Journal of Civil Aspects and Structural Engineering

www.case.reapress.com

J. Civ. Asp. Struct. Eng. Vol. 2, No. 4 (2025) 234–244.

Paper Type: Original Article

Evaluating the Feasibility of Using Roof Types in Multi-Story Buildings in Terms of Quality, Cost, and Time

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Citation:

Received: 05 November 2024
Revised: 02 January 2025
Accepted: 24 April 2025

Ali Aghazadeh Rudsari, M., Faghihmaleki, A (2025). Evaluating the feasibility of using roof types in multi-story buildings in terms of quality, cost, and time. *Journal of civil aspects and structural engineering*, 2(4), 234-244.

Abstract

In this study, the evaluation of the possibility of using this type of roof in multi-story buildings in terms of quality, cost, and time was considered. In this regard, various types of roof systems, both traditional and modern, including beam and block roofs -chromite-concrete slabs- uboot and cobox, etc., were initially evaluated and prioritized using the AHP method and AHP SOLVER software based on various technical, economic, and executive criteria. Subsequently, roof systems were evaluated for 2, 5, 10, and 12-story buildings. The results of the analysis showed that overall, the Kubiax and Ubot roofs are ranked first and second as two new roofs. Given that the weights obtained for these two ceilings are equal to each other, it is possible to unanimously consider these two ceilings to be ranked first. The beam and block roof with a weight of 0.174 was in second place. The composite roof with a weight of 0.141 was the third option, and finally the concrete slab option with a weight of 0.135 was the fourth option. The chromite roof with a weight of 0.122 was in last place. Also, as it was determined, for the beam and block roof, after optimizing the 2, 5, 10, and 12-story structures, the weight of the 5, 10, and 12-story structures increased by 3.24, 7.87, and 9.42 times, respectively, compared to the 2-story structure .For the concrete slab roof, after optimizing the 2, 5, 10, and 12-story structures, the weight of the 5, 10, and 12-story structures increased by 3.36, 8.23, and 9.85 times, respectively, compared to the 2-story structure. The weight of the structure was reduced by a maximum of about 30% when the roof was a U-shaped roof compared to a concrete slab roof. For 2- and 5-story structures, the structural weight reduction ratio (Roof weight and its optimization and, as a result, the impact on the structural weight) was 20 percent, for 10-story structures this ratio was 25 percent, and for 12-story structures this ratio was 30 percent.

Keywords: Traditional roof system, Modern roof system, AHP method, Cubix roof, Concrete slab.

1 | Introduction

Roofs are among the main elements of buildings that carry and transfer gravity and lateral loads. In this regard, roofs must be resistant and rigid, yet have appropriate ductility, and on the other hand, they must have a

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https://doi.org/10.48314/jcase.v2i3.67

proper connection to the structure and have appropriate seismic behavior. The next issue is controlling roof deformation and vibrations, which is very important. Another important issue is the weight of the roof, because the weight of the roof accounts for a large part of the dead load of the structure, and therefore this issue must also be considered. Considering the costs and time of implementing the structure and roof types, if the roof is selected and implemented improperly, in addition to the structure not performing optimally, a lot of costs are imposed on it, which consequently requires the need for retrofitting in the future. Therefore, this issue should be examined based on various parameters to ultimately select the appropriate roof system in terms of implementation, economy, and technology [1].

Rezania reviewed and compared the new U-Boat and Waffle roofs in 2019. Roofs are the main element of buildings, being the first load-bearing element of the structure. Therefore, the importance of this member is more important than ever. The main role of this member is to transfer horizontal and vertical forces resulting from the dead weight of the roof, overhead loads, and earthquake forces to the beams, columns, and load-bearing walls. Today, the construction industry is constantly evolving. In every era, engineers and researchers have been trying to create new equipment and technology to improve on past systems. In this study, an attempt has been made to examine new technologies in ceiling systems. Two examples of these new systems are U-Bot and Waffle hollow ceilings. Due to its architectural and structural advantages, including the possibility of increasing openings, reducing the weight of the structure, etc., the use of this type of roof is increasing day by day [2].

For years, disagreements among builders regarding the superiority of steel and concrete structures over each other have caused doubts about the choice of the type of structure; in principle, the choice of the type of structure is a function of economic, climatic, technical, administrative, and other issues of this kind, and none of these types of structures has an absolute superiority over each other, and depending on the circumstances, each has a relative superiority over the other [3].

