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An Economic Comparison between Using Concrete and Steel Frames in a Medium MultiStory Building in Iraq

Zainab A. Thoeny [a*], *Mustafa A. Thwaini* [b]
a Department of Political Thought, Collage of Political Sciences, University of Baghdad, Baghdad, Iraq.
b Department of Civil Engineering, College of Engineering, (Islamic Azad University) Isfahan (Khorasgan) Branch, Isfahan, Iran.

Keywords:
Economic comparison; ETABS; Multistory building; Quantitative analysis; Reinforced concrete frame.

Highlights:
- *The building was modeled using computer software ETABS 2018.*
- *An economic comparison was performed between reinforced concrete and steel building.*
- *The Quantitative analysis was used.*
- *implementing the steel building saved time compared to reinforced concrete building.*

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**Corresponding author:*

Zainab A. Thoeny
Department of Political Thought, Collage of Political Sciences, University of Baghdad, Baghdad, Iraq.

Abstract: Building materials have always played essential roles in construction assessment, and cost calculation is important in selecting appropriate materials. Reinforced concrete and steel materials are usually used to construct multistory building structures. This study aims to evaluate and analyze using reinforced concrete and steel, frequently used as alternative structural building materials within the Iraqi construction sector, to determine which is cost-effective for building beams, columns, and slabs. In the present research, two multistory building models were designed with different concrete and steel raw materials, considering similar functions. Then, an economic comparison was made between them. The total height of the building was 16 meters at the top. The building was designed using a computer program (ETABS 2018). The designed building was adapted for several uses, such as a commercial center, offices, and service center. According to the study's results, the reinforced concrete frame was 57.8% more economical than the steel frame in Iraq, according to the work activities quantitative analysis. While the time savings for the steel frame was 66 % better than the concrete frame.

مقارنة اقتصادية بين استخدام الهيكل الخرساني والفولاذي في مبنى متوسط متعدد الطوابق في العراق

زينب عبد الرضا ثويني[١]، مصطفى عبد الرضا ثويني[٢]

[١] قسم الفكر السياسي/ كلية الالعلوم السياسية / جامعة بغداد / بغداد – العراق.

[٢] قسم الهندسة المدنية/ كلية الهندسة /جامعة ازاد الاسلامية / فرع اصفهان (خوراسكان) / اصفهان - ايران.

الخلاصة

لعبت مواد البناء دائمًا أدوارًا أساسية في تقييم الإنشاءات، ويعد حساب التكلفة الاقتصادية عاملًا مهمًا في اختيار المواد المناسبة. عادة ما يتم استخدام مواد الخرسانة المسلحة والصلب لبناء هياكل المباني متعددة الطوابق. الهدف الأساسي من الدراسة هو تقييم وتحليل الخرسانة المسلحة والفولاذ اللذان يستخدمان بشكل متكرر كمواد بناء هيكلية بديلة داخل قطاع البناء العراقي لتحديد أيهما فعال من حيث التكلفة لاستخدامه في عوارض البناء والأعمدة والألواح. في هذا البحث تم تصميم نموذجين للمبنى متعدد الطوابق بمواد خام مختلفة من الخرسانة والصلب، مع وظائف مماثلة تم أخذها في الاعتبار، ثم إجراء مقارنة اقتصادية بينهما. يبلغ الارتفاع الإجمالي للمبنى ١٦ مترًا في الأعلى، وقد تم تصميم المبنى باستخدام برنامج كمبيوتر (ETABS 2018)، وتم تكييف المبنى المصمم لعدة استخدامات كمركز تجاري، ومكاتب، ومركز خدمات، وما إلى ذلك. وأظهرت الدراسة أن التكلفة الإجمالية التي تم توفيرها من خلال الإطار الخرساني بلغت حوالي ٥٧,٨٪ مقارنة بالإطار الفولاذي، في حين أن توفير الوقت للإطار الفولاذي كان حوالي ٦٦٪ نسبة الى الإطار الخرساني.

الكلمات الدالة: أتمتة جداول الكميات، نمذجة معلومات البناء، مشاريع بناء المدارس، جداول الكميات التقليدية، نماذج معلومات البناء ثلاثية الابعاد.

