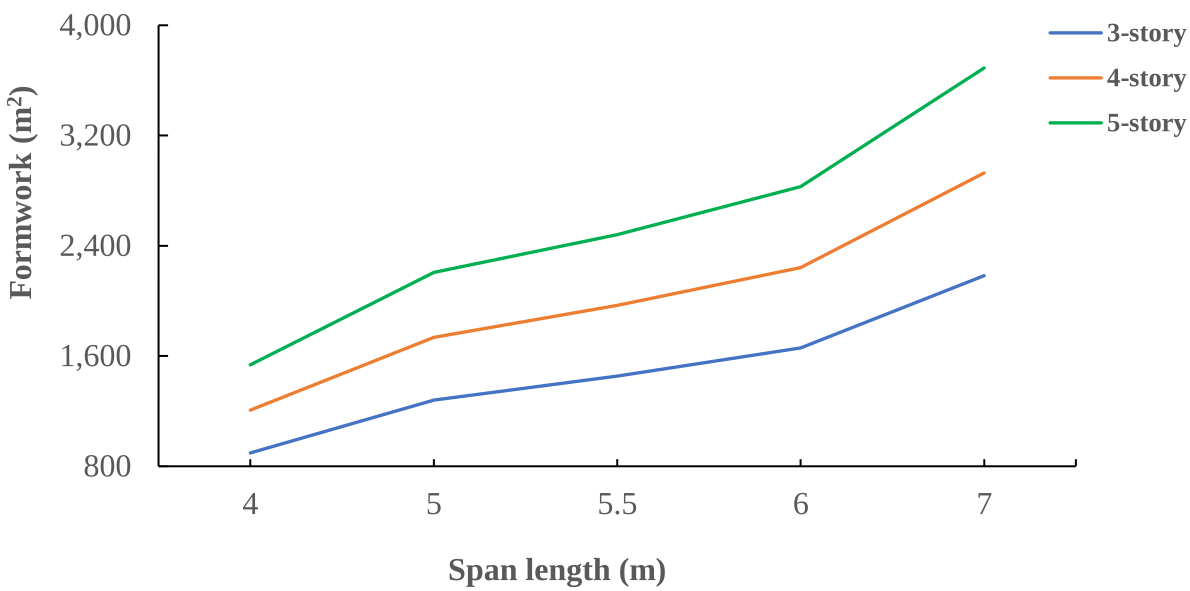


**Figure A.1.4:** Formwork quantity versus various span length in the RCS with H= 3.6 m

### A.1.1.3 Formwork quantity in various story heights (3.3 m and 3.6 m) of RC structures

**Table A.1.3:** The increased formwork quantity in RCS by rising story height from 3.3 m to 3.6 m

| L (m) | Increased quantity of formwork ($m^2$) | | |
|---|---|---|---|
| | **3-story** | **4-story** | **5-story** |
| **4** | 43.61 | 57.66 | 49.84 |
| **5** | 28.04 | 42.96 | 56.88 |
| **5.5** | 23.04 | 60.52 | 47.77 |
| **6** | 25.44 | 38.72 | 43.20 |
| **7** | 45.44 | 40.80 | 57.15 |

**Table A.1.4:** Percentage of increased formwork in RCS by rising story height from 3.3 m to 3.6 m

| L (m) | %Increased concrete formwork | | |
|---|---|---|---|
| | **3-story** | **4-story** | **5-story** |
| **4** | 5.11 | 4.89 | 3.35 |
| **5** | 2.24 | 2.57 | 2.70 |
| **5.5** | 1.61 | 3.17 | 2.00 |
| **6** | 1.56 | 1.77 | 1.53 |
| **7** | 2.13 | 1.41 | 1.57 |

**Table A.1.5:** Formwork quantity per square meter of RCS by rising story height from 3.3 m to 3.6 m

| L (m) | H (m) | Formwork quantity ($m^2$) per square meter | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 1.85 | 1.92 | 1.93 |
| | **3.6** | 1.94 | 2.01 | 2.00 |
| **5** | **3.3** | 1.76 | 1.76 | 1.78 |
| | **3.6** | 1.80 | 1.81 | 1.83 |
| **5.5** | **3.3** | 1.67 | 1.67 | 1.68 |
| | **3.6** | 1.70 | 1.72 | 1.71 |
| **6** | **3.3** | 1.59 | 1.60 | 1.65 |
| | **3.6** | 1.62 | 1.63 | 1.68 |
| **7** | **3.3** | 1.54 | 1.56 | 1.57 |
| | **3.6** | 1.57 | 1.58 | 1.60 |

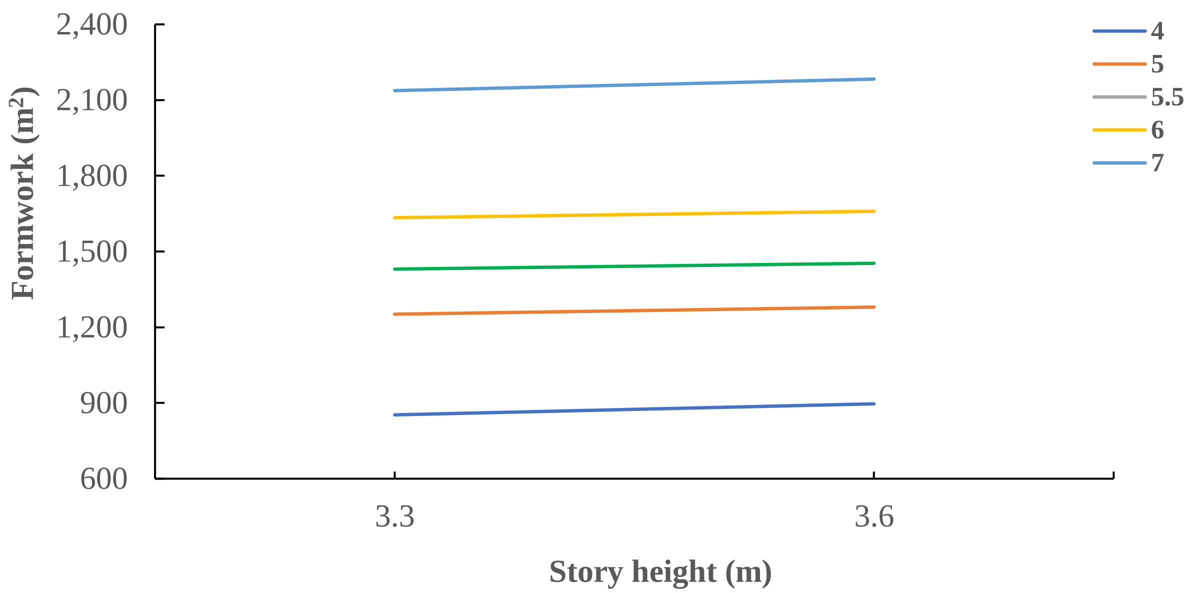


**Figure A.1.5:** Formwork quantity versus story heights in the 3-story RCS

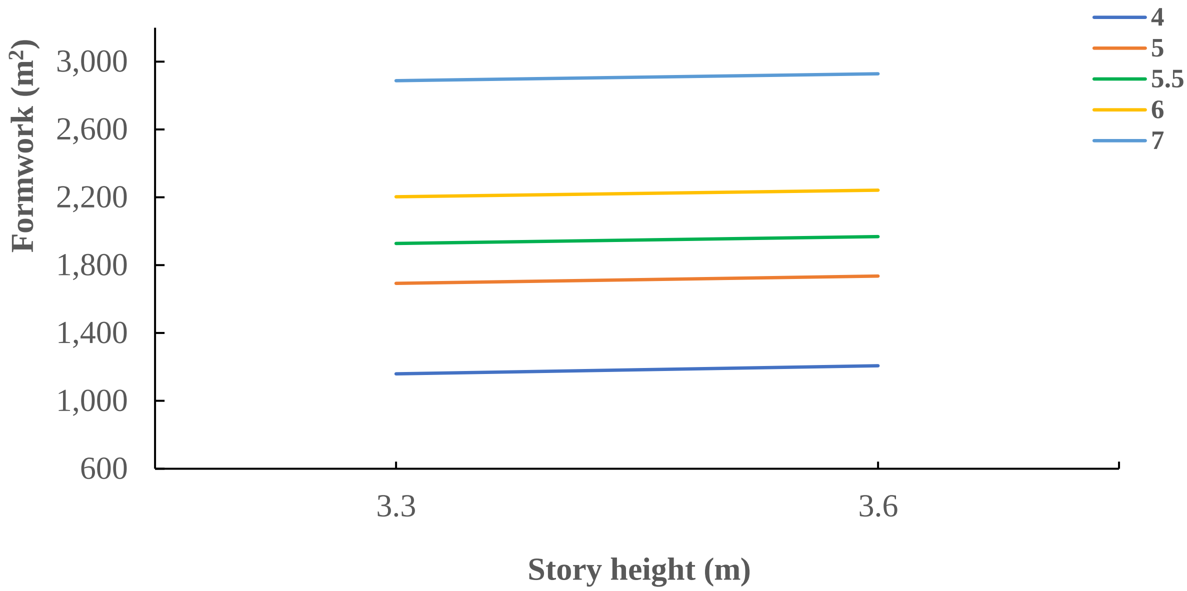


**Figure A.1.6:** Formwork quantity versus story height in the 4-story RCS

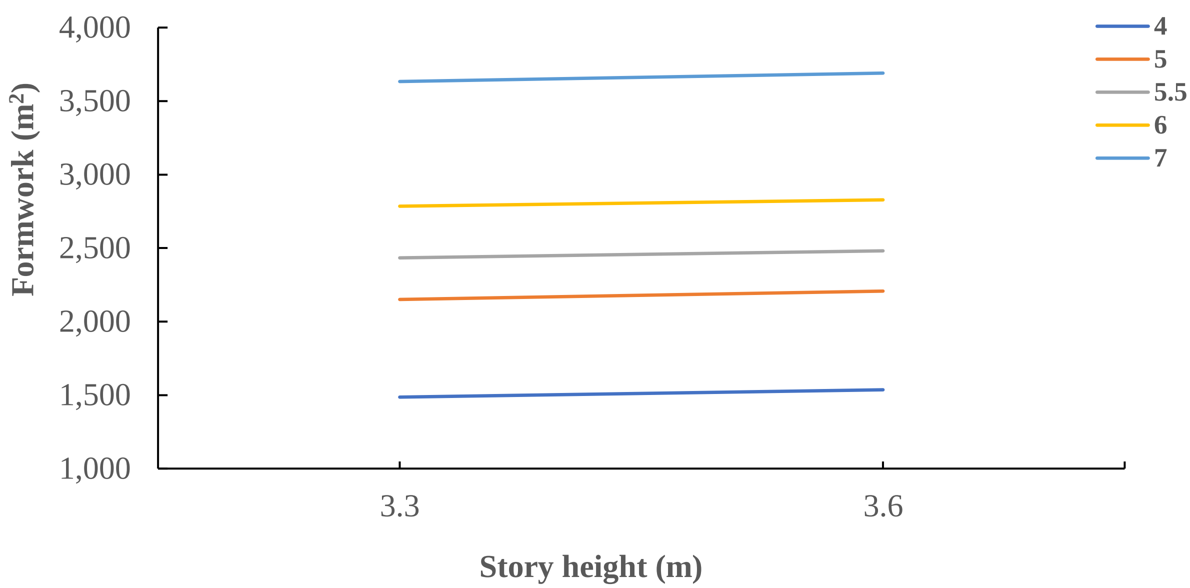


**Figure A.1.7:** Formwork quantity versus story height in the 5-story RCS

### A.1.2 Concrete Quantity in RC Multi-Story Structures

**Table A.1.6:** Concrete quantity of the whole RC structures

| L (m) | H (m) | Total concrete ($m^3$) | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 135.7 | 227.3 | 297.1 |
| **5** | **3.3** | 205.6 | 336.0 | 437.0 |
| **5.5** | **3.3** | 238.8 | 395.5 | 506.0 |
| **6** | **3.3** | 319.9 | 533.9 | 689.3 |
| **7** | **3.3** | 468.8 | 821.5 | 1069.6 |
| **4** | **3.6** | 141.3 | 235.8 | 304.5 |
| **5** | **3.6** | 210.6 | 343.3 | 445.2 |
| **5.5** | **3.6** | 243.1 | 402.4 | 513.6 |
| **6** | **3.6** | 324.0 | 539.6 | 695.7 |
| **7** | **3.6** | 472.3 | 826.6 | 1075.5 |

**Table A.1.7:** Concrete quantity per square meter of RC structures

| L (m) | H (m) | Concrete ($m^3$) per square meter | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 0.294 | 0.370 | 0.386 |
| **5** | **3.3** | 0.289 | 0.354 | 0.369 |
| **5.5** | **3.3** | 0.279 | 0.346 | 0.354 |
| **6** | **3.3** | 0.312 | 0.390 | 0.403 |
| **7** | **3.3** | 0.338 | 0.444 | 0.463 |
| **4** | **3.6** | 0.306 | 0.383 | 0.396 |
| **5** | **3.6** | 0.296 | 0.362 | 0.375 |
| **5.5** | **3.6** | 0.284 | 0.352 | 0.360 |
| **6** | **3.6** | 0.316 | 0.394 | 0.407 |
| **7** | **3.6** | 0.341 | 0.447 | 0.465 |