In the present study, in order to select the optimal type of structure, an attempt was made to conduct a technical and economic evaluation of building systems in a comparative manner between concrete frame and steel frame buildings. For this purpose, first, by examining and evaluating the basic concepts regarding the research topic, theoretical foundations were assessed, and then, using ETABS software, a number of concrete and steel buildings with different structural, roof, and wall systems were modeled, analyzed, and designed in a common urban structure with the same plan type, based on conventional regulations and standards. After analyzing and modeling the aforementioned structures, in order to select the optimal building system with concrete and steel skeletons, the results of the analysis and design of the structures were compared based on various technical and economic parameters. The results of economic analysis of concrete buildings showed that the cost of constructing concrete buildings with a flexural frame system and a flexural frame system plus a shear wall does not vary much [4].

In addition, in both types of structural systems mentioned, the cheapest system is the combination of a block joist roof system and a sandwich panel wall system, and the most expensive concrete system is the combination of a flat slab roof system and a drywall wall system. In addition, the results of the economic analysis of steel buildings showed that the cost of constructing steel buildings with a flexural frame system is higher than that of a simple frame system plus bracing due to the heavy weight of the skeleton. The results also showed that in both of the aforementioned building systems, with changes in the ceiling and wall systems, there is a cost difference of about 23% between the highest and lowest costs for different models [5], [6].

An attempt has been made to provide information about the basic principles of prestressed and hollow slab (Waffle) systems, implementation methods, calculation principles, and their general advantages. After providing general information, the use of each system in this project is briefly reviewed. Since the use of these slabs will also have an impact on the structural system of the building, the proposed structural system is first introduced and then the proposed option for covering the roofs is presented. After presenting the proposed structural option, the advantages of using each of the slabs in this project are stated [7].

Since implementation costs are one of the influential factors in major project decisions, an estimate of the project implementation costs if the proposed option is used is provided. It is expected that by studying this article, users will be provided with the necessary tools to select this system [8].

Ardeshiro et al. studied and selected the optimal roof system of a building using the TOPSIS method in 2017 [9]. One of the most important processes in the construction of any building that has a significant impact on the speed, ease, and costs of its implementation is the implementation of the roof of the building. Given the variety of modern roofing systems and the increasing use of their types, deciding on the best roofing system based on the specific conditions of each project is one of the most important decisions in any construction project. In this study, the most commonly used building roof systems, especially modern roof implementation systems, including steel deck roofs, hollowcore roofs, Cubix roofs, waffle roofs, Rofix roofs, and U-Boat roofs, are first introduced, and the unique features, advantages, and disadvantages of each are somewhat mentioned. Then, these roof systems were compared with each other from the perspective of various characteristics such as weight, material and implementation costs, implementation speed, and architecture using the Prioritization Based on Similarity to Ideal Solution (TOPSIS) method. Finally, with this analysis, the optimal building roof system can be selected according to the specific conditions of each project such as geographical region, type of structure, availability of systems, and volume and scope of the project [10].

In 2017, Shadfar and Mohammadi Golafshani investigated and evaluated the feasibility of optimal use of modern roof systems in concrete frame projects using the similarity to ideal option method [11]. The use of modern technologies is always considered as one of the criteria for project success from the perspective of most project stakeholders. In the construction industry and the concrete skeleton roof sector, which is the subject of this research, knowledge-based feasibility studies for the correct and optimal use of modern roof systems can be considered the most important and first step. In this article, in order to achieve the most appropriate roof system in concrete frame projects, the knowledge of operations research and its branch called systems analysis and design, and specifically the Topsis tool, has been used.

The options under consideration are traditional slab, waffle slabs, U-boat, Cubix, prestressed post-tensioned and joists, which are measured against 7 criteria. It was determined that for each specific project, the feasibility of the same project should be assessed according to criteria such as architectural openness, time, cost, service load performance, sound and fire resistance, and seismic performance, and the priority of the mentioned options should be determined. In this study, feasibility studies were conducted separately for spans up to 8 meters, 8 meters to 12 meters, and 12 meters and above, and the results showed that for spans up to 8 meters, U-boat, for spans between 8 meters and 12 meters, waffle roof, and for spans over 12 meters, post-tensioned prestressed roofs are the superior options [12].