1.INTRODUCTION

Building materials have a substantial role in the construction sector and a weighty impact on reaching sustainability goals. In building construction, thoughtful material selection can help limit environmental damage while improving economic and social outcomes [1]. The economic comparison between concrete and steel frames in construction is an important topic in construction economics and materials engineering. Most researchers and professionals in architecture, civil engineering, and construction management investigate the economic aspects of choosing between concrete and steel frames for building structures to include several aspects, including the cost, such as the cost of materials construction, i.e., the costs of workers, equipment and construction time, and maintenance and repairs, average life expectancy, the environmental impact during production and transportation, the performance of the structure under the influence of seismic activity and severe environmental conditions. The chosen type of structural frame is critical because it interacts with many other aspects of the building, affecting its specifications and ability to be built. The choice of material to employ as a structural frame is significantly influenced by the type of building to be erected and site-specific constraints. When comparing steel and concrete structures, two important factors are considered: the optimum construction time and the total cost of the structures. Each structure's construction is divided into several operations, allowing for relative time savings and optimal building times [2]. Before making a final decision, various factors, such as weight, strength, constructability, durability, fire resistance, and sustainability, should be considered. Sirikci [3] reported that the dead load of a reinforced concrete frame for a certain building was 1450 tons, while constructing the same building could be made of 718 tons of steel. The time saved was 2% to 3% by adopting a steel rather than a reinforced concrete structure. Implementing the building materials and construction costs were estimated according to Iraq's local market rates in 2022. The cost of each structural system of the two building structures was calculated for the materials and construction costs of the buildings under this study. Comparing composite and concrete slabs is limited to the structural frame and slab only, while the foundation was assumed to be raft foundation type for both cases as commonly used for such building situations based on soil reports conducted in the surrounding area. The steel-framed structural model with the composite slab would result in significant cost savings during a project's lifetime [4]. The benefits of using a composite floor have enhanced the adoption of steel-framed buildings during the last decades [5]. Structural steel can be formed in various shapes, bolted, and welded on the site together during construction. As a schedule-friendly building material, steel can be installed as soon as the elements are available on-site, whereas curing concrete lasts for at least 1–2 weeks after casting before the building can be resumed [6]. The durability of reinforced concrete frames can be lowered by seismic loading-induced cracking and strength loss. However, the steel frames' durability is similar in fire and post-earthquake fire conditions [7]. Concrete is a good compressive strength composite material; however, it lacks tensile strength and ductility [8]. Once properly constructed, exceptional corrosion resistance is offered by reinforced concrete. Nevertheless, to prevent corrosion, the steel reinforcement in the concrete must not be exposed, as this might considerably impair the structure's strength [9]. The British Construction Steelwork Association provides the design criteria to certify sufficient concrete above at any point of steel reinforcement to keep it from corroding [10]. The steel-framed buildings perform better than reinforced concrete-framed buildings in terms of increased area, interior space flexibility, recycled rate, renewability, waste level, labor savings, and construction duration [11]. The steel building materials might be more lightweight and decrease construction time compared to reinforced concrete beams and columns [6]. While reinforced concrete-framed buildings perform better than steel-framed buildings in terms of structural, maintenance, and financial costs [12], till now, concrete and steel are the most used construction materials. The present research aims to conduct a comprehensive economic and time comparison by reviewing the literature, collecting data from case studies, analyzing and comparing the costs and benefits of using concrete and steel frames according to specific project requirements and local conditions, and providing valuable insight to determine economic feasibility and accurate understanding for decision-makers in the construction industry. The present research is restricted to the Iraqi construction industry's economic and speed-up evaluation framework for reinforced concrete and steel frames. The methodology of this study relies on evaluations and comparisons through quantitative analysis of cost data for the case study in the context of the main features of the economy. This study was considered through methods of collecting data on prices in local markets in terms of materials, construction costs, and time for completing activities. In addition, the results of evaluations through sequential activities were analyzed to accomplish the required work according to the type of facility to reach a comprehensive comparison.