### A.1.2.1 Concrete quantity in low- and med-rise RC structures

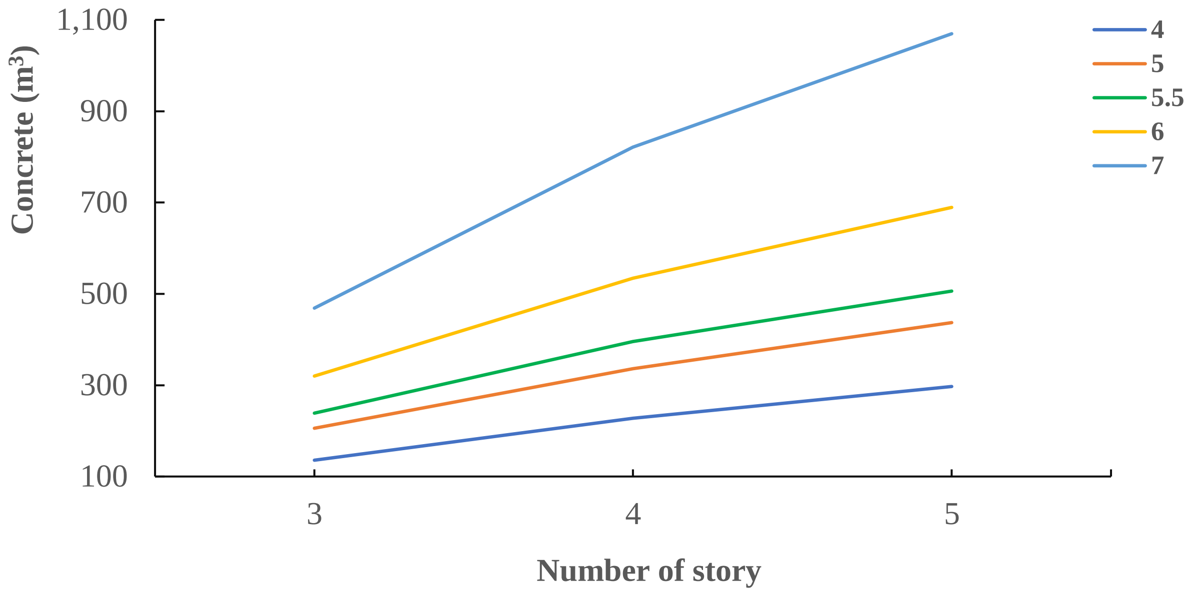


**Figure A.1.8:** Concrete quantity versus number of stories in the RCS with H=3.3 m

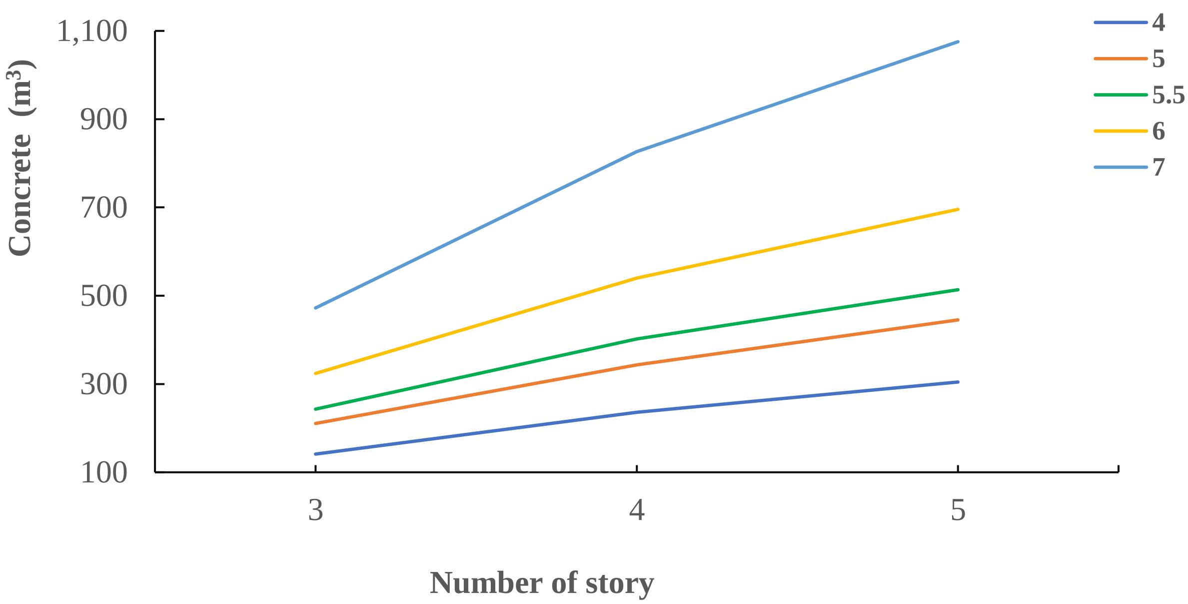


**Figure A.1.9:** Concrete quantity versus number of stories in the RCS with H=3.6 m

### A.1.2.2 Concrete quantity in various span lengths of RC structures

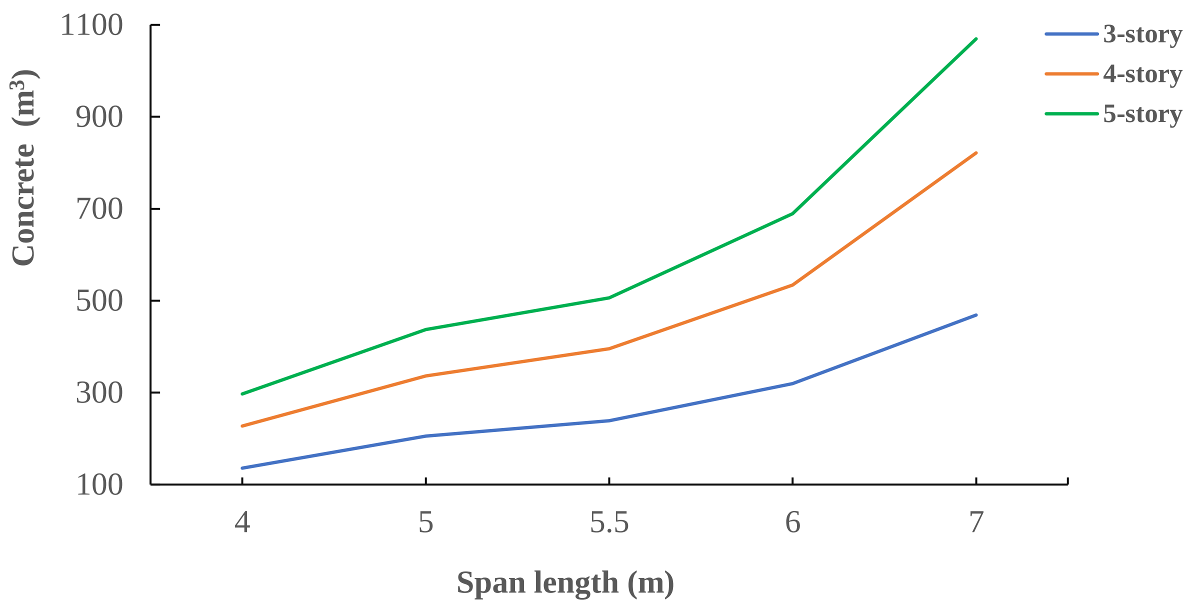


**Figure A.1.10:** Concrete quantity versus span lengths in the RCS with H=3.3 m

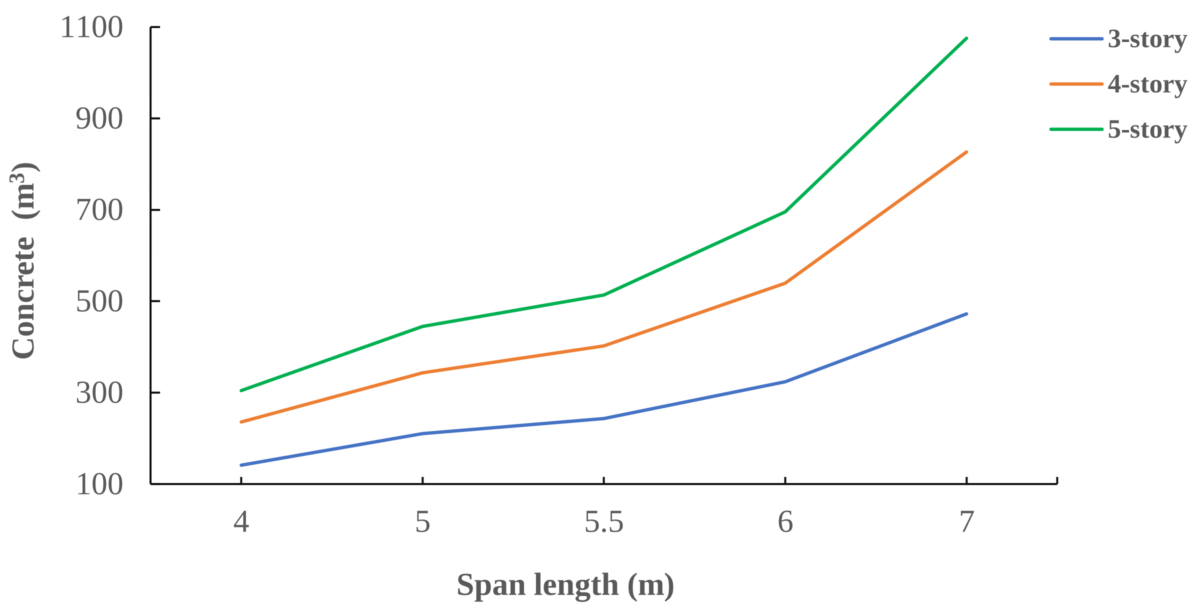


**Figure A.1.11:** Concrete quantity versus span lengths in the RCS with H=3.6 m

### A.1.2.3 Concrete quantity in different story height (3.3 m and 3.6 m) of RC structures

**Table A.1.8:** Increased concrete quantity by rising story height from 3.3 m to 3.6 m in RCS

| L (m) | Increased quantity of concrete ($m^3$) | | |
|---|---|---|---|
| | 3-story | 4-story | 5-story |
| **4** | 5.6 | 8.5 | 7.4 |
| **5** | 4.9 | 7.3 | 8.2 |
| **5.5** | 4.3 | 6.9 | 7.6 |
| **6** | 4 | 5.7 | 6.4 |
| **7** | 3.6 | 5.1 | 5.9 |

**Table A.1.9:** Percentage of increased concrete quantity by rising story height from 3.3 m to 3.6 m in RCS

| L (m) | % Concrete increase | | |
|---|---|---|---|
| | 3-story | 4-story | 5-story |
| **4** | 4.1 | 3.7 | 2.5 |
| **5** | 2.4 | 2.2 | 1.9 |
| **5.5** | 1.8 | 1.7 | 1.5 |
| **6** | 1.3 | 1.1 | 0.9 |
| **7** | 0.8 | 0.6 | 0.6 |

**Table A.1.10:** Amount of increased concrete quantity by rising story height from 3.3 m to 3.6 m per square meter of RCS

| L (m) | H (m) | Increased concrete ($m^3$) per square meter | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 0.294 | 0.370 | 0.386 |
| | **3.6** | 0.306 | 0.383 | 0.396 |
| **5** | **3.3** | 0.289 | 0.354 | 0.369 |
| | **3.6** | 0.296 | 0.362 | 0.375 |
| **5.5** | **3.3** | 0.279 | 0.346 | 0.354 |
| | **3.6** | 0.284 | 0.352 | 0.360 |
| **6** | **3.3** | 0.312 | 0.390 | 0.403 |
| | **3.6** | 0.316 | 0.394 | 0.407 |
| **7** | **3.3** | 0.338 | 0.444 | 0.463 |
| | **3.6** | 0.341 | 0.447 | 0.465 |