In 2017, Bakhshizadeh and Adib compared the construction costs of steel frame buildings with a fixed plan, different number of floors, and different lateral load-bearing and roof systems [13]. Today, due to the increasing cost of materials and labor, cost and construction time criteria are very important. In this study, the goal is to compare the total cost of a steel frame building with a fixed plan and different number of floors, as well as different gravity and lateral load-bearing systems, and to reach a criterion for selecting the best possible systems in the design of steel frame buildings with different numbers of floors. For this purpose, steel frame buildings with a fixed plan and a number of floors of 4, 6, and 8 floors and different gravity load-bearing systems including block joist, kermit, conventional composite, and steel deck roof systems, as well as different lateral load-bearing systems including two-way wind-braking, one-way wind-braking-one-way bending, and two-way bending systems, were modeled and designed using Etabs9.7.4 software.

After designing the models, the cross-sections and weight of the structural skeleton were obtained. Then, using the building price list, the cost of production and implementation of different models, including the cost of producing the skeleton and roof of the buildings, was calculated. Finally, the systems were ranked according to the cost of different models. After examining the results, it was observed that buildings with block joist roofs have the lowest construction costs. After this roof, buildings with kermit roofs, steel decks, and composite roofs are in the next ranks, respectively [14].

In 2017, Bakhshizadeh and Adib compared the construction time of steel frame buildings with a fixed plan, different number of floors, and different lateral load-bearing and roof systems [13]. Nowadays, due to the increasing cost of materials and labor, cost and construction time criteria are very important. In this research, the aim is to compare the production time and the finished construction of a steel frame building with a fixed plan and different number of floors, as well as different gravity and lateral load-bearing systems, and to reach a criterion for selecting the best possible systems in the design of steel frame buildings with different number of floors. For this purpose, steel frame buildings with a fixed plan and a number of floors of 4, 6, and 8 floors and different gravity load-bearing systems including block joist, kermit, conventional composite, and steel deck roof systems, as well as different lateral load-bearing systems including two-way wind-braking, one-way wind-braking-one-way bending, and two-way bending systems, were modeled and designed using Etabs9.7.4 software.

After designing the models, the cross-sections and weight of the structural skeleton were obtained. Then, using the price analysis of the building price list, the production and implementation time of different models, including the production time of the skeleton and roof of the buildings, was calculated. Finally, the systems were ranked according to the time of different models. After examining the results, it was observed that block joist roof systems require more time than other roofs. In comparing buildings with kermit roofs and steel decks, it was also observed that in 4-story buildings, buildings with steel deck roofs have less production and implementation time, and in 6- and 8-story buildings, buildings with kermit roofs have less production and implementation time [15].

2 | Research Scenarios

In this study, the evaluation of the possibility of using the type of roof in multi-story buildings in terms of quality, cost, and time has been considered and investigated. At the beginning of this chapter, research scenarios are presented, followed by an analysis of the samples. Categorizing roofs for study and review (Determining and categorizing options).

2.1 | Determining Criteria to Prioritize Options

I. Ranking of alternatives using the AHP method and AHP SOLVER software.

II. Technical and economic comparison of 2-, 5-, 10-, and 12-story structures with beam and block roofs using ETABS2000 software.

III. Technical and economic comparison of 2-, 5-, 10-, and 12-story structures with U-Boat and Kubiax roofs using ETABS2000 software.

IV. Technical and economic comparison of 2-, 5-, 10-, and 12-story structures with slab roofs using ETABS2000 software.

2.2 | Types of Roofs

I. Beam and block roof (Monolithic block).

II. Chromite beam ceiling.

III. Concrete slab roof (Flat slab or slab with beams).

IV. Composite roof.

V. Yobot roof.

VI. Kubiax roof.

4|Technical and Economic Comparison of 2-, 5-, 10-, and 12-story Structures with Beam and Block Ceilings Using ETABS2000 Software

This section examines and compares the technical and economic design of 2-, 5-, 10-, and 12-story structures with beam and block ceilings.In this regard, the mentioned structures were designed using the software method and ETABS2000 software, and finally the amount and percentage of weight increase of the mentioned structures with this roof system was investigated. The ground type was assumed to be 3 and the structural system was assumed to be of the bending frame type. The height of each floor was assumed to be 3 meters and the structure was assumed to be regular.