2.STUDY METHODOLOGY

For the present case study, the most appropriate cost between the concrete frame and steel frame was compared and estimated considering materials usage, construction cost, including the time needed for construction work in the foundation, columns, beams, and slabs of the building structure. Furthermore, the methodology of this paper analyzed the cost of activities for both buildings in terms of the prevailing market price for materials and construction operations. The foundation of the case study building was designed with a raft foundation or as called box footings and concrete pedestals to bear the steel columns. Steel columns fixed with providing anchor bolts distributed in position depending on design requirements. The composite roof between the steel beam and slim concrete slab through using shear connectors is accountable for a substantial increase in the load-bearing capacity and sufficient stiffness of the steel beams can save a large amount in steel weight and construction depth design. The self-taping machine is used to weld shear studs leading to less time for activity; however, this method is more expensive than the typical welding mode [13]. Columns and beams of the steel construction can be erected for all stories at the same time while constructing composite slab is progressed for lower stories, i.e., on deck sheet placed on the third floor, or shear stud welding on the second floor, opening many work activities at the same time; thus, a lot of time and cost can be saved.

3.CASE STUDY BUILDING

The present study designed a multistory building adapted for several uses, such as a commercial center, offices, and service center of 30 meters in length and 15 meters in width, i.e., 450 square meters in total area, with each span for the horizontal side was 5 meters, and the longitudinal side was 6 meters. The building was designed according to ACI 318-19 [14] and AISC 360-16 [15] and modeled using computer software (ETABS 2018) [16]. In the case of the concrete design model, the main columns were designed with dimensions of (500×250) mm oriented with the strong axis in the longitudinal direction to provide maximum resistance to the axial force, shear, and bending moment. All beams' dimensions were (600×250) mm, and the slab thickness was 200 mm, reinforced concrete lift section that contained four shear walls. Figure 1 illustrates the three-dimensional model of the building, and Table 1 lists the applied load in detail. The hot-rolled steel was produced using the arc furnace method, and the continuous casting was the utmost common type of steel used in components and joints of structures. The main columns designed using steel HEA 320 were connected to the beams by fixed joints and connected to the foundation by rigid joints, fixed against rotation in the plane of the frame using end gusset plates and anchor bolts. Figure 2 shows the three-dimensional model of the building. Concrete elements made of concrete C 30 are ideal for enhancing the durability of the concrete structure. The steel elements in the steel structure are made of steel grade S275, i.e., S denotes structural steel, and 275 indicates the steel's minimum yield strength. This type is unalloyed low-carbon mild steel that provides low strength and good machinability and is suitable for welding. Steel with high strength and low ductility is brittle. The analysis was performed using software to obtain the critical bending moment, axial force, and shear force. All the concrete members and steel elements were checked and satisfied after analysis. The building was assumed to be in Baghdad City. It featured Terrain category II and wind load zone I. The average bearing capacity for soil was between (6-8) tons/m^2, and the area was uncovered by environmental protection. The best construction material for the structure was selected according to the project requirements.