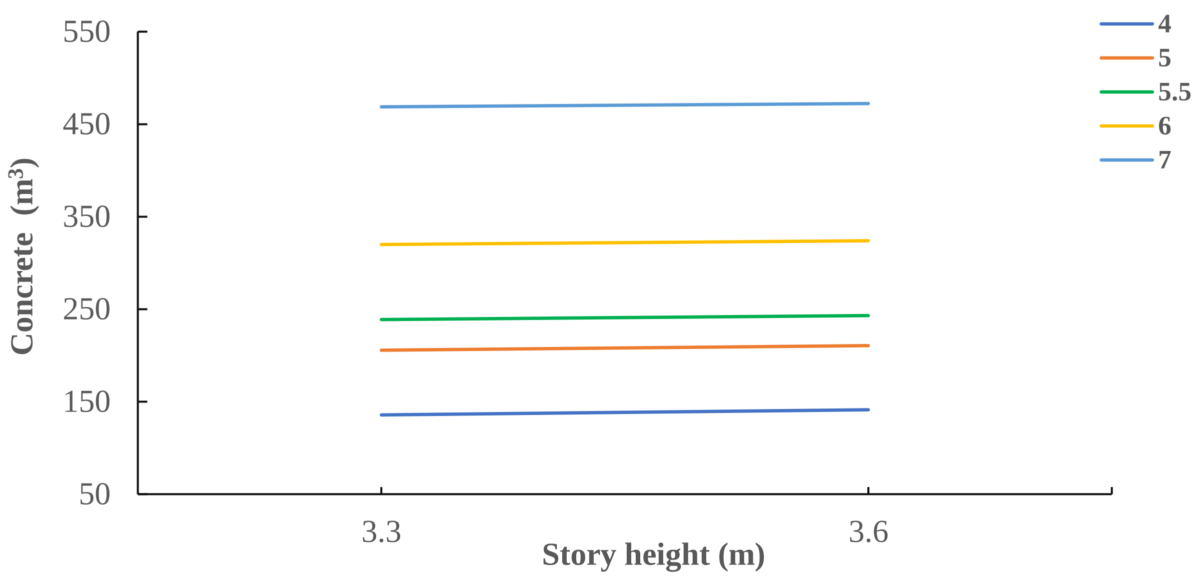


**Figure A.1.12:** Concrete quantity versus story heights in the 3-story RCS

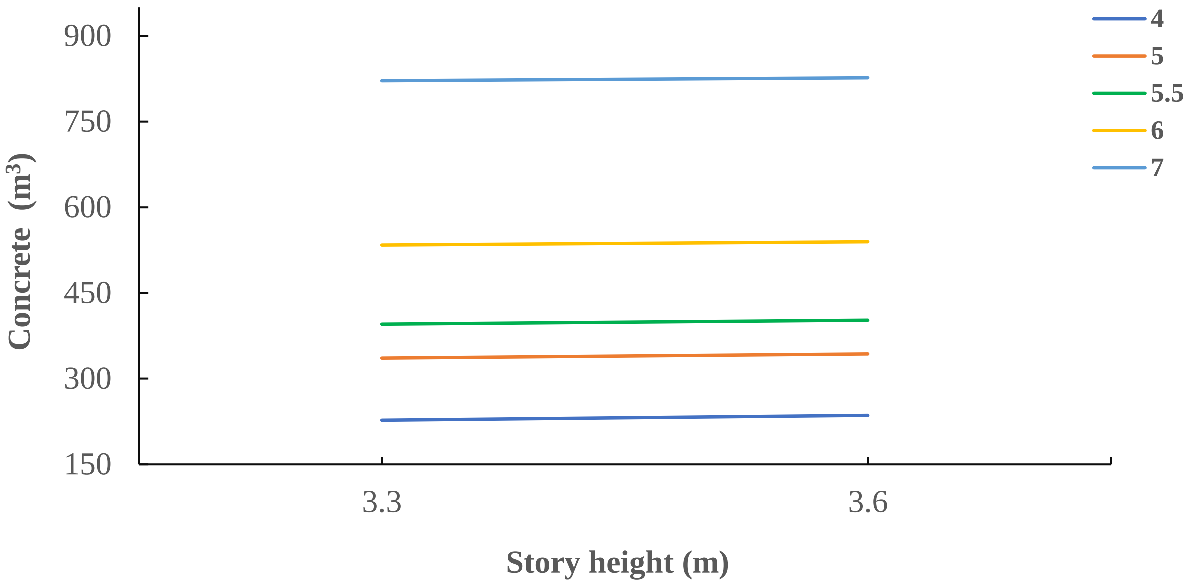


**Figure A.1.13:** Concrete quantity versus story heights in the 4-story RCS

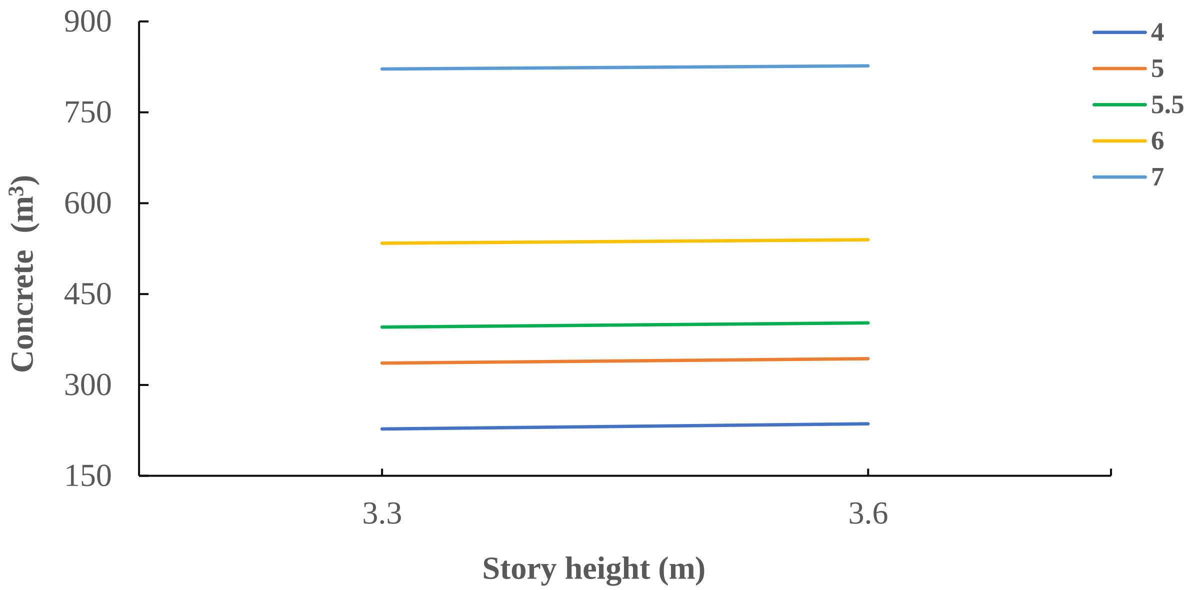


**Figure A.1.14:** Concrete quantity versus story heights in the 5-story RCS

### A.1.3 Steel Bar Quantities in RC Multi-Story Structures

**Table A.1.11:** Steel bar quantity of the whole RC structures

| L (m) | H (m) | Total steel bar (kg) | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 16,027 | 25,276 | 33,085 |
| **5** | **3.3** | 22,348 | 34,758 | 44,749 |
| **5.5** | **3.3** | 26,546 | 39,931 | 51,773 |
| **6** | **3.3** | 32,113 | 48,185 | 63,793 |
| **7** | **3.3** | 46,579 | 70,794 | 92,222 |
| **4** | **3.6** | 16,745 | 27,410 | 36,415 |
| **5** | **3.6** | 24,142 | 37,827 | 50,246 |
| **5.5** | **3.6** | 27,461 | 41,088 | 56,145 |
| **6** | **3.6** | 33,743 | 50,969 | 69,096 |
| **7** | **3.6** | 48,952 | 74,933 | 99,836 |

**Table A.1.12:** Steel bar quantity per square meter of RC structures

| L (m) | H (m) | Steel bar (kg) per square meter of RCS | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 34.74 | 41.10 | 43.03 |
| **5** | **3.3** | 31.41 | 36.64 | 37.74 |
| **5.5** | **3.3** | 30.98 | 34.95 | 36.25 |
| **6** | **3.3** | 31.28 | 35.20 | 37.28 |
| **7** | **3.3** | 33.59 | 38.29 | 39.90 |
| **4** | **3.6** | 36.30 | 44.57 | 47.37 |
| **5** | **3.6** | 33.93 | 39.87 | 42.37 |
| **5.5** | **3.6** | 32.05 | 35.97 | 39.32 |
| **6** | **3.6** | 32.86 | 37.23 | 40.38 |
| **7** | **3.6** | 35.30 | 40.53 | 43.20 |

### A.1.3.1 Steel bar quantity in low- and medium-rise RC structures

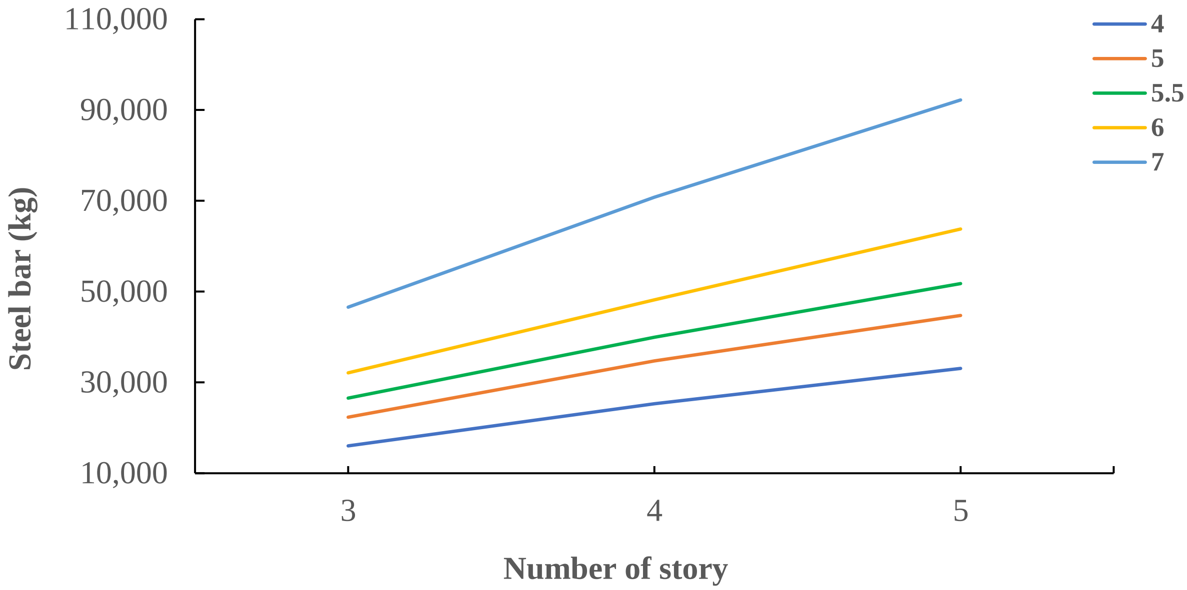


**Figure A.1.15:** Steel bar quantity versus number of stories in the RCS with H=3.3 m

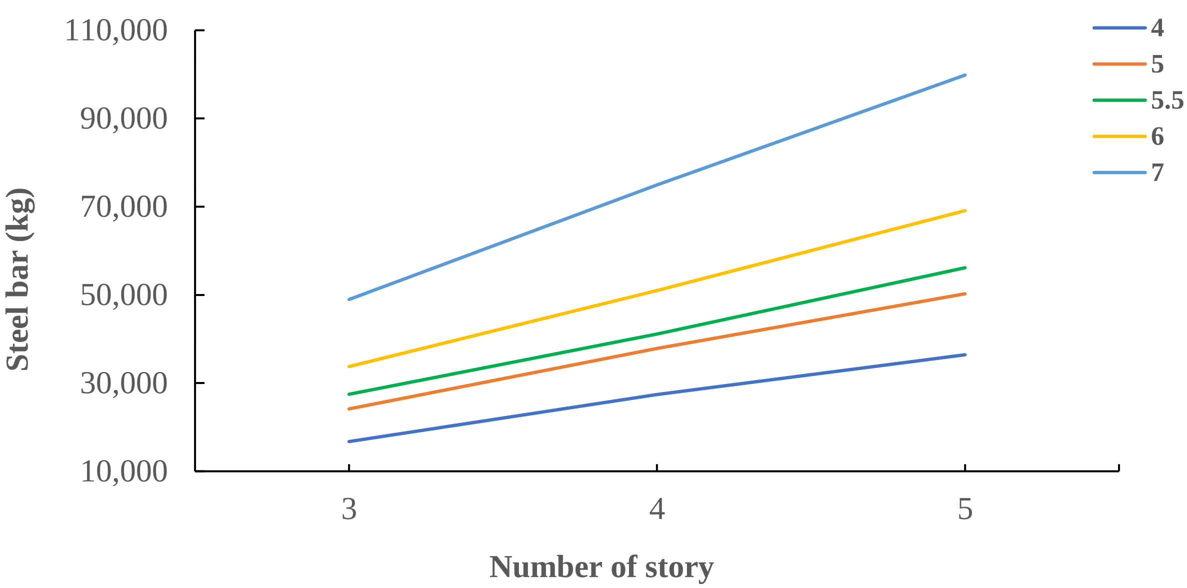


**Figure A.1.16** Steel bar quantity versus number of stories in the RCS with H=3.6 m

### A.1.3.2 Steel bar quantity in various span lengths of RC structures

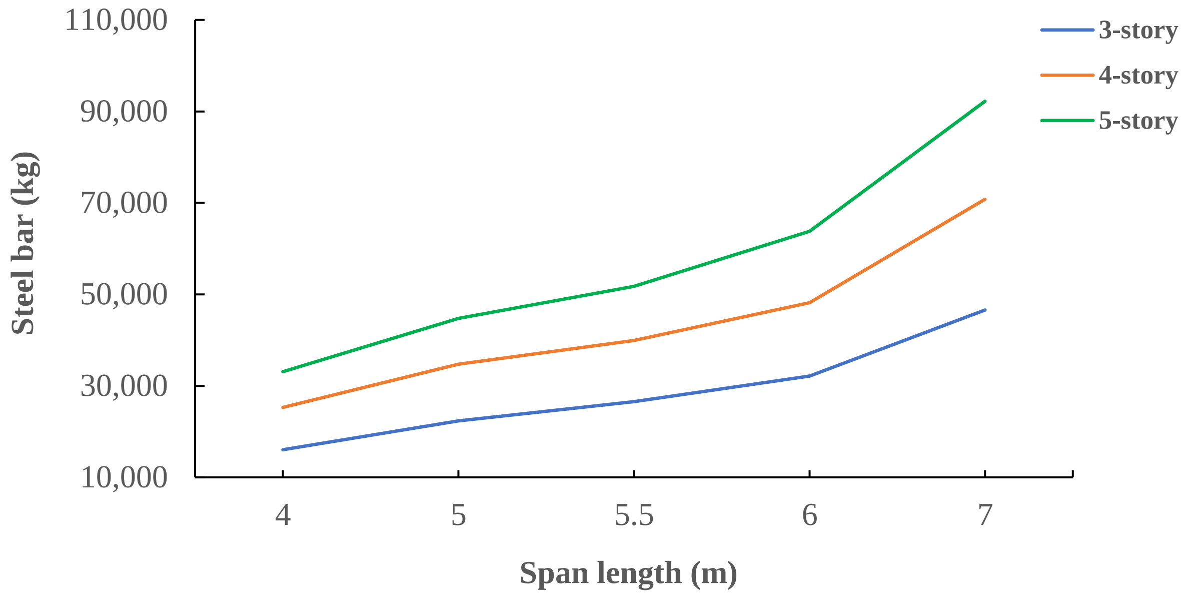


**Figure A.1.17:** Steel bar quantity versus span length in the RCS with H=3.3 m

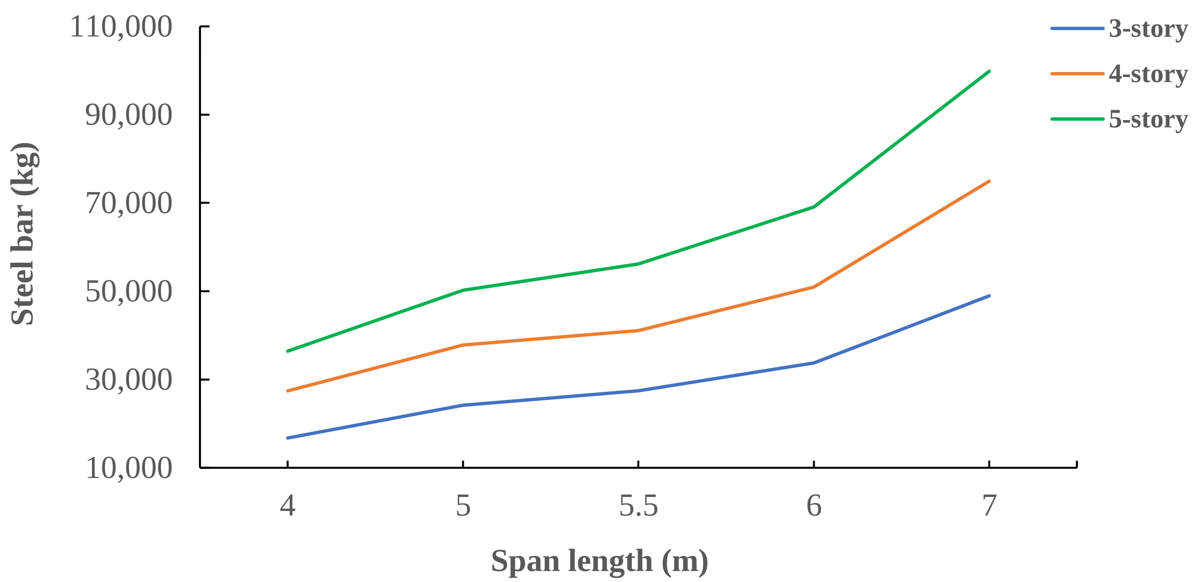


**Figure A.1.18:** Steel bar quantity versus span length in the RCS with H=3.6 m

### A.1.3.3 Steel bar quantity in various story heights (3.3 m and 3.6 m) of RC structures

**Table A.1.13:** Increased steel bars quantity by rising story height from 3.3 m to 3.6 m in RCS

| L (m) | Increased steel bars (kg) | | |
|---|---|---|---|
| | 3-story | 4-story | 5-story |
| **4** | 718 | 2,134 | 3,329 |
| **5** | 1,794 | 3,068 | 5,497 |
| **5.5** | 915 | 1,156 | 4,371 |
| **6** | 1,629 | 2,783 | 5,303 |
| **7** | 2,373 | 4,138 | 7,913 |

**Table A.1.14:** Percentage of increased steel bars by rising the story height from 3.3 m to 3.6 m in RCS

| L (m) | % Steel bar increase | | |
|---|---|---|---|
| | 3-story | 4-story | 5-story |
| **4** | 4.48 | 8.44 | 10.06 |
| **5** | 8.03 | 8.83 | 12.28 |
| **5.5** | 3.45 | 2.90 | 8.44 |
| **6** | 5.08 | 5.78 | 8.31 |
| **7** | 5.09 | 5.85 | 8.26 |