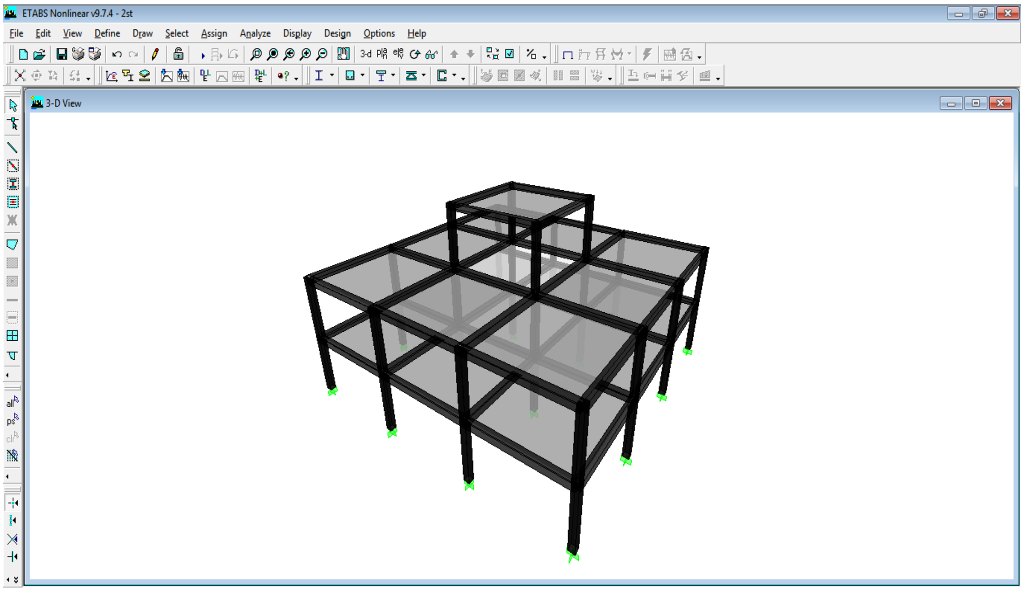

Fig. 1. 2-story concrete structure with a beam and block roof.

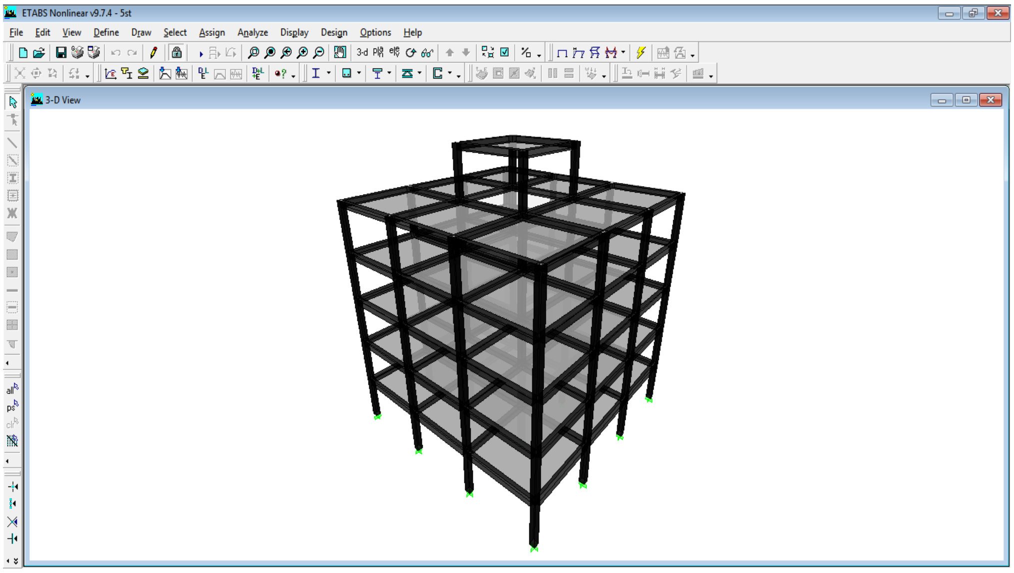

Fig. 2. 5-story concrete structure with a beam and block roof.