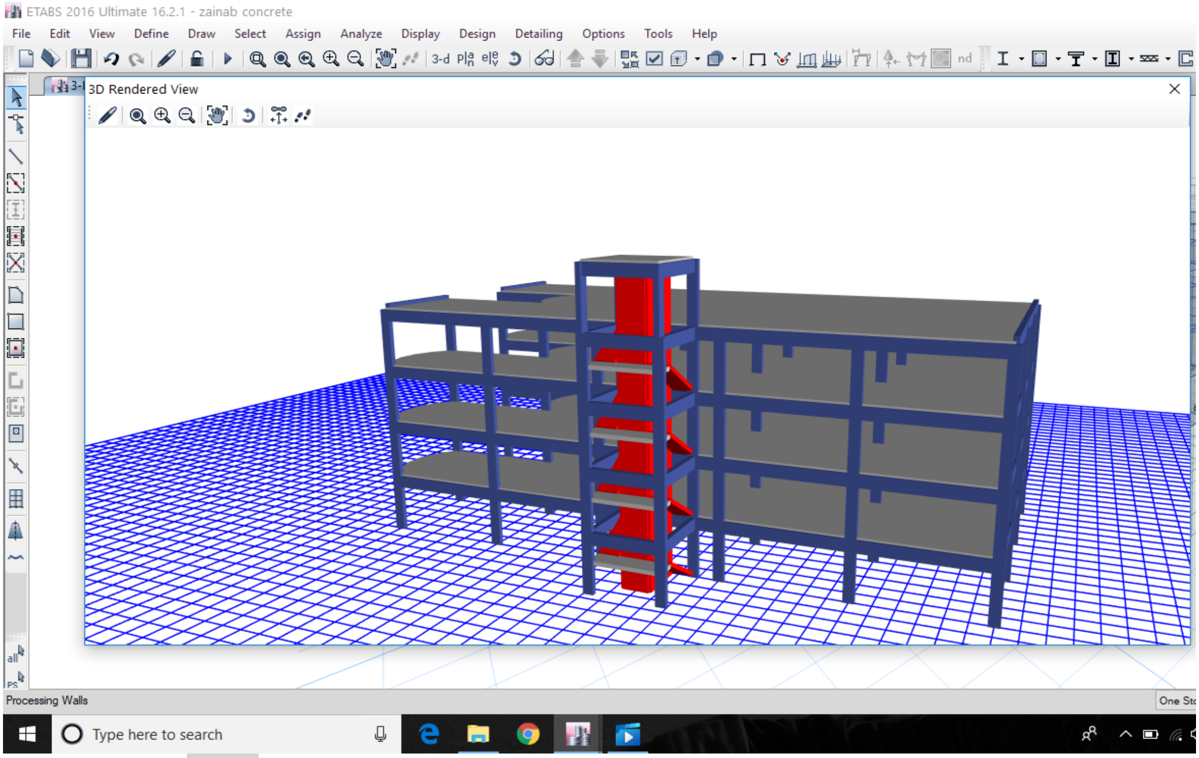


Fig. 1 Three-Dimensional Reinforced Concrete Model of the Building.

Table 1 The Applied Load.

Load Case	Details
Dead load Self-weight	Reinforced concrete C30 with a 2400 kg/m^3 density and 400 kg/m^2 (250 kg/m^2 for interior partition + 150kg/m^2 floor finishing).
Live load	The live load on the floor was 250 kg/m^2
Earthquake load	According to ASCE 7-10 code
Wind load	UBC 97 code

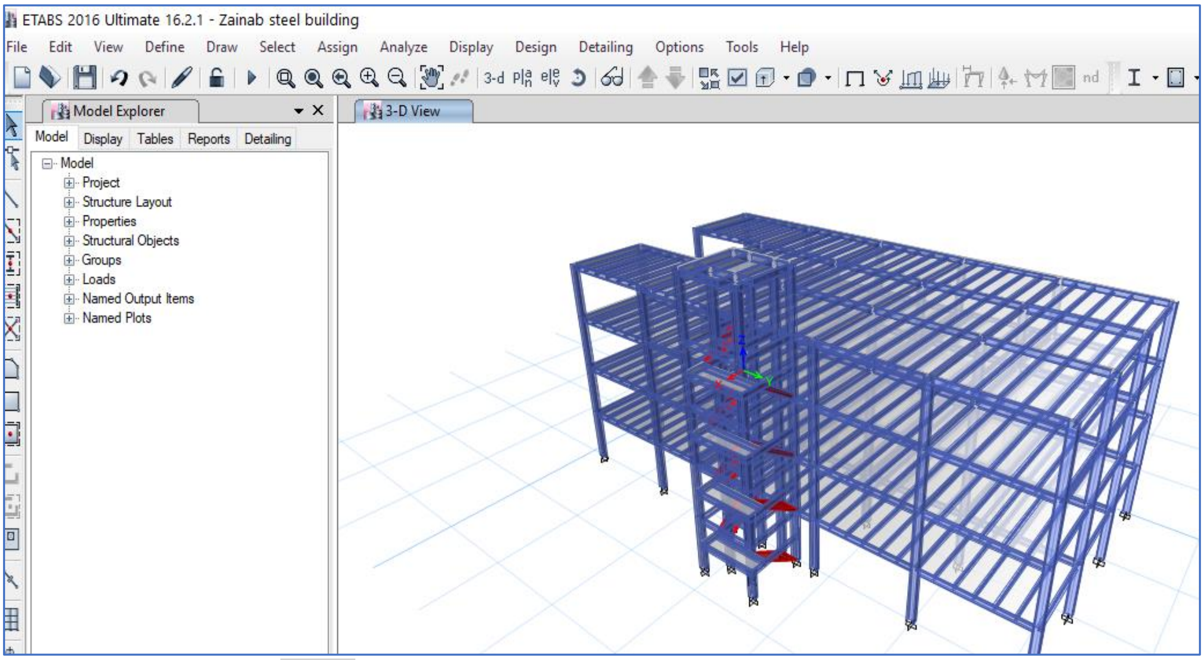
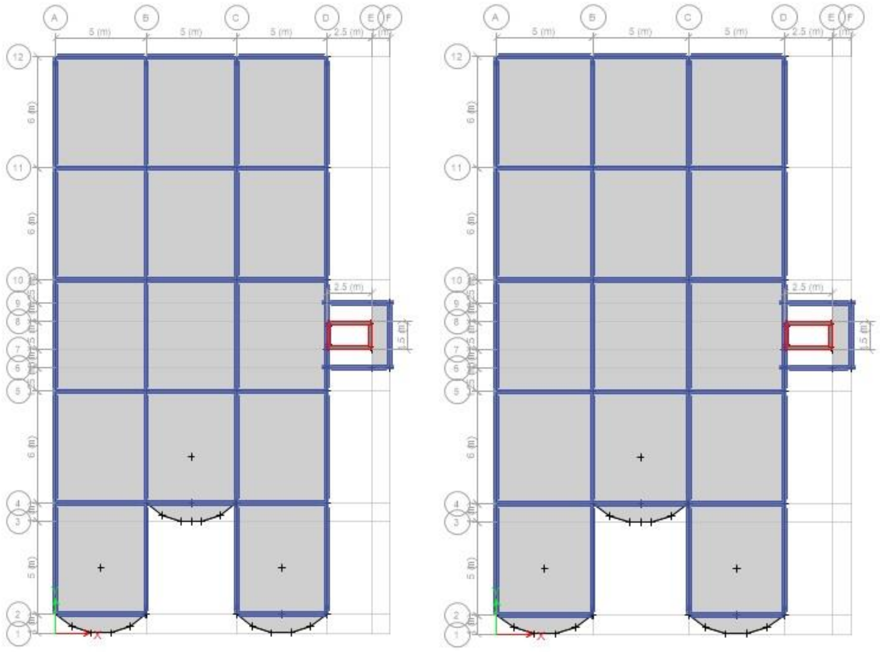


