Mathematical Modelling of Engineering Problems
Vol. 9, No. 2, April, 2022, pp. 343-350
Journal homepage: http://iieta.org/journals/mmep

Investigating the Optimal Design Variables of Concrete Slabs with Impact Resistance by Development a Multi-Objective Model to Save Cost-Time of Construction

Ahmed Kamil Al Kulabi*, Ali Adnan Al Zahid

Faculty of Civil Engineering, University of Kufa, Najaf 54001, Iraq

Corresponding Author Email: ahmedk.kadhim@uokufa.edu.iq

https://doi.org/10.18280/mmep.090207

Received: 11 January 2022
Accepted: 6 April 2022

Keywords:
concrete slab, impact load, construction cost, construction time, operation research

ABSTRACT

Globally, construction industry plays a key role in development of an economy of any country. On the other side, construction projects suffer extensive delays and cost overruns exceeding by that the budgeted money and the estimated time. Therefore, adopting techniques like optimization technique in construction media became a necessity for preventing the actual cost and execution time of projects from exceeding the planned cost and estimated time, respectively. Since, concrete is the most essential construction and the most used material in construction projects construction where it influences extremely gross domestic products of numerous nations in the world, a multi-objective mathematical model with mixed linear and binary constraints is developed to specify the optimal solution of differently designed concrete slabs to impact loads. Eight concrete slabs had various design parameters, such as concrete thickness, steel fiber ratio, reinforcement ratio, and steel stiffener thickness are used in this study. The mathematical model comprised two objective functions: minimization cost and time, and had a number of constraints like concrete ingredients, load, deflection, and weight. The outputs of the developed model revealed a variety of slab design combinations with different cost, time, and deadloads depending on the limitations of serviceability loads.

1. INTRODUCTION

Nowadays, infrastructure dominates and plays a primary role in the development of economic of nations. Needless to say that economic expansion and infrastructure growth go well together [1, 2]. In addition to its necessity in economy development, construction industry incentivizes growth in other sectors (e.g. it produces millions of jobs occasions and contributes exceedingly to the Gross Domestic Product worldwide) [3]. Construction projects provide the requisite needs of infrastructure like power, housing, water supply, etc. Thus, there is a need to develop and improve the infrastructure without stopping to meet demand and the continuous increase in population.

Anyhow, construction projects experience the global state, which is cost overruns and time delays. In fact, cost overruns and time retards in construction projects is a universal phenomenon [4, 5]. Numerous factors cause cost overrun in construction projects and can be grouped mainly into a number of groups, such as factors related to contract administration and project management, site management by contractor, communication, information, documentation, design, financial management, human resources, non-human resources, and environmental related factors [6]. While time delays can be related to factors like contract changes and modifications, quality high demand, and construction materials market rates [7]. This phenomenon caused by these factors results in negative consequences and leads to losing the reputation of the execution company in the construction media, disagreement, behind schedule completion, extending the project schedule, reducing the contractor's profit as a result to the increment in the project cost, lessening the chance of winning new projects in the future, and affecting the quality of the constructed project [8].

Competition in the construction industry has been increasing pointedly as a consequence to the slow growth in the globe economy, rising of rigid cost, inflation, and deflating of credit policy. The thing that calls for adopting a suitable cost management to deal with the prices sharp competition in the construction media [9]. Additionally, clients persistently desire execution projects in a high quality and high level of performance with decreasing costs and contracting execution time, confirming the necessity for developing and considering new techniques in the construction industry like optimization technique [10].

Recently, researchers have been applying a number of optimization algorithms to specify the optimum design of various structures. The main concern of the applied methods is cost reduction as the major objective [11]. It is obvious that cost optimization is one of the main factors to be well considered in construction projects. Alreshaid et al. [12] revealed that design- construction members are involved in performing the required analytical processes for projects cost optimization. Moreover, the maximum benefits of optimization can be obtained when the analytical procedures consider cost minimization of construction rather than weight at the earliest parts of projects life cycles [13].

In this study, technique of optimization is applied to find the optimal slab design with the least construction cost and best execution time. A multi-objective mathematical model with mixed linear and binary constraints is developed. Two objective functions are modelled: cost and time minimization.

Besides, a number of constrains are formulated in the developed model to comprise: cement, silica fume, sand, glenium, steel fiber, steel stiffener, and reinforcement available quantities in addition to total deadloads, impact load, and deflection. The model is developed by using the input data of eight slabs designed differently by varying a number of design parameters, such as slab thickness, steel fiber content ratio, steel stiffener thickness, and reinforcement ratio. The results of the developed model revealed a variety of slab design combinations with different cost, time, and deadloads outputs depending on the limitations of serviceability loads.

2. OPERATION RESEARCH

A detailed description of the developed mathematical model is illustrated in this section.