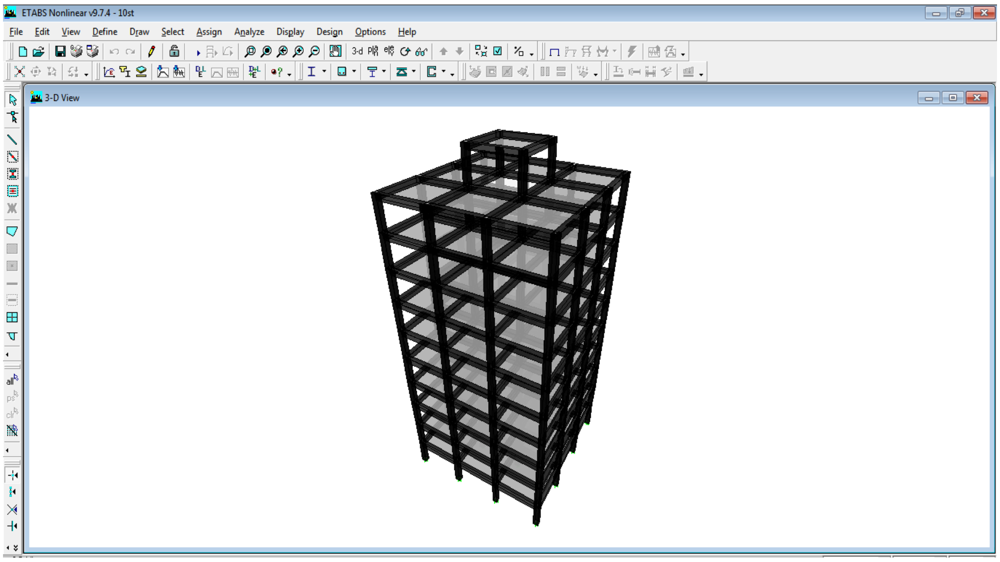

Fig. 3. 10-story concrete structure with a beam and block roof.

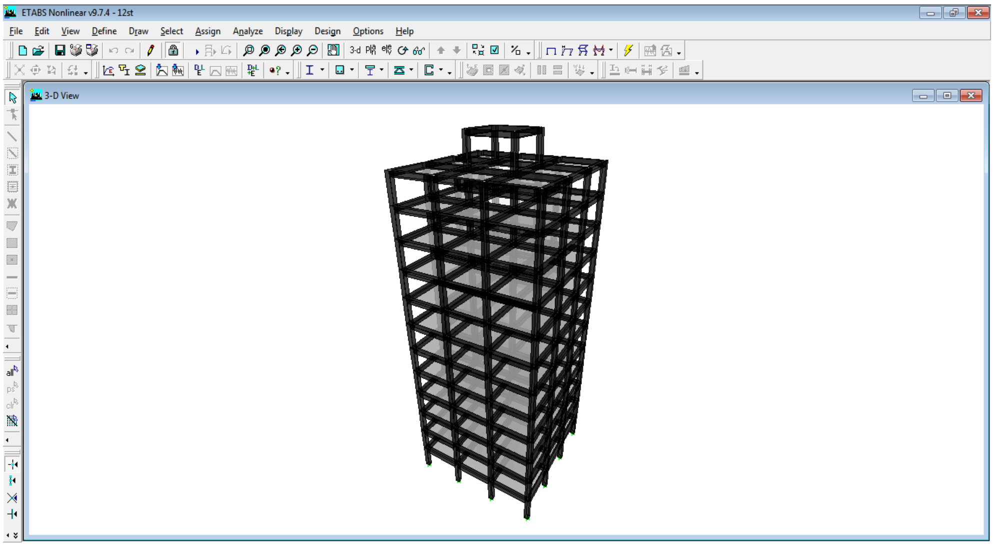

Fig. 4. 12-story concrete structure with a beam and block roof.