Fig. 2 Three-Dimensional Steel Model of the Building.

4.BUILDING ANALYSIS

Figure 3 shows the top view of the buildings. The buildings with reinforcement concrete structures and steel structures have been checked, considering the whole structure as a three-dimensional model, and analyzed using ETABS, as shown in Fig. 4. The major objective of modeling the structures as a 3D-dimensional model is to consider the behavior of every component in the space of the structural environment. The reinforced concrete building slab was designed with a thickness of 200 mm. The steel building slab was designed as a composite-filled deck slab (ribbed steel deck sheet thickness 2 mm+ shear stud diameter 19 mm + concrete slab 8-12 mm) to afford its weight; steel decks were employed in composite slab systems as reinforcement following the hardening of the concrete and as formwork during construction, in addition to the dead load and live load as a gravity distributed pressure, as shown in Fig. 5. Elevator and staircase walls in a concrete model were designed as a thin plate shear wall to endure the lateral load, such as wind and earthquake loads. While the lift and staircase in the steel model consisted of steel frames with thin concrete floors.



(a) **(b)**

Fig. 3 Top View of Structure (a) Concrete Structure, (b) Steel Structure.

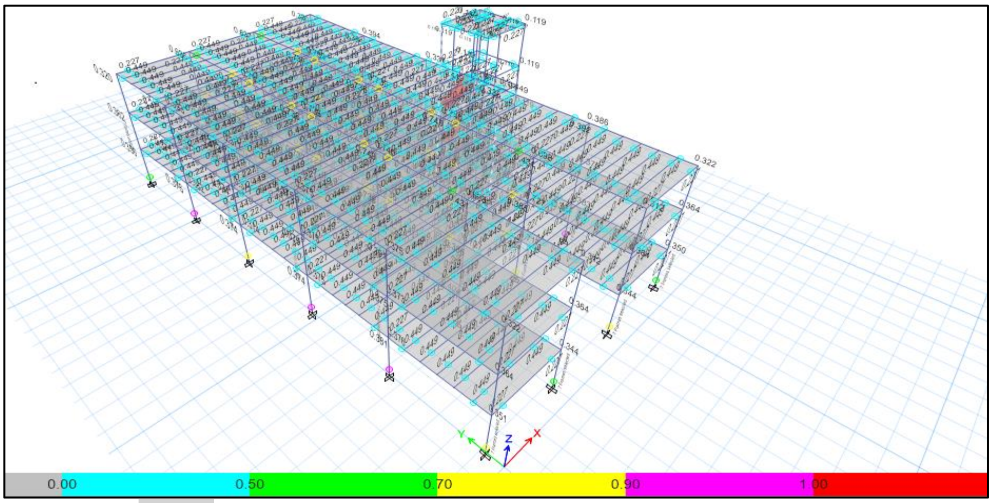


Fig. 4 The Analysis Process for All Members of the Building.