**Table A.1.15:** Steel bars quantity in different story heights (3.3 m and 3.6 m) per square meter of RCS

| L (m) | H (m) | Steel bar (kg) square meter | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 34.74 | 41.10 | 43.03 |
| | **3.6** | 36.30 | 44.57 | 47.37 |
| **5** | **3.3** | 31.41 | 36.64 | 37.74 |
| | **3.6** | 33.93 | 39.87 | 42.37 |
| **5.5** | **3.3** | 30.98 | 34.95 | 36.25 |
| | **3.6** | 32.05 | 35.97 | 39.32 |
| **6** | **3.3** | 31.28 | 35.20 | 37.28 |
| | **3.6** | 32.86 | 37.23 | 40.38 |
| **7** | **3.3** | 33.59 | 38.29 | 39.90 |
| | **3.6** | 35.30 | 40.53 | 43.20 |

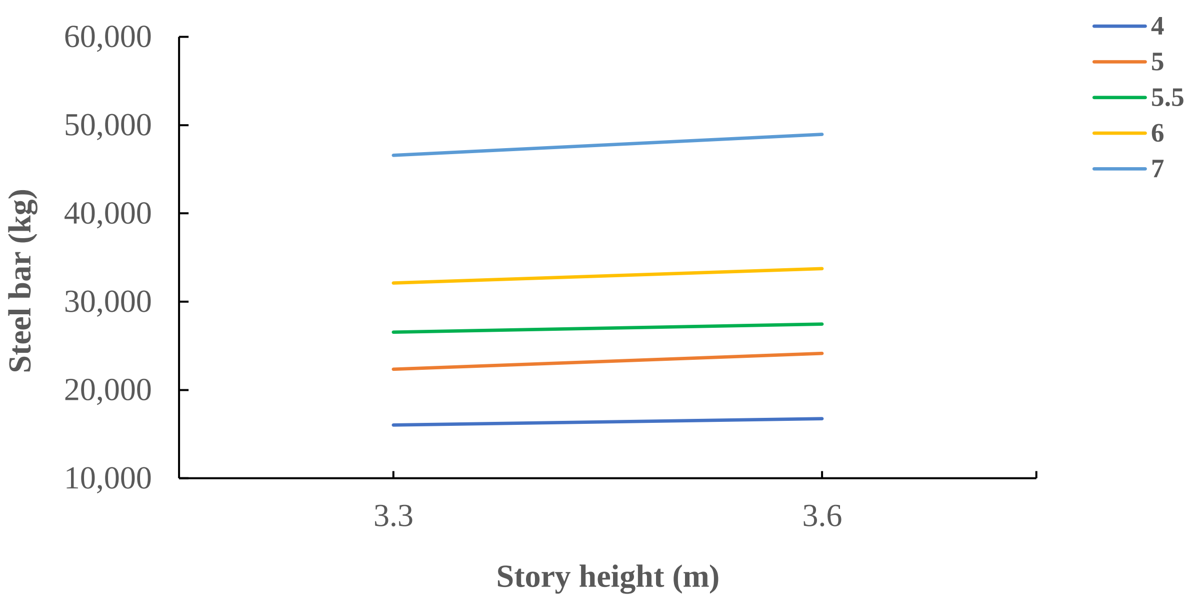


**Figure A.1.19:** Steel bar quantity versus story heights in the 3-story RCS

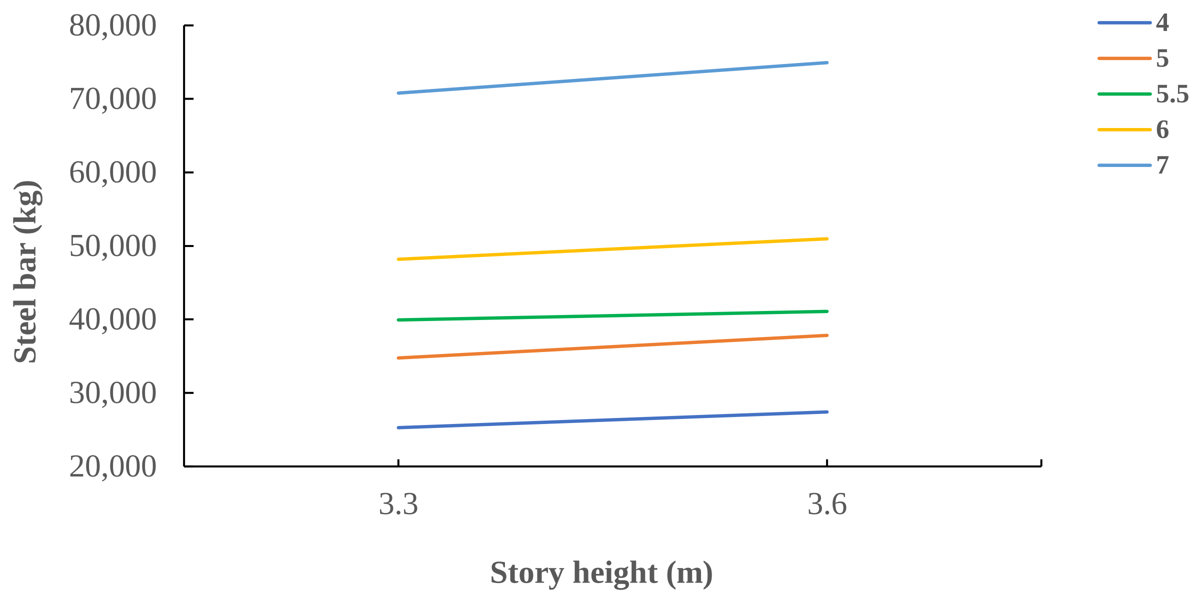


**Figure A.1.20:** Steel bar quantity versus story heights in the 4-story RCS

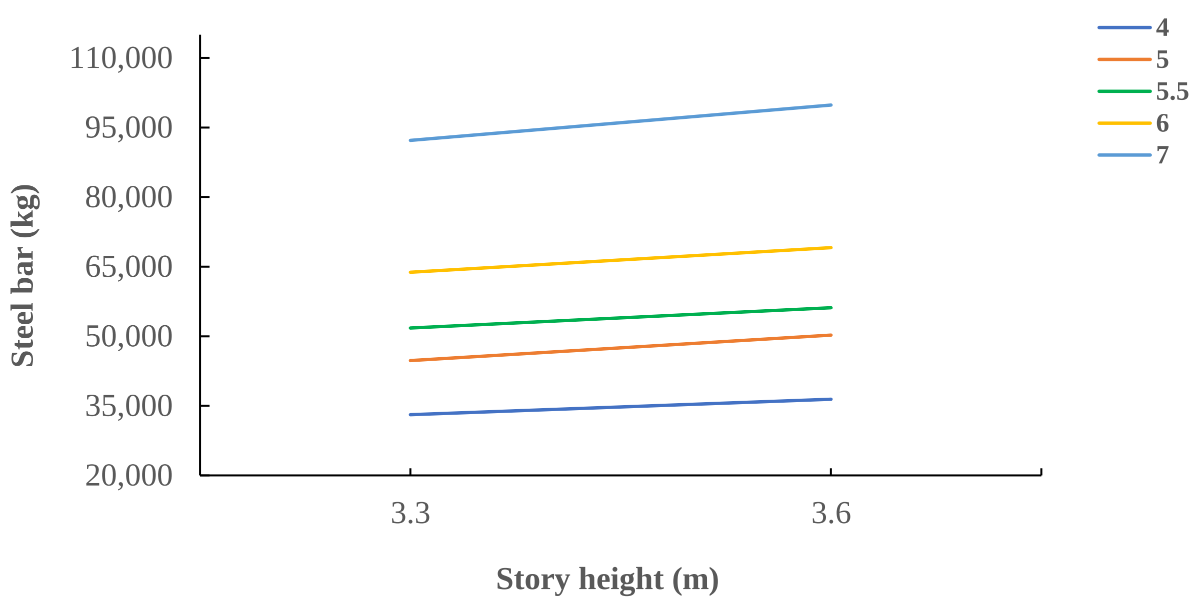


**Figure A.1.21:** Steel bar quantity versus story heights in the 5-story RCS

### A.1.4 Steel Quantity in Multi-Story Steel Structures

**Table A.1.16:** Quantity of steel for the whole steel structure

| L (m) | H (m) | Total steel quantity (kg) | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 43,071 | 58,369 | 77,807 |
| **5** | **3.3** | 67,070 | 90,757 | 123,025 |
| **5.5** | **3.3** | 82,843 | 113,706 | 153,078 |
| **6** | **3.3** | 105,620 | 143,688 | 193,540 |
| **7** | **3.3** | 157,714 | 213,096 | 279,750 |
| **4** | **3.6** | 43,794 | 60,094 | 80,738 |
| **5** | **3.6** | 69,104 | 95,371 | 126,974 |
| **5.5** | **3.6** | 86,056 | 118,314 | 157,612 |
| **6** | **3.6** | 111,141 | 153,006 | 198,432 |
| **7** | **3.6** | 164,454 | 222,084 | 283,409 |

**Table A.1.17:** Quantity of steel per square meter of SS

| L (m) | H (m) | Steel (kg) per square meter of SS | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 93.4 | 94.9 | 101.2 |
| **5** | **3.3** | 94.3 | 95.6 | 103.7 |
| **5.5** | **3.3** | 96.7 | 99.5 | 107.2 |
| **6** | **3.3** | 102.8 | 104.9 | 113.1 |
| **7** | **3.3** | 113.7 | 115.2 | 121.1 |
| **4** | **3.6** | 94.9 | 97.7 | 105.2 |
| **5** | **3.6** | 97.1 | 100.5 | 107.1 |
| **5.5** | **3.6** | 100.4 | 103.5 | 110.4 |
| **6** | **3.6** | 108.2 | 111.7 | 115.9 |
| **7** | **3.6** | 118.6 | 120.1 | 122.6 |