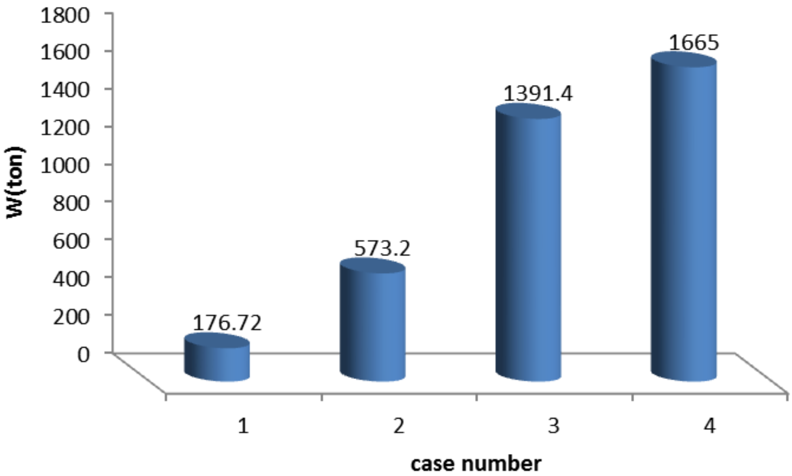

Fig. 5. Weight of optimized structures with different numbers of floors.

Weight of optimized structures of 2-, 5-, 10-, and 12 floors with beam and block roofs.As it was found, for the beam and block roof, after optimizing the 2-, 5-, 10- and 12-story structures, the weight of the 5-, 10-, and 12-story structures increased by 3.24, 7.87, and 9.42 times, respectively, compared to the 2-story structure.

6|Technical and Economic Comparison of 2-, 5-, 10-, and 12-story Structures with Slab Roofs Using ETABS2000 Software

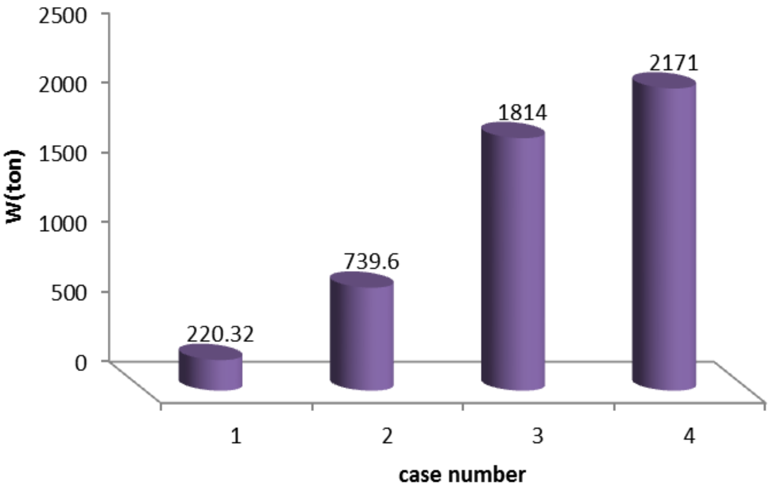

Fig. 6. Weight of optimized structures of 2, 5, 10, and 12 floors with concrete slab roof.

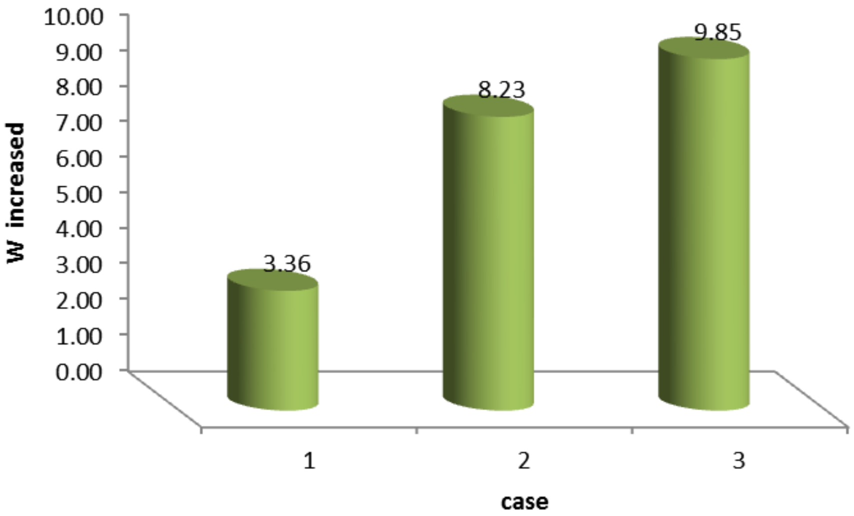

Fig. 7. Increased weight ratio for optimized 5-, 10-, and 12-story concrete structures compared to the optimized 2-story structure with concrete slab roof.