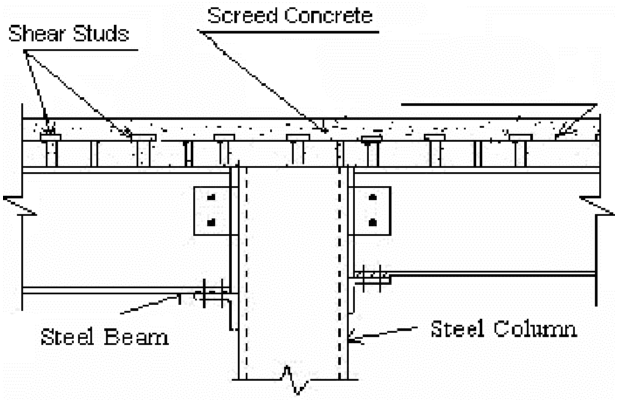


Fig. 5 Composite Roof Sample of the Steel Model.

5.RESULTS AND DISCUSSION

Four main construction activities determine the final project cost, i.e., foundations, columns, beams, and slab construction. Tables 2 and 3 present the distribution of material and construction costs for the named activities for each type of building. The cost of steel frames is more expensive. Moreover, it requires a qualified workforce. Iraq suffers from a deficit production of steel sections, while different types of 220-wide flange sections are produced in Europe [17]. The maximum construction cost due to the erection of elements, joint connections, transportation process, and import cost is illustrated for the steel frame, while for the concrete frame, the maximum material cost is related to material quality and using additives to the concrete mixture. The total cost savings for concrete structures associated with beam and column elements were (82.4 and67)%, respectively, compared to steel frames. For foundation and slab elements, the percentage of cost in the steel frame was less than that in the reinforced concrete frame by (16.6% and 50%), respectively. For stairs, elements in a steel frame save cost about 46.42% compared to the reinforced concrete frame. Table 4 shows that the cost of column items was only (6.5 and 11.5) % of the total cost of concrete and steel frames, respectively. The foundation item shows that the percentage of costs was (23.66 and 11.4) %of the total cost of concrete and steel frames, respectively, attributed to the light weight of the steel frame, where a steel frame weighed 60% less than concrete [18]. The percentage of beam items was (17.5 and 58.4) % of the total cost of concrete and steel frames, respectively. Also, the cost for concrete and steel structures was (40.9, 11.8)% for slab items, where the thickness of the slab was (20)mm in concrete slab compared to the (10)mm thickness of the steel structure. Constructing the structure included several work activities and the completion time for each activity. Table 5 illustrates the estimated required time for two types of structures.

Table 2 Unit's Prices for Concrete Building.

No	Item	Unit	Depth (m)	Area (m^2)	Total quantity(m^3)	Price (ID*)	Sum (ID)
1	Site preparation and Excavation works (depth 2 m)	m^3	2.00	500	1000	8500	8500000
2	Filling with well-compacted approved subbase, 50cm thickness (divided into 2 layers)	m^3	0.50	500	250	25000	6250000
3	Lean concrete layer 10 cm thickness (C20)	m^2	-------	460	-------	20000	9200000
4	Foundation Reinforced concrete (Raft C35)	m^3	0.60	450	270	300000	81000000
5	Columns (All stories) (500×250) mm	m^3	0.50	0.12	50	450000	22500000
6	Beams (All stories) (600×250) mm	m^3	0.60	0.15	150	400000	60000000
7	Slabs (All stories) 200 mm thickness	m^3	0.20	-----	350	400000	140000000
8	Shear walls (Thick 200 mm)	m^3	0.20	------	20	450000	9000000
9	Stairs (all stories) C35	m^3	0.20		13	450000	5850000
Total cost							342300000

*ID: Iraqi Dinar.