### A.1.4.1 Steel quantity in low- and med-rise steel structures

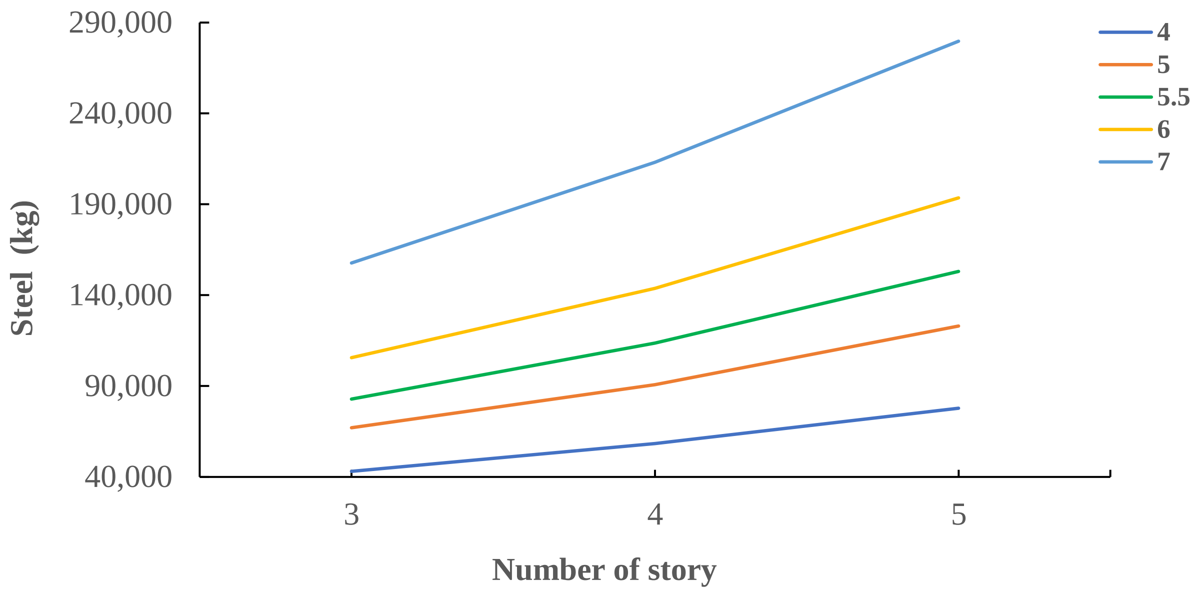


**Figure A.1.22:** Steel quantity versus number of stories in the SS with H=3.3 m

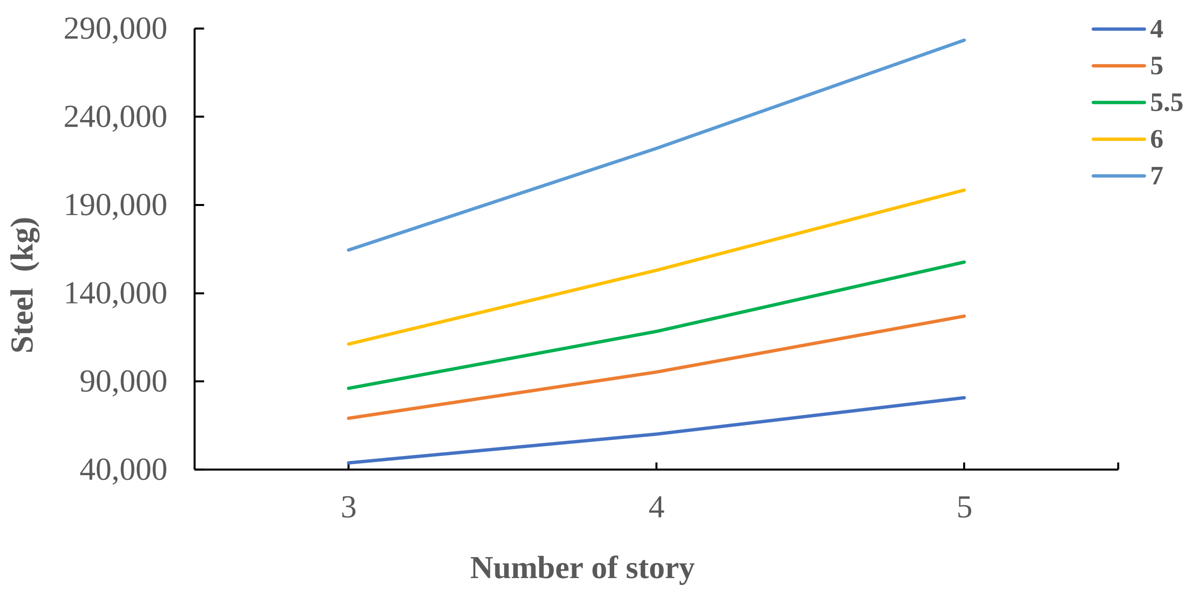


**Figure A.1.23:** Steel quantity versus number of stories in the SS with H=3.6 m

### A.1.4.2 Steel quantity in various span lengths of steel structure

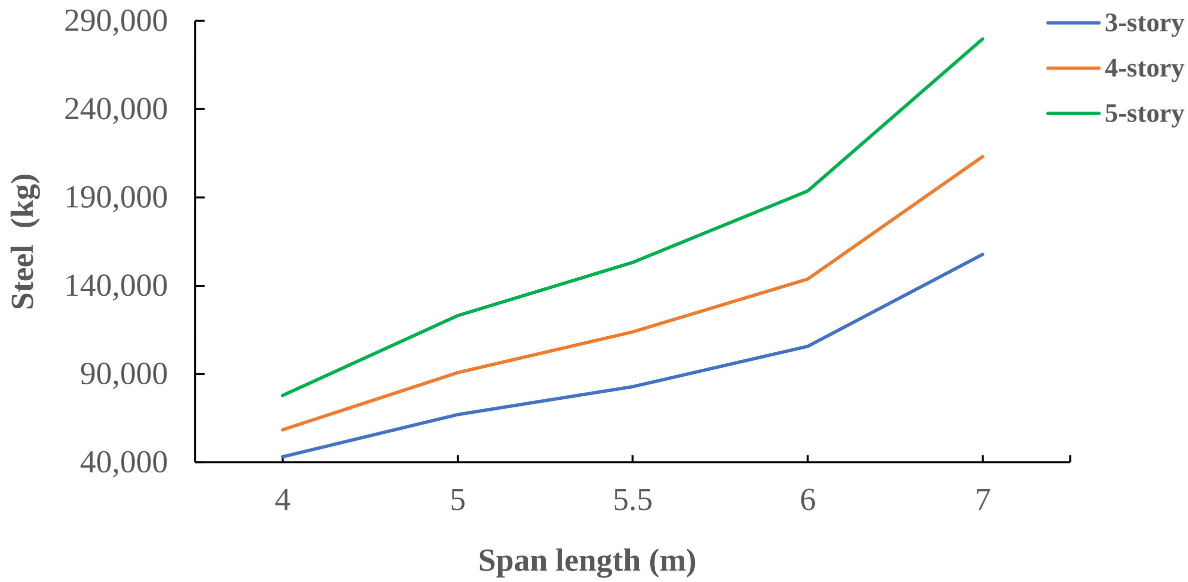


**Figure A.1.24:** Steel quantity versus span lengths in the SS with H=3.3 m

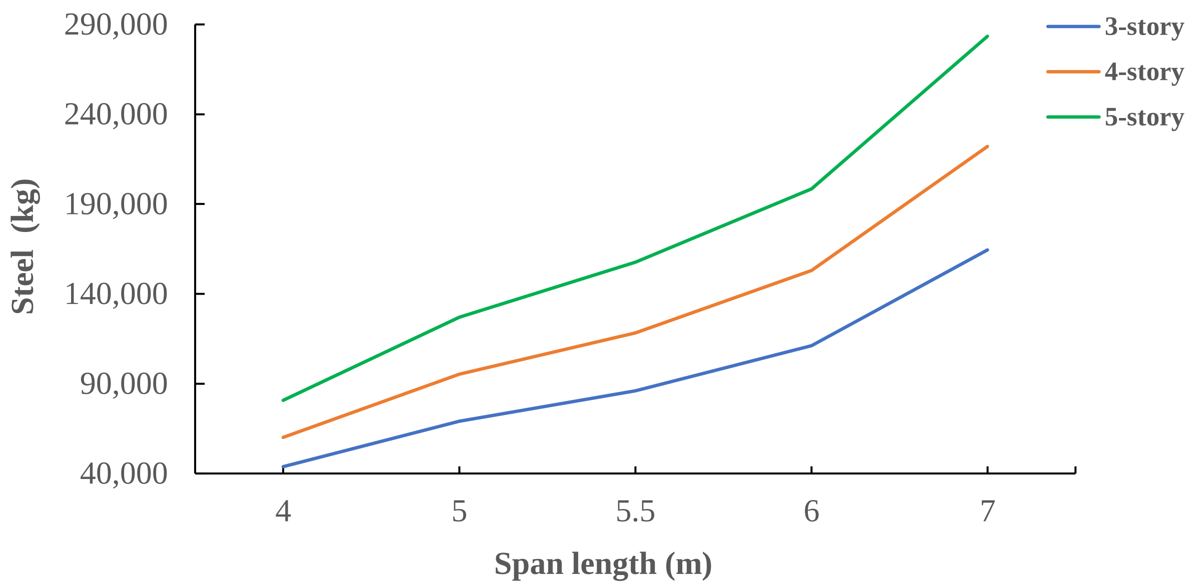


**Figure A.2.25:** Steel quantity versus span lengths in the SS with H=3.6 m

### A.1.4.3 Steel quantity in various story height (3.3 m and 3.6 m) of steel structure

**Table A.1.18:** Amount of increased steel quantity by rising story height from 3.3 m to 3.6 m in SS

| L (m) | Increased steel quantity (kg) | | |
|---|---|---|---|
| | 3-story | 4-story | 5-story |
| **4** | 723 | 1,725 | 2,931 |
| **5** | 2,034 | 4,614 | 3,949 |
| **5.5** | 3,213 | 4,608 | 4,534 |
| **6** | 5,521 | 9,318 | 4,892 |
| **7** | 6,740 | 8,988 | 3,659 |

**Table A.1.19:** Percentage of increased steel quantity by rising story height from 3.3 m to 3.6 m in SS

| L (m) | % Increased steel quantity | | |
|---|---|---|---|
| | 3-story | 4-story | 5-story |
| **4** | 1.68 | 2.96 | 3.77 |
| **5** | 3.03 | 5.08 | 3.21 |
| **5.5** | 3.88 | 4.05 | 2.96 |
| **6** | 5.23 | 6.48 | 2.53 |
| **7** | 4.27 | 4.22 | 1.31 |

**Table A.1.20:** Steel quantity in different story height (3.3 m and 3.6 m) per square meter of SS

| L (m) | H (m) | Steel quantity (kg) per square meter | | |
|---|---|---|---|---|
| | | 3-story | 4-story | 5-story |
| **4** | **3.3** | 93.4 | 94.9 | 101.2 |
| | **3.6** | 94.9 | 97.7 | 105.1 |
| **5** | **3.3** | 94.3 | 95.6 | 103.7 |
| | **3.6** | 97.1 | 100.5 | 107.1 |
| **5.5** | **3.3** | 96.7 | 99.5 | 107.2 |
| | **3.6** | 100.4 | 103.5 | 110.4 |
| **6** | **3.3** | 102.8 | 104.9 | 113.1 |
| | **3.6** | 108.2 | 111.7 | 115.9 |
| **7** | **3.3** | 113.7 | 115.2 | 121.1 |
| | **3.6** | 118.6 | 120.1 | 122.6 |

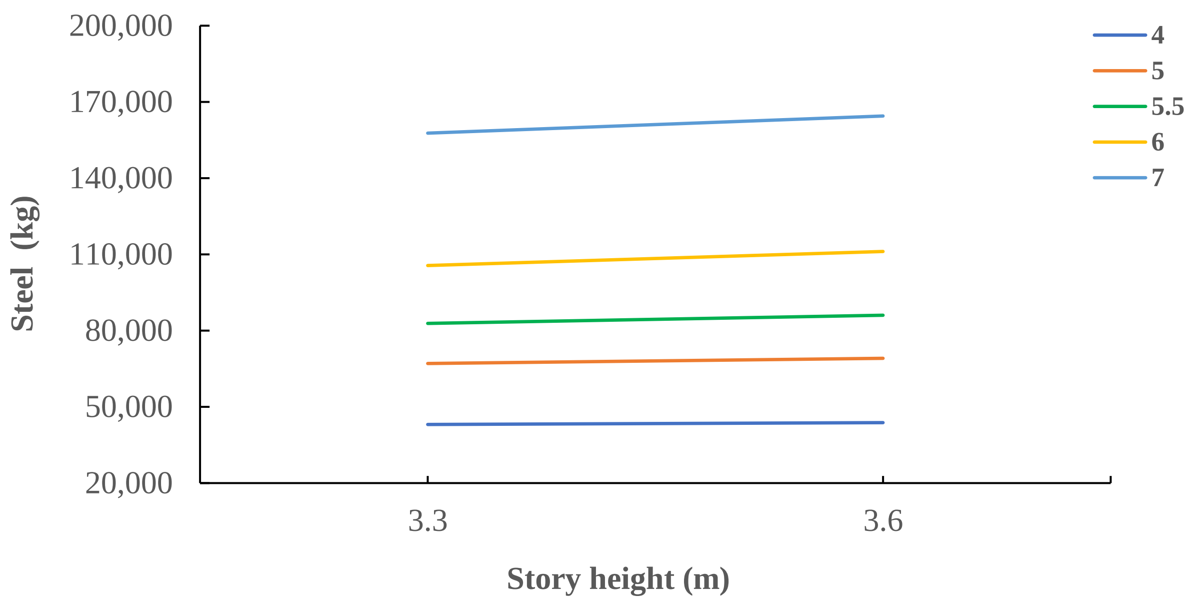


**Figure A.1.26:** Steel quantity versus story height in the 3-story SS

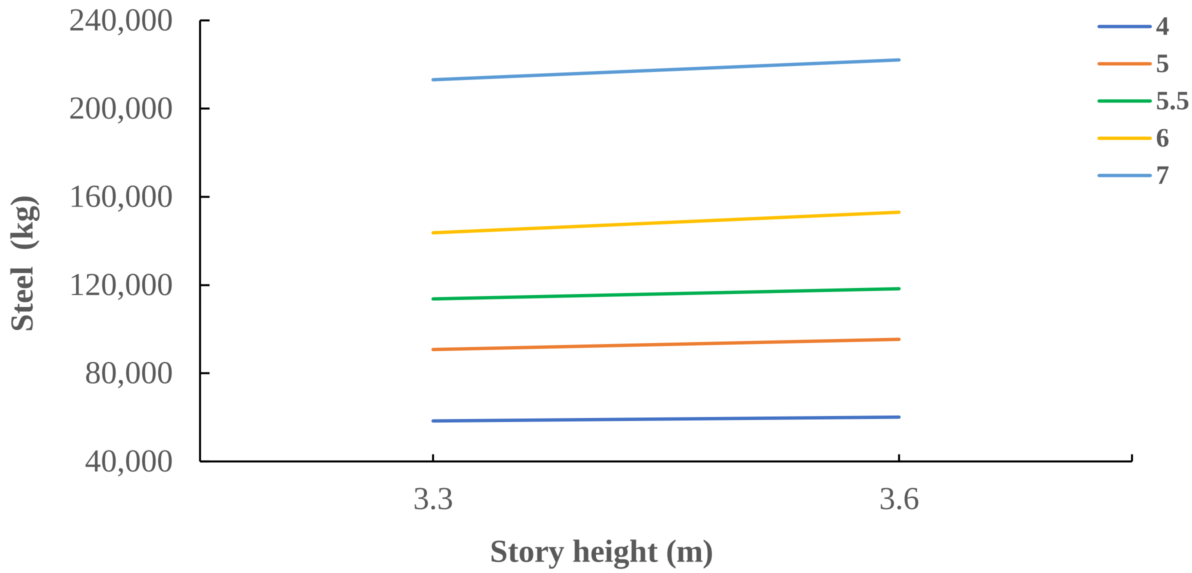


**Figure A.1.27:** Steel quantity versus story height in the 4-story SS

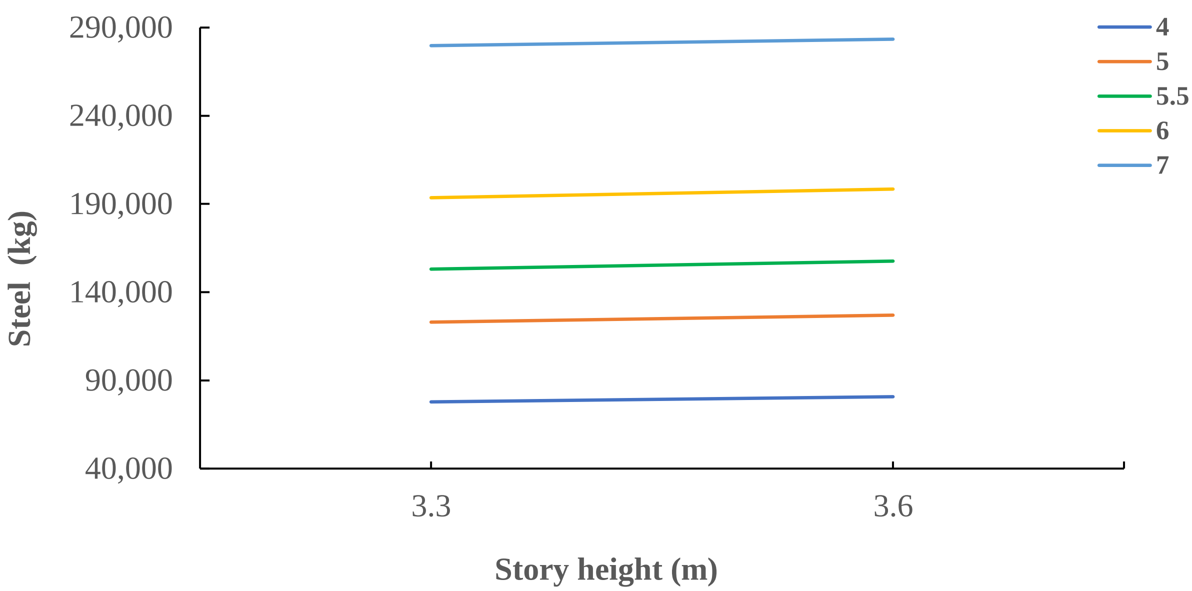


**Figure A.1.28:** Steel quantity versus story height in the 5-story SS

# APPENDIX 2

# TOTAL COST OF STRUCTURAL CONSTRUCTION

**Table A.2.1:** Price of structural building construction material in Erbil- Iraq

| Company Name | Formwork ($) / $m^2$ | Steel bar ($) / ton | Concrete ($) / $m^3$ | Steel sections ($) / ton |
|---|---|---|---|---|
| Gulan | 8 | 570 | 42 | 640 |
| Soran | 7.8 | 570 | 41 | 634 |
| Bahat | 8.1 | 575 | 41 | 645 |
| Hemn | 8 | 560 | 43 | 645 |
| Average price | 8 | 568.75 | 41.75 | 641 |