As it was found, for the concrete slab roof, after optimizing the 2-, 5-, 10-, and 12-story structures, the weight of the 5-, 10-, and 12-story structures increased by 3.36, 8.23, and 9.85 times, respectively, compared to the 2-story structure.

7|Technical and Economic Comparison of 2-, 5-, 10-, and 12-story Structures with a U-shaped Roof Using ETABS2000 Software

This section examines and compares the technical and economic design of 2-, 5-, 10-, and 12-story structures with a U-shaped roof. In order to model this type of roof, the slab thickness must first be estimated based on the selected span.

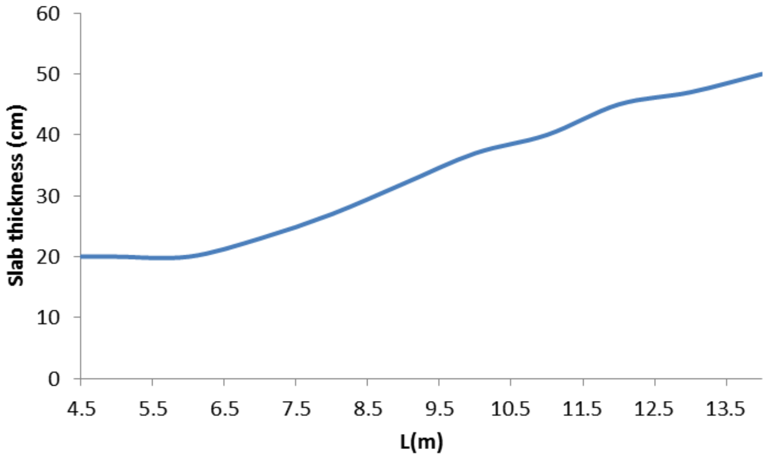

Fig. 8. Relationship between span length and required concrete slab thickness for a U-boat roof.

In *Fig. 8*, the roof load can be predicted based on the thickness of the concrete slab. Accordingly, for a span of 7.5 meters (Based on the dimensions of the structure, which is 15 meters by 15 meters, two spans of 7.5 meters are considered for the structure), the thickness of the concrete slab is considered to be 30 centimeters, based on which the weight of the roof part of the U-boat is considered to be 475 kg/m2. Explanation: For a ceiling thickness of 30 cm, the U16 form is used, for a ceiling thickness of 34 cm, the U20 form is used, for a ceiling thickness of 38 cm, the U24 form is used, for a ceiling thickness of 40 cm, the U26 form is used, for a ceiling thickness of 42 cm, the U28 form is used, and for a ceiling thickness of 46 cm, the U32 form is used.

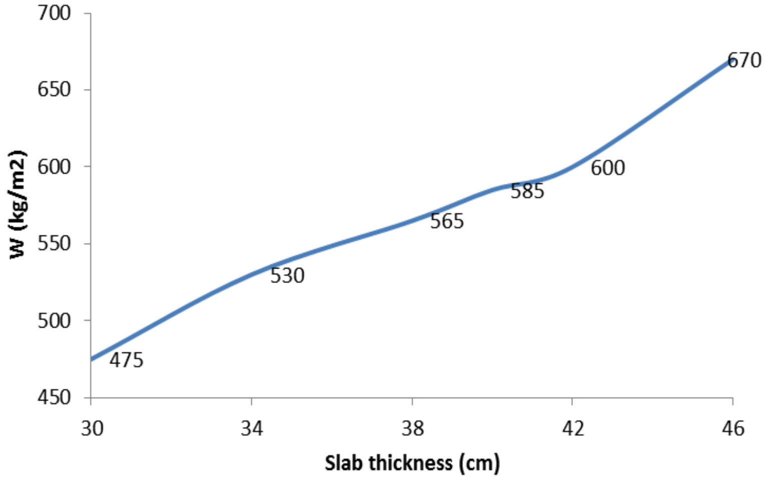

Fig. 9. Relationship between slab thickness and weight of U-boat roof.