Table 3 Units Prices for Steel Building.

No.	Item	Unit	Depth (m)	Area (m^2)	Total length (m)	Price (ID)	Sum (ID)
1	Site preparation and Excavation work	m^3	2.00	500	1000	8500	8500000
2	Filling with well-compacted approved subbase, 50cm thickness (divided into 2 layers)	m^3	0.50	500	250	25000	6250000
3	Lean concrete layer 10 cm thickness (C20)	m^2	-----	460	----	20000	9200000
4	Foundation Reinforced concrete (Raft C35)	m^3	0.50	450	225	300000	67500000
5	Columns (All stories) HE 360 M section	m.l	0.35	-----	350	195000	68250000
6	Main beams (All stories) IPE 300 section	m.l	0.30	------	950	140000	133000000
7	Secondary beams (All stories) W 8× 21 section	m.l	0.20	------	1420	150000	213000000
8	Composite Concrete slab (All stories) (C 35)	m^3	0.10	2000	----	350000	70000000
9	Connection Base plate	no.	-----	-----	sum	25000000	25000000
	Bolts+ stiffners+ welder	no.	-----	-----			
10	Stairs (steel parts only for all stories and concrete part included in item no.8)	m.l	-----	---	70	180000	12600000
11	Elevator (steel parts only for all stories)	m.l	-----	----	100	195000	19500000
Total cost							592200000

Table 4 The Percentage of Item Costs to the Total Cost of Frames.

Type of frame	Item			
	Foundation	**Column**	**Beam**	**Slab**
Concrete structure	23.66	6.5	17.5	40.9
Steel structure	11.4	11.5	58.4	11.8

Table 5 Schedule of Activities.

ID	Task name	Reinforced Concrete Building (days)	Steel Structure Building (days)	Notes
1	Soil investigation	10	10	Same for both cases
2	Cleaning of site preparing	2	2	Same for both cases
3	Excavation	10	10	
4	Backfilling with boulder layer of two subbase layers (50 cm) with compacting	14	14	
5	Lean concrete layer	2	2	
5	Footing + Curing process	12	10	Reduction of time For steel frame due to synchronization with column erection.
6	1st column	15	8	
7	Beam and Slab for 1st story + casting	16	10	Reduction of time For steel frame due to synchronization with column erection.
8	2nd column	15	8	
9	Beam and Slab for 2nd story + casting	16	10	
10	3rd story column	15	8	
11	Beams and Slab for 3rd	16	10	
12	4th story column	15	8	
13	Beams and Slab for 4th story + casting	16	10	
14	5th stairwell column	7	1	
15	Beams and Slab and casting for the stairwell	7	3	
		188	124	

The construction activity schedules in the present case study were prepared separately for two building construction methods. The construction activities of the structural frame designed by reinforced concrete were expected to be open for 188 days; on the other hand, the construction of the steel structure was open for 124 days. As a result, it was observed that the time savings of about 66 % for steel frame proportion to the reinforced concrete frame. This result agrees with the time savings of the foundation, wall, and structural frame of a two-story villa with a lightweight steel frame compared to a reinforced concrete design by 70.9 % [2].

6.CONCLUSION

Due to their efficiency, reinforced concrete and steel structural systems are becoming more common construction materials. Extensive research is still being done on them. The present paper summarizes the cost of planned activities in reinforced concrete and steel frames related to the prevailing market price in Iraq to select a more suitable economic and time-saving system.

- Materials selected for construction buildings play a significant role in selecting proper building materials and obtaining economic sustainability in the Iraqi construction buildings industry.
- The total cost for each structure model was calculated based on the material types and construction costs for each structural member only, so the concrete frame saved about 57.8 % of the total cost compared with the steel model and composite slab.
- The total cost savings for concrete structures associated with beam and column elements were (82.4 and67)%, respectively, compared to the steel frames. While for foundation and slab elements, the percentage of cost in the steel frame was less than that in the reinforced concrete frame by (16.6%, 50%)
- The costs of foundations and columns for both types of buildings were less than the cost for beams and slab construction. While stairs cost in concrete buildings saved about 46.42 % compared to a steel frame.
- The result showed that a time saving of about 66% was obtained for steel-framed composite slab construction rather than concrete-framed construction due to the speed of the steel frame erection and the lack of a curing process.

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