2.1 Objective function

For this study, two various objective functions are developed. The first objective function is the construction cost, and the second objective function to be optimised is the construction time. For this purpose, the cost of construction is calculated by defining three parameters, which are: weight of steel fiber and reinforcement, volume of concrete, and cost of labor of all of formwork, reinforcing, and casting. Both of the presented objective functions should be minimized. The prepared objective functions are introduced below in Eq. (1) through Eq. (4):

$$\text{Minimize } F_1 = f(C_{S,R}, C_C, C_{f,R,Ca}) \quad (1)$$

$$\text{Minimize } \sum_{i=1}^{N} C_{S,R} S_i + C_C\, S_i + C_{f,R,Ca}\, S_i \quad (2)$$

$$\text{Minimize } F_2 = f(T_f, T_R, T_{Ca}) \quad (3)$$

$$\text{Minimize } \sum_{i=1}^{N} T_f\, S_i + T_R\, S_i + T_{Ca}\, S_i \quad (4)$$

where, F_1 is the first objective function to minimize cost of construction, $C_{S,R}$ is the cost of steel fiber and reinforcement per slab in \$, C_C is the cost of concrete per slab in \$, $C_{f,R,Ca}$ is the cost of labor, including framing, reinforcing, and casting in \$, i is the slab design combination, S_i is the number of slab design combination no. i, N is the total number of slab design combinations, F_2 is the second objective function to minimize time of construction, T_f is the required time for framing per slab in hr, T_R is the needed time for reinforcement per slab in hr, and T_{Ca} is the demanded time for casting per slab in hr.

2.2 Constraints

In general, most of the engineering mathematical optimization problems comprise constraints that must be satisfied. For this paper, a number of constraints are set in the formulated model to ensure obtaining the optimal solution within the resources' availability and structural requirements. The set constraints for this study include the followings:

Cement Constraint: Eq. (5) is set to guarantee that quantity of cement needed to produce the required number of slabs will not exceed the available amount of cement.

$$\sum_i \mathrm{CE_i} \times \mathrm{S_i} \leq \mathrm{CE}\ \mathrm{i} \in \{1, \mathrm{N}\} \quad (5)$$

where, Ce_i is the quantity of cement per one produced slab type i in Kg, S_i is the number of produced slabs type i, and Ce is the gross obtainable cement amount in Kg.

Silic Fume Constraint: To produce the required number of slabs with considering the available total amount of silica fume, Eq. (6) is formulated for that purpose.

$$\sum_i \mathrm{SF_i} \times \mathrm{S_i} \leq \mathrm{SF}\ \ \mathrm{i} \in \{1, \mathrm{N}\} \quad (6)$$

where, SF_i is the silica fume quantity per one produced slab type i in Kg, and SF is the gross available amount of silica fume in Kg.

Sand Constraint: This constraint is formulated to take into account the gross obtainable quantity of sand as expressed in Eq. (7).

$$\sum_i \mathrm{SA_i} \times \mathrm{S_i} \leq \mathrm{SA}\ \mathrm{i} \in \{1, \mathrm{N}\} \quad (7)$$

where, SA_i is the quantity of sand per one produced slab type i in Kg, and SA is the total available amount of sand in Kg.

Glenium Constraint: is developed to set the maximum availability of glenium as illustrated in Eq. (8).

$$\sum_i \mathrm{GL_i} \times \mathrm{S_i} \leq \mathrm{GL}\ \mathrm{i} \in \{1, \mathrm{N}\} \quad (8)$$

where, GL_i is the quantity of glenium per one produced slab type i in kg, and GL is the gross obtainable amount of glenium in kg.

Steel Fiber Constraint: This constraint is about adjusting the required quantity of fibers for slabs production to be within the maximum attainability limits, as modelled in Eq. (9).

$$\sum_i \mathrm{ST_i} \times \mathrm{S_i} \leq \mathrm{ST}\ \mathrm{i} \in \{1, \mathrm{N}\} \quad (9)$$

where, ST_i is the quantity of steel fiber per one produced slab type i in kg, and ST is the overall available amount of steel fiber in kg.

Steel Stiffener Constraint: To specify the effect of steel plates obtainability on the optimal solution, Eq. (10) is formulated.

$$\sum_i \mathrm{SS_i} \times \mathrm{S_i} \leq \mathrm{SS}\ \mathrm{i} \in \{1, \mathrm{N}\} \quad (10)$$

where, SS_i is the steel plates quantity per one produced slab type i in kg, and SS is the overall available amount of steel plates in kg.

Reinforcement Constraint: The overall obtainable amount of reinforcement is also a necessity to be considered and investigated. Therefore, Eq. (11) is set to figure out the importance of reinforcement availability on slabs total cost and time of construction.

$$\sum_i \mathrm{RE_i} \times \mathrm{S_i} \leq \mathrm{RE}\ \ \mathrm{i} \in \{1, \mathrm{N}\} \quad (11)$$

where, RE_i is the quantity of reinforcement per one produced slab type i, in kg, and RE is the overall available amount of reinforcement in kg.