In general, along with the many advantages of this type of roof system, there are also disadvantages to the U-shaped roof. Among these disadvantages is the necessity of implementing a lower flat formwork and implementing foundations to support the roof during the reinforcement, U-shaped tile, and concreting operations for the entire roof surface.

This problem is also present in the implementation of ordinary concrete slabs. Another problem with this type of roof is the breakage of poor quality U-Bot forms that have recently been produced by some profit-seeking companies, and it is occasionally seen that employers are deceived by the lower prices of these types of forms and use them in their projects.This type of formwork is subject to breakage and damage during construction, causing the empty space inside the formwork to fill. Based on the results obtained, the weight of the structure in this case (The case where the roof is of the U-shaped type)

It was reduced by up to about 30% compared to the concrete slab roof (As expected, this range is between 20 and 30%). For the 2- and 5-story structures, the ratio of structural weight reduction (Roof weight and its optimization and consequently the impact on the weight of the structure) was 20%, for the 10 story structure this ratio was 25%, and for the 12 story structure this ratio was 30%.

8 | Conclusion

In this study, the evaluation of the possibility of using the type of roof in multi-story buildings in terms of quality, cost and time was considered, and based on the AHP method and AHP SOLVER software, the roofs were ranked, and based on modeling and software methods and ETABS2000 software, technical and economic analysis was performed. Based on this, the following results were obtained: The results of the analysis showed that overall, the Kubiax and Ubot roofs, as two relatively new roofs, are ranked first and second. Given that the weights obtained for these two roofs are equal to each other, it can be considered that these two roofs are ranked first.

These two types of roofs have high implementation costs, but in terms of other items such as reducing the number of columns, rigidity, high resistance to incoming loads, and resistance to earthquakes and fires, etc., they are excellent options. All these advantages are valuable compared to the implementation cost of these types of roofs, and their implementation is recommended in construction projects. The beam and block roof with a weight of 0.174 is in second place. Considering that this roof has a special place for construction in most regions in terms of access to materials, high speed of implementation, local and traditional, well-known, and of course, its reasonable cost And it is applicable in all regions, so this type of roof is in a way in the second place. However, its rigidity is low compared to composite roofs and concrete slab roofs, and it is not recommended in tall buildings and structures with special and high loads and vibration loads caused by devices, etc., as well as irregular structures and long spans. In this case, using the third option, namely composite roof with an option weight of 0.141, can be considered a suitable option. Given that composite roof (Combination of concrete slab and steel beams) is used in steel structures (Of course, it is also used in concrete structures) However, the proper connection of the steel secondary beams to the main concrete beams of the structure is debatable and studies on its behavior are ongoing. Therefore, the concrete slab option with a weight of 0.135 is considered and used as a suitable option in concrete structures. In general, along with the many advantages of this type of roof system, there are also disadvantages to the U-shaped roof.

Among these disadvantages is the necessity of implementing a lower flat formwork and implementing foundations to support the roof during the reinforcement, U-shaped tile, and concreting operations for the entire roof surface. This problem is also present in the implementation of ordinary concrete slabs. Another problem with this type of roof is the breakage of poor quality U-Bot forms that have recently been produced by some profit-seeking companies, and it is occasionally seen that employers are deceived by the lower prices of these types of forms and use them in their projects.These types of forms are subject to breakage and damage during construction, causing the empty space inside the forms to be filled. Based on the results obtained, the weight of the structure in this case (The case where the roof is a U-shaped roof) was reduced by a maximum of about 30 percent compared to the concrete slab roof (As expected, this range is between 20 and 30 percent). For 2- and 5-story structures, the structural weight reduction ratio (Roof weight and its optimization and, as a result, the impact on the structural weight) was 20 percent, for 10-story structures this ratio was 25 percent, and for 12-story structures this ratio was 30 percent.

Acknowledgments

The authors would like to acknowledge the constructive perspectives provided during the manuscript evaluation, which contributed to improving the clarity of the comparative analysis and strengthening the interpretation of the results. The efforts of the editorial team in facilitating a structured and efficient review process are also appreciated.

Funding

This research was conducted without financial backing from any external organizations and was carried out through the authors' independent academic efforts.

Data Availability

The findings of this study are based on analytical evaluations performed using AHP methodology and related software tools. The input data, criteria weights, and model outputs can be made available by the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest that could have influenced the outcomes of this research.

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