**Table A.2.2:** Total structural cost of RCS and SS

| **L (m)** | **H (m)** | **Cost of RCS ($)** | | | **Cost of SS ($)** | | |
|---|---|---|---|---|---|---|---|
| | | **3-story** | **4-story** | **5-story** | **3-story** | **4-story** | **5-story** |
| **4** | **3.3** | 23,261 | 35,758 | 46,535 | 37,410 | 50,985 | 66,961 |
| **5** | **3.3** | 33,622 | 50,943 | 65,539 | 58,340 | 79,401 | 106,129 |
| **5.5** | **3.3** | 39,257 | 58,789 | 75,407 | 71,631 | 99,278 | 131,237 |
| **6** | **3.3** | 48,023 | 72,334 | 93,969 | 90,268 | 125,399 | 165,649 |
| **7** | **3.3** | 67,998 | 105,036 | 135,776 | 133,906 | 183,606 | 240,831 |
| **4** | **3.6** | 24,327 | 37,926 | 49,475 | 37,962 | 52,524 | 69,071 |
| **5** | **3.6** | 35,257 | 53,650 | 69,222 | 59,835 | 82,721 | 108,975 |
| **5.5** | **3.6** | 40,236 | 60,177 | 79,038 | 73,944 | 102,591 | 135,081 |
| **6** | **3.6** | 49,489 | 74,749 | 98,136 | 94,242 | 132,109 | 169,171 |
| **7** | **3.6** | 70,099 | 108,351 | 141,582 | 138,759 | 190,077 | 244,298 |

**Table A.2.3:** Total cost of structures per square meter of RCS and SS

| L (m) | H (m) | Cost of RCS ($) per m$^2$ | | | Cost of SS ($) per m$^2$ | | |
|---|---|---|---|---|---|---|---|
| | | 3-story | 4-story | 5-story | 3-story | 4-story | 5-story |
| **4** | **3.3** | 50.4 | 58.1 | 60.5 | 81.1 | 82.9 | 87.1 |
| **5** | **3.3** | 47.3 | 53.7 | 55.3 | 82.0 | 83.7 | 89.5 |
| **5.5** | **3.3** | 45.8 | 51.5 | 52.8 | 83.6 | 86.9 | 91.9 |
| **6** | **3.3** | 46.8 | 52.8 | 54.9 | 87.9 | 91.6 | 96.8 |
| **7** | **3.3** | 49.0 | 56.8 | 58.7 | 96.6 | 99.3 | 104.2 |
| **4** | **3.6** | 52.7 | 61.7 | 64.4 | 82.3 | 85.4 | 89.8 |
| **5** | **3.6** | 49.6 | 56.6 | 58.4 | 84.1 | 87.2 | 91.9 |
| **5.5** | **3.6** | 47.0 | 52.7 | 55.3 | 86.3 | 89.8 | 94.6 |
| **6** | **3.6** | 48.2 | 54.6 | 57.3 | 91.8 | 96.5 | 98.9 |
| **7** | **3.6** | 50.5 | 58.6 | 61.3 | 100.1 | 102.8 | 105.7 |

### A.2.1 Effects of Number of Stories on the Total Cost of RC and Steel Structures

**Table A.2.4:** Percentage of total cost increase per square meter of RCS and SS by adding the number of stories

| L (m) | H (m) | RC structure | | Steel structure | |
|---|---|---|---|---|---|
| | | %Cost increase from 3- to 4- story | %Cost increase from 4- to 5- story | %Cost increase from 3- to 4- story | %Cost increase from 4- to 5- story |
| **4** | **3.3** | 15.2 | 4.1 | 2.2 | 5.1 |
| **5** | **3.3** | 13.6 | 3.0 | 2.1 | 6.9 |
| **5.5** | **3.3** | 12.4 | 2.5 | 3.9 | 5.8 |
| **6** | **3.3** | 12.9 | 4.0 | 4.2 | 5.7 |
| **7** | **3.3** | 15.8 | 3.3 | 2.8 | 4.9 |
| **4** | **3.6** | 17.0 | 4.4 | 3.8 | 5.2 |
| **5** | **3.6** | 14.2 | 3.2 | 3.7 | 5.4 |
| **5.5** | **3.6** | 12.2 | 4.9 | 4.1 | 5.3 |
| **6** | **3.6** | 13.3 | 4.9 | 5.1 | 2.4 |
| **7** | **3.6** | 15.9 | 4.6 | 2.7 | 2.8 |

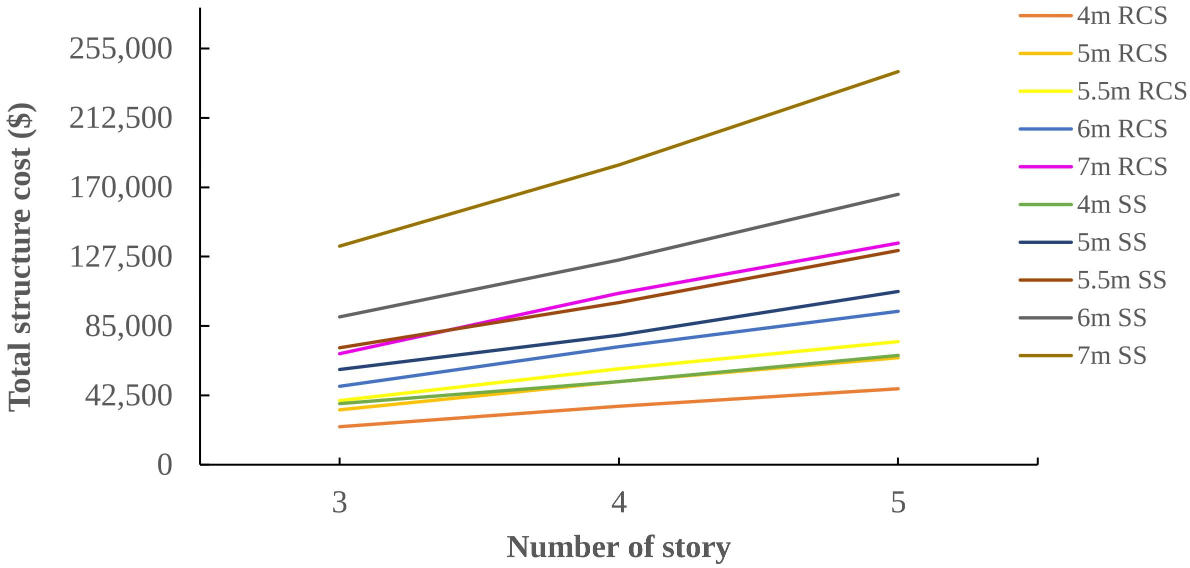


**Figure A.2.1:** Total cost versus numbers of stories in the RCS and SS with H= 3.3 m

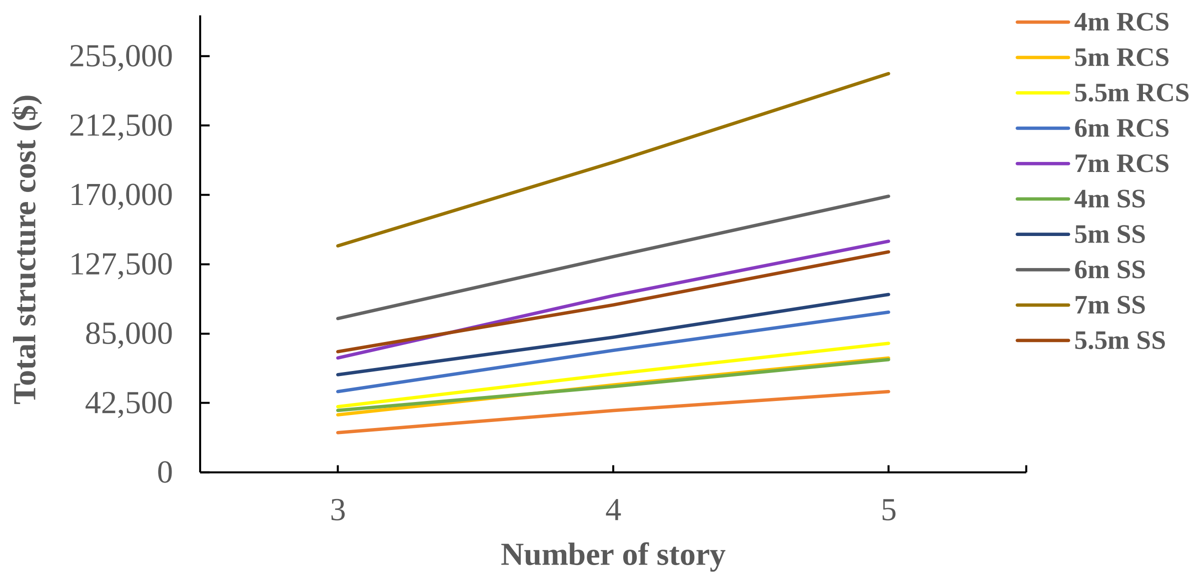


**Figure A.2.2:** Total cost versus number of stories in the RCS and SS with H= 3.6 m

### A.2.2 Effects of Extending Spans Length on the Total Cost of RC and Steel Structures

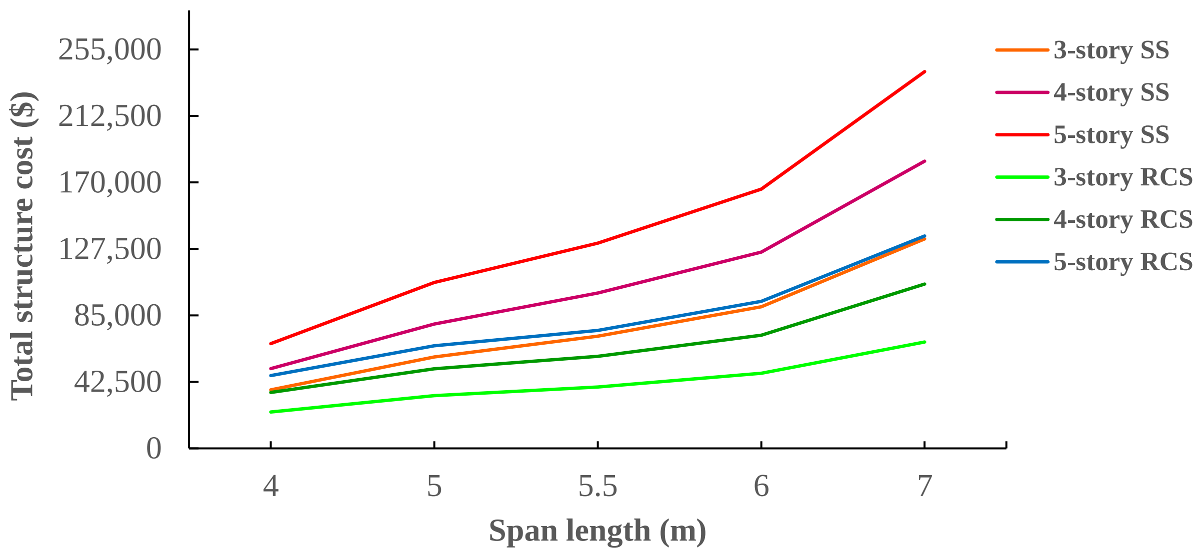


**Figure A.2.3:** Total cost versus span length in the RCS and SS with H=3.3 m

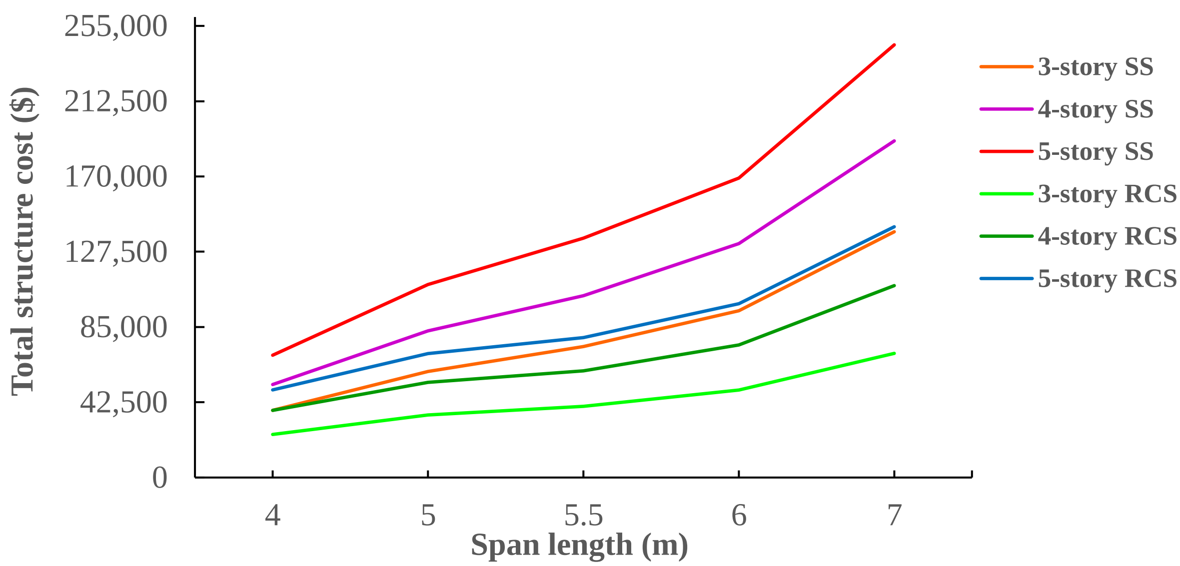


**Figure A.2.4:** Total cost versus span length in the RCS and SS with H=3.6 m

### A.2.3 Effects of Rising Story Height on the Total Cost of RC and Steel Structure

**Table A.2.5:** Amount of cost increase in RCS and SS by rising story height from 3.3 m to 3.6 m

| L (m) | The cost increase in RCS | | | The cost increase in SS | | |
|---|---|---|---|---|---|---|
| | **3-story** | **4-story** | **5-story** | **3-story** | **4-story** | **5-story** |
| **4** | 1,066 | 2,168 | 2,941 | 552 | 1,540 | 2,110 |
| **5** | 1,635 | 2,707 | 3,682 | 1,494 | 3,320 | 2,846 |
| **5.5** | 978 | 1,388 | 3,630 | 2,313 | 3,313 | 3,843 |
| **6** | 1,466 | 2,415 | 4,167 | 3,974 | 6,709 | 3,522 |
| **7** | 2,100 | 3,315 | 5,806 | 4,853 | 6,471 | 3,467 |

**Table A.2.6:** Percentage of RCS and SS cost increase by rising story height from 3.3 m to 3.6 m

| L (m) | The % Cost increase in RCS | | | The % Cost increase in SS | | |
|---|---|---|---|---|---|---|
| | **3-story** | **4-story** | **5-story** | **3-story** | **4-story** | **5-story** |
| **4** | 4.58 | 6.06 | 6.32 | 1.48 | 3.02 | 3.15 |
| **5** | 4.86 | 5.31 | 5.62 | 2.56 | 4.18 | 2.68 |
| **5.5** | 2.49 | 2.36 | 4.81 | 3.23 | 3.34 | 2.93 |
| **6** | 3.05 | 3.34 | 4.43 | 4.40 | 5.35 | 2.13 |
| **7** | 3.09 | 3.16 | 4.28 | 3.62 | 3.52 | 1.44 |