Weight Constraint: Weight of each slab design combination is taken into account as well by formulating Eq. (12). This constraint is necessary to not exceed the maximum allowable load of the produced slabs.

$$\sum_i \mathrm{WE_i} \times \mathrm{S_i} \leq \mathrm{WE}\ \mathrm{i} \in \{1, \mathrm{N}\} \quad (12)$$

where, WE_i is the amount of weight per one produced slab type i in Kg, and WE is the total allowable load in kg.

Load Constraint: Impact load of each slab design combination is set as a constraint to meet the structural requirements. For that purpose, Eq. (11) is developed.

$$L_i \times S_i - M \times S_i \geq 0 \quad i \in \{1, N\} \quad (13)$$

where, L_i is the amount of impact load per one produced slab type i in kN, and M is the minimum required load in kN.

Deflection Constraint: Deflection of the investigated slab design combination is adopted as well. Eq. (14) is formulated to set deflection of the studied design combinations as constraint.

$$D_i \times S_i - N \times S_i \leq 0 \quad i \in \{1, N\} \quad (14)$$

where, D_i is the amount of deflection per one produced slab type i in mm, and N is the maximum specified deflection in mm.

Total Number: Total required number of slabs should be specified to get minimum cost and time as outputs. Eq. (15) is set to appoint the minimum required number.

$$\sum_i S_i \geq TN \quad i \in \{1, N\} \quad (15)$$

where, TN is the total required number of slabs to be produced.

Other Constraints: Other constraints are needed to get the developed model work as required. These constraints are binary integer constraints as illustrated in Eq. (16).

$$S_i - K_i \times B_i \leq 0 \quad i \in \{1, N\} \quad (16)$$

where, K_i is the maximum value of S_i, and B_i is the binary variable to ensure that if S_i> 0, then Bi.

3. TECHNIQUE OF SOLUTION

The most recognizable difference between single and multiple objective optimization problems is the optimal solution of the single objective problems is easily specified among the other solutions by comparing the values of the objective function. While, the superiority solution of the multiple objective problems is defined by the dominance. Hence, in the multiple-objective optimization, there would be Pareto-optimal set, which is a non-dominated set of the whole space of feasible region. Moreover, non-dominated set can be defined as a set of the not dominated solutions by any member of the solution set [14].

Therefore, there is a need to adopt a number of techniques to solve multiple objective function optimization problems. Jaimes et al. [15] defined a number of techniques for solving multiple objective optimization problems as listed and summarized:

The Weighted Sum Technique: It is one of the most conjectural techniques to solve problems with multiple objective functions. The main approach of this technique is to weight the multiple objectives with positive weight wi > 0, and then to optimize a weighted sum of multiple objective functions by adopting one of the used methods for solving single objective problems. In this technique, finding the total optimal Pareto-solutions is guaranteed.

The Goal Programming Technique: It is the most considered technique in the mathematical programming when there is no way to meet a number of constraints. In this technique, there would be multi-goals like objectives for which it is desired to meet a number of targets.

The ε-Constraint Technique: By this technique, the multiple objective optimization problem is solved by keeping one function as objective function and restricting the other objective functions. What differentiates this technique from the previous ones is applicable to both convex and non-convex optimization problems.

For this study, the developed multi-objective model is solved by adopting the ε -constraint technique. Accordingly, cost minimization function is kept as objective function of the mathematical model with restricting time objective minimization function. After that, the whole model is re-written in LINDO 6.1 software to get the outputs of the mathematical model.

4. TESTED SAMPLES AND RESULTS

Eight various slab design combinations with (80×80) mm dimensions designed by Muteb et al. [16] to provide a resistance to impact loads are used for this study as shown in Figure 1. The utilized design combinations had different design parameters, such as slab thickness, steel fiber ratio, reinforcement ratio, and steel stiffener thickness. The studied slabs are designed to provide a resistance to impact loads with a range of (5-7) kN.

These slabs are tested practically after locally manufacturing the needed apparatus for impact test performance by Muteb et al. [16], see Figure 2. The impact test is performed by freely falling a mass with a weight of 5 kg on the center of the top face of all slab design combinations. Hence, a steel ball of 5 kg weight is freely dropped from a height of 120 cm on the top face of all design combinations and for one time only as shown in Figure 2. The impact load and the corresponding mid-span deflection of all slab design combinations are recorded and used as input data in the developed model. The mix ratio that was put to use for casting the slab design combinations is included in Table 1. Based on that, cost and time of casting each design combination are estimated. The ingredients quantities required for cast each slab design combination are calculated by considering the mix ratio and dimensions of each design combination. Cost of each slab includes cost of concrete ingredients, cost of steel fiber, cost of reinforcement, cost of labor, cost of rebar work and formwork. Citing a number of concrete materials suppliers, carpenters, and rebar workers is conducted to get as accurate cost as possible. In addition, time of labor for casting every slab design combination is performed since various slab thicknesses and other different variables are comprised in this study, causing a variety in the cast time.

Figure 1. Slab design combinations