**Table A.2.7:** Amount of RCS and SS cost in different story height (3.3 m and 3.6 m)

| L (m) | H (m) | Cost of RCS ($) | | | Cost of SS ($) | | |
|---|---|---|---|---|---|---|---|
| | | 3-story | 4-story | 5-story | 3-story | 4-story | 5-story |
| **4** | **3.3** | 23,261 | 35,758 | 46,535 | 37,411 | 50,985 | 66,962 |
| | **3.6** | 24,327 | 37,926 | 49,475 | 37,962 | 52,525 | 69,072 |
| **5** | **3.3** | 33,623 | 50,943 | 65,539 | 58,341 | 79,401 | 106,129 |
| | **3.6** | 35,258 | 53,650 | 69,222 | 59,835 | 82,721 | 108,975 |
| **5.5** | **3.3** | 39,258 | 58,789 | 75,407 | 71,631 | 99,278 | 131,238 |
| | **3.6** | 40,236 | 60,177 | 79,038 | 73,944 | 102,591 | 135,081 |
| **6** | **3.3** | 48,023 | 72,335 | 93,969 | 90,268 | 125,400 | 165,649 |
| | **3.6** | 49,489 | 74,750 | 98,137 | 94,242 | 132,109 | 169,171 |
| **7** | **3.3** | 67,998 | 105,036 | 135,776 | 133,906 | 183,606 | 240,832 |
| | **3.6** | 70,099 | 108,351 | 141,582 | 138,759 | 190,077 | 244,299 |

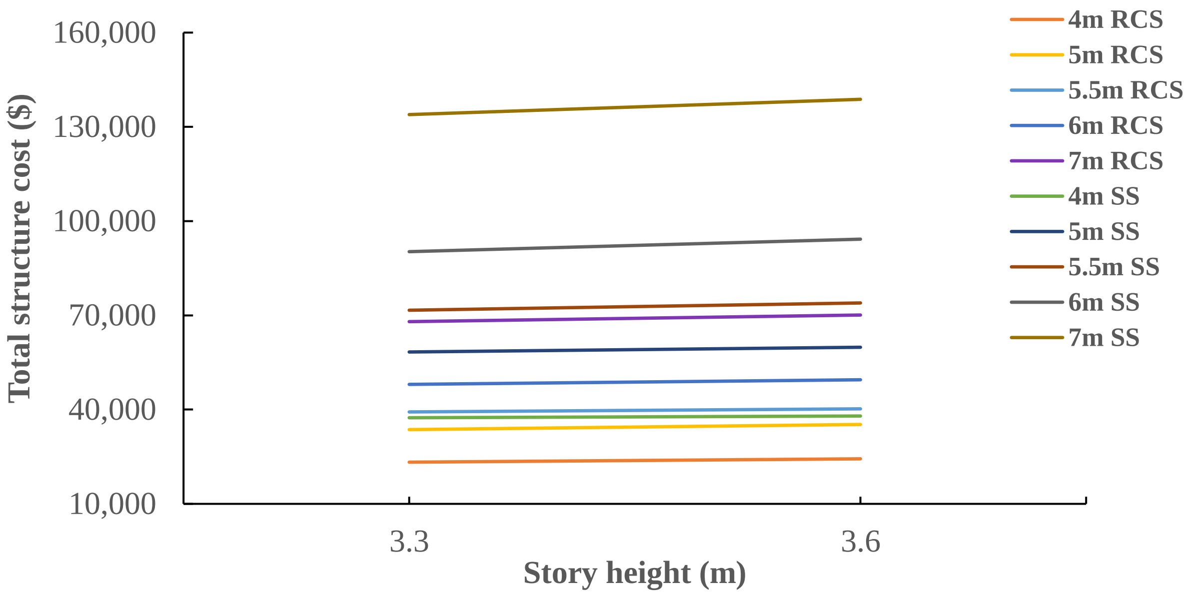


**Figure A.2.5:** Total cost versus story height in the 3-story RCS and SS

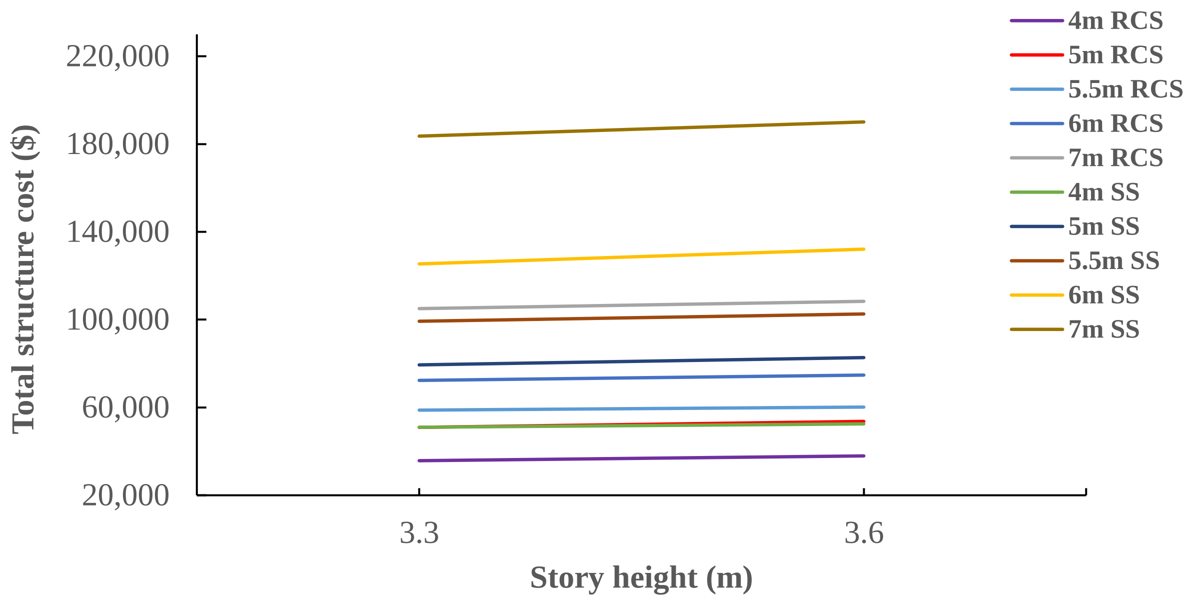


**Figure A.2.6:** Total cost versus story height in the 4-story RC and SS

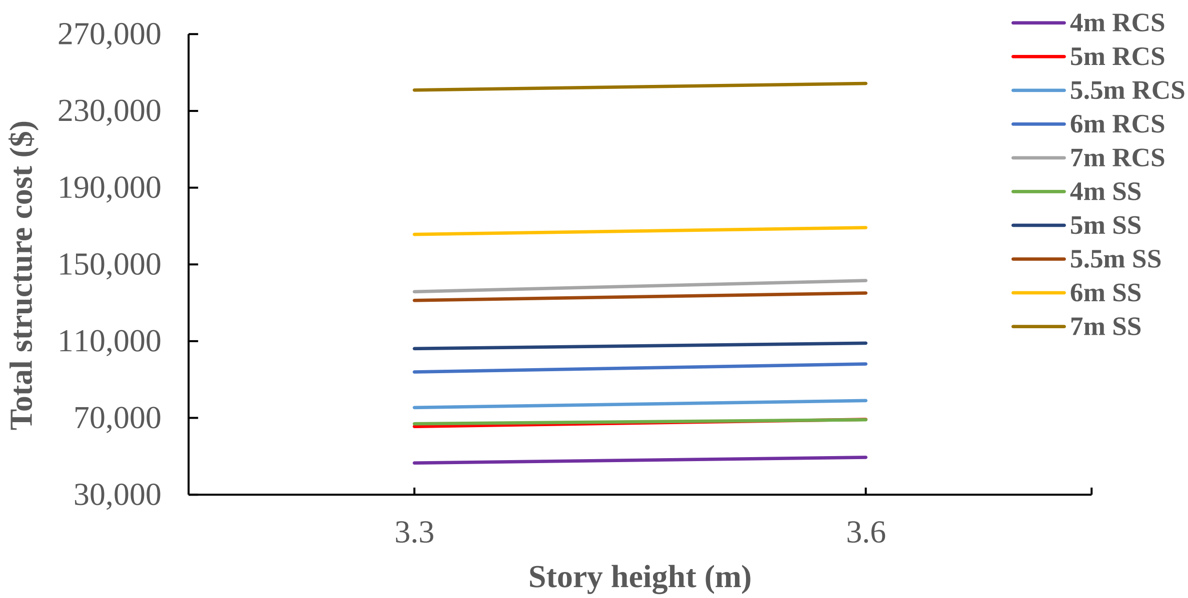


**Figure A.2.7:** Total cost versus story height in the 5-story RC and SS

### A.2.4 Influence of Using Different Materials (RC and steel) on the Total Structural Construction Cost

**Table A.2.8:** Extra structural construction cost of SS over RCS

| L (m) | H (m) | The extra cost of SS over RCS | | |
|---|---|---|---|---|
| | | **3-story** | **4-story** | **5-story** |
| 4 | 3.3 | 14,149 | 15,227 | 20,427 |
| 5 | 3.3 | 24,718 | 28,458 | 40,590 |
| 5.5 | 3.3 | 32,373 | 40,489 | 55,830 |
| 6 | 3.3 | 42,245 | 53,065 | 71,680 |
| 7 | 3.3 | 65,908 | 78,570 | 105,056 |
| 4 | 3.6 | 13,635 | 14,599 | 19,596 |
| 5 | 3.6 | 24,577 | 29,071 | 39,754 |
| 5.5 | 3.6 | 33,708 | 42,414 | 56,043 |
| 6 | 3.6 | 44,753 | 57,359 | 71,035 |
| 7 | 3.6 | 68,660 | 81,726 | 102,717 |

**Table A.2.9:** Percentage of extra structural construction cost by steel over RC

| L (m) | H (m) | % Extra cost of SS | | |
|---|---|---|---|---|
| | | **3-story** | **4-story** | **5-story** |
| **4** | **3.3** | 60.8 | 42.6 | 43.9 |
| **5** | **3.3** | 73.5 | 55.9 | 61.9 |
| **5.5** | **3.3** | 82.5 | 68.9 | 74.0 |
| **6** | **3.3** | 88.0 | 73.4 | 76.3 |
| **7** | **3.3** | 96.9 | 74.8 | 77.4 |
| **4** | **3.6** | 56.1 | 38.5 | 39.6 |
| **5** | **3.6** | 69.7 | 54.2 | 57.4 |
| **5.5** | **3.6** | 83.8 | 70.5 | 70.9 |
| **6** | **3.6** | 90.4 | 76.7 | 72.4 |
| **7** | **3.6** | 97.9 | 75.4 | 72.5 |

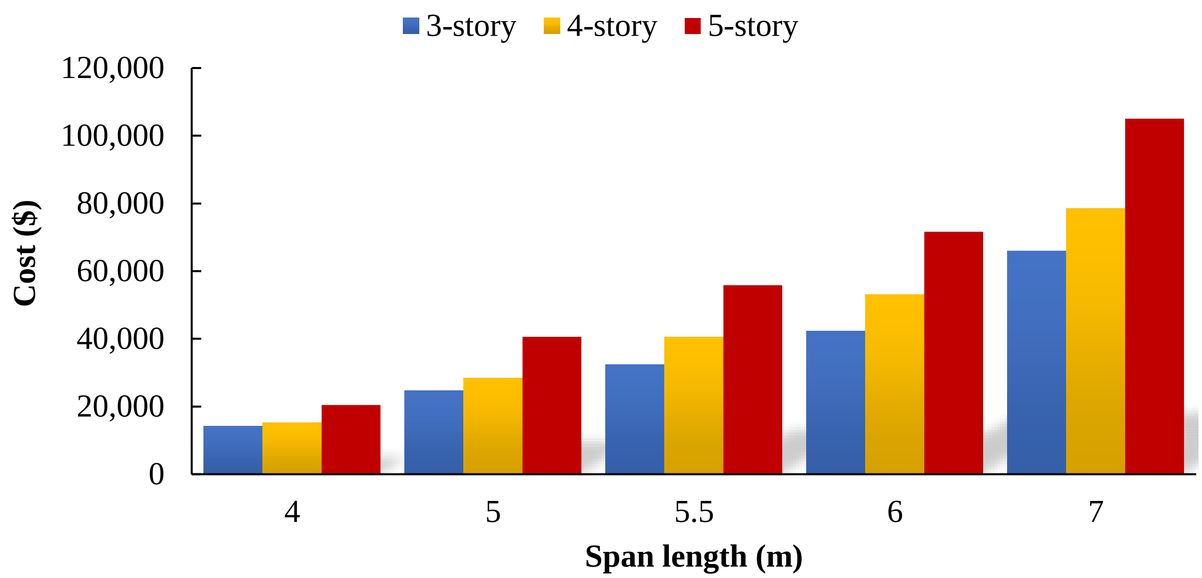


**Figure A.2.8:** Extra cost of SS over RCS with H=3.3 m

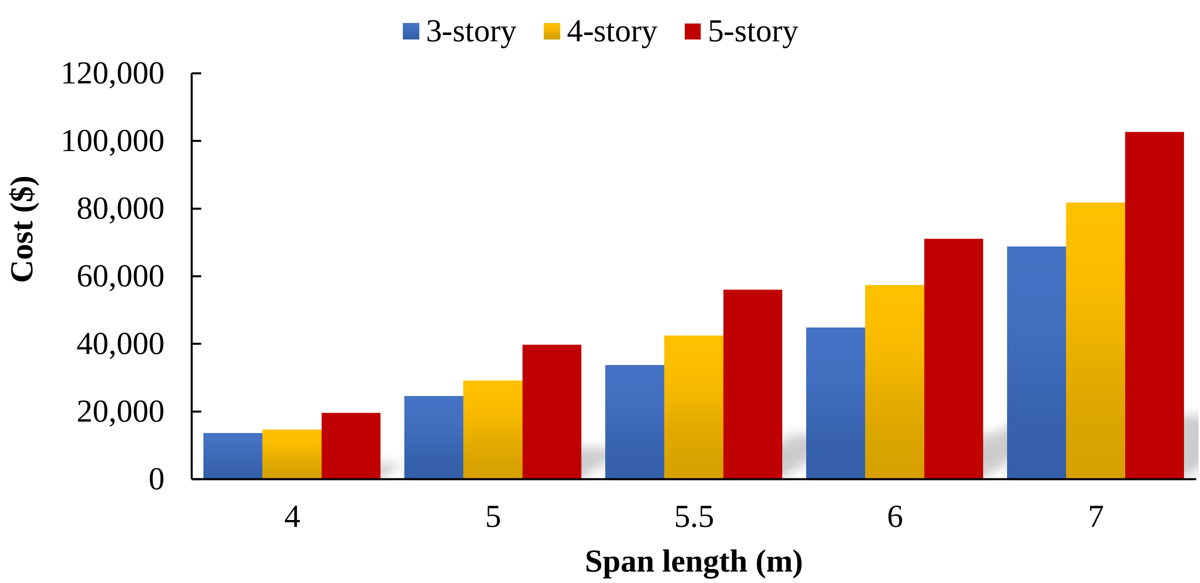


**Figure A.2.9:** Extra cost of SS over RCS with H=3.6 m

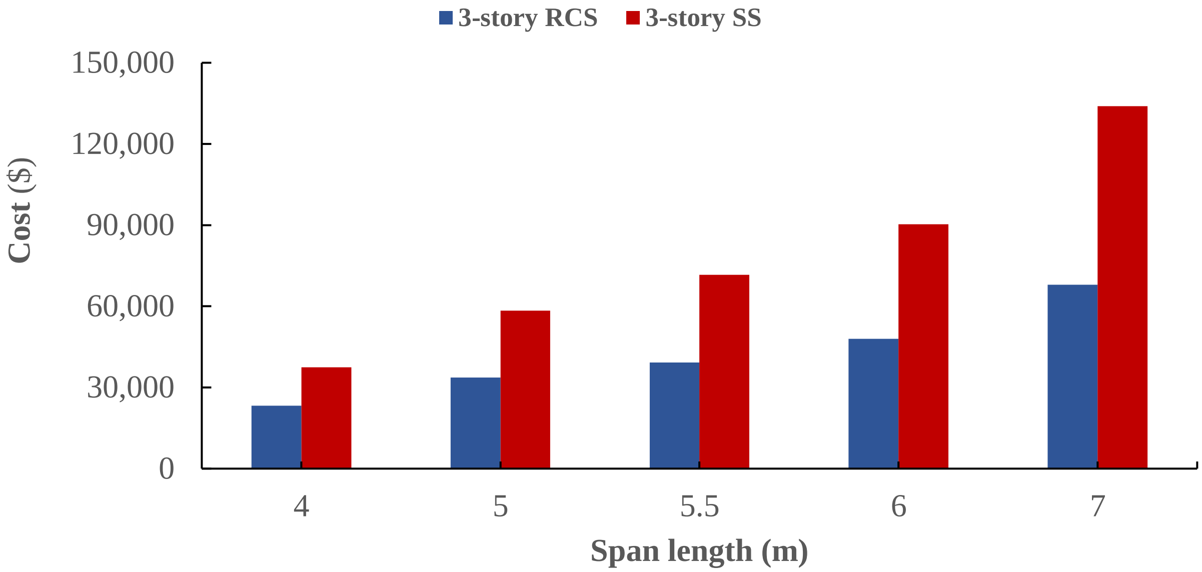


**Figure A.2.10:** Cost of 3-story SS and RCS with H=3.3 m

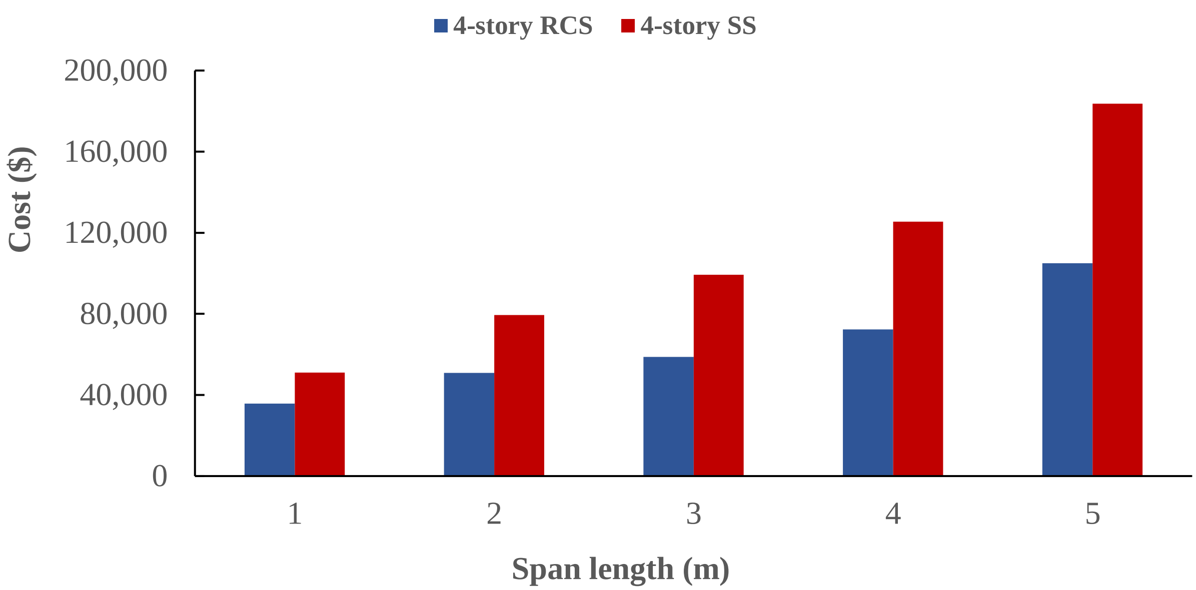


**Figure A.2.11:** Cost of 4-story SS and RCS with H=3.3 m

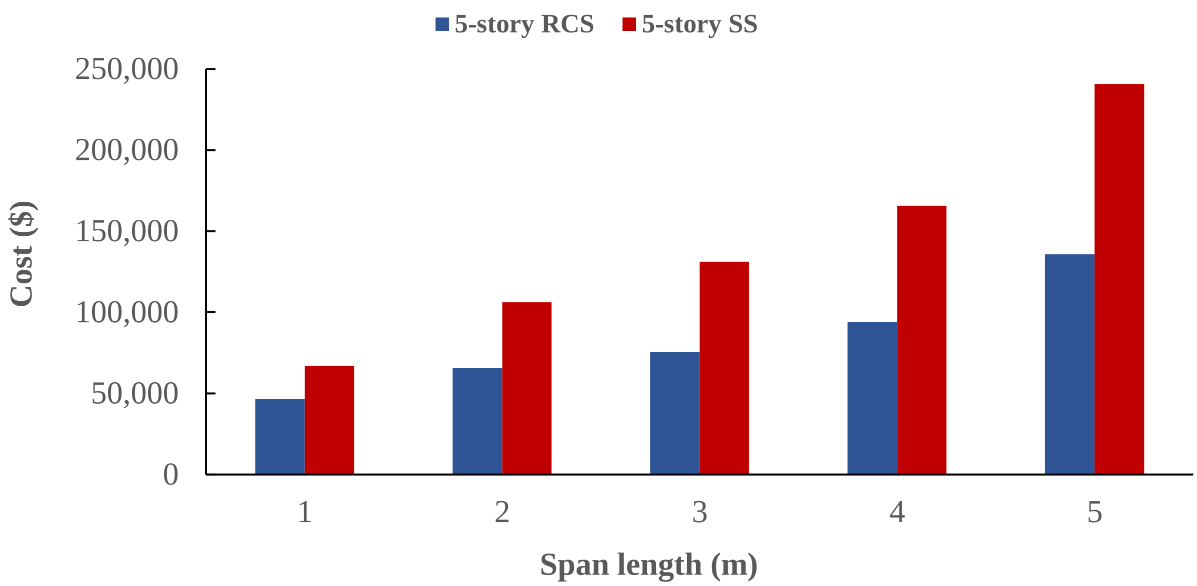


**Figure A.2.12:** Cost of 5-story SS and RCS with H=3.3 m

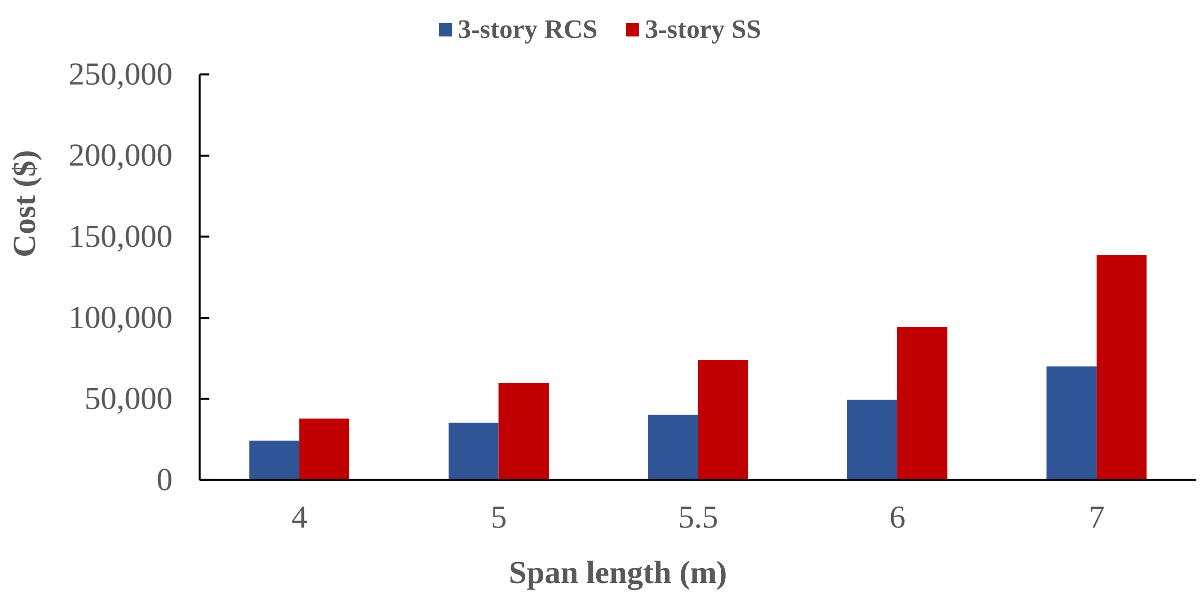


**Figure A.2.13:** Cost of 3-story SS and RCS with H=3.6 m

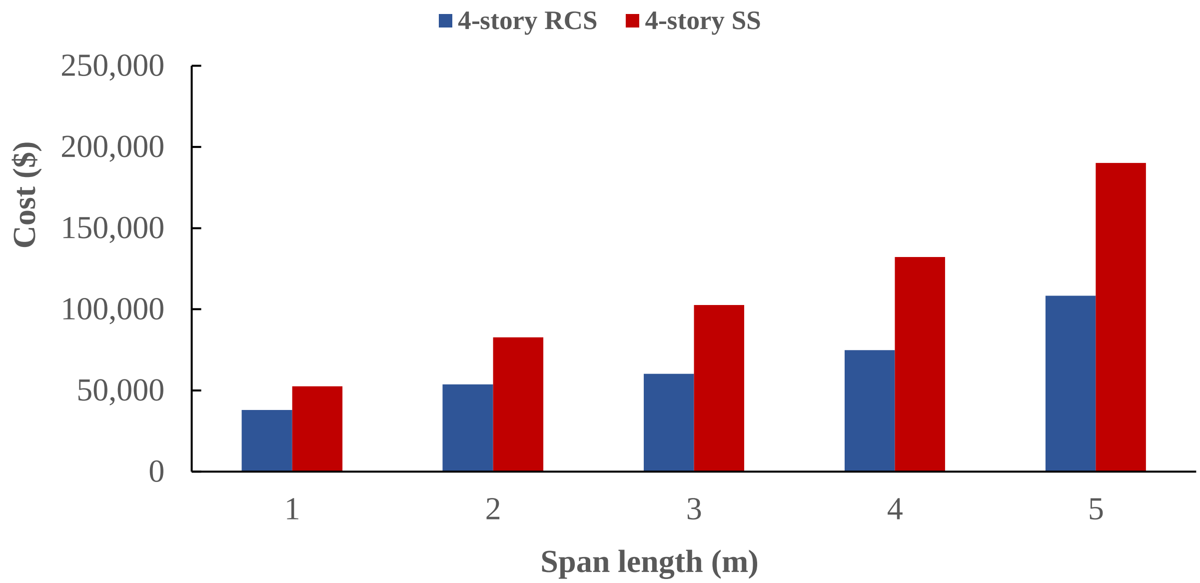


**Figure A.2.14:** Cost of 4-story SS and RCS with H=3.6 m

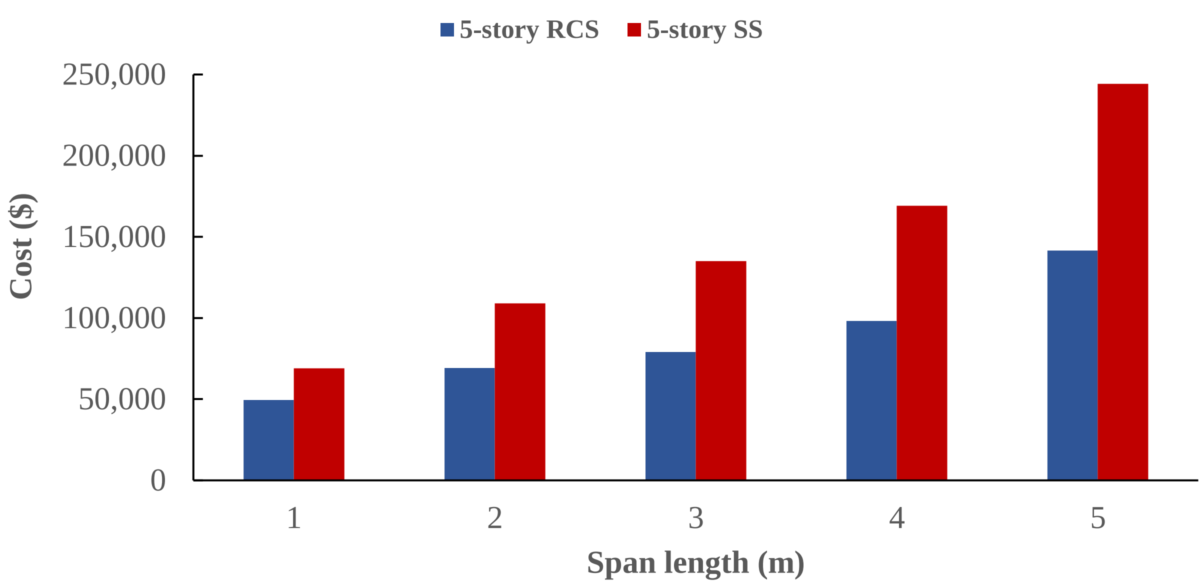


**Figure A.2.15:** Cost of 5-story SS and RCS with H=3.6 m

## APPENDIX 3

## PLAGIARISM AND ETHICAL RULES CONTERACT FORM

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# APPENDIX 4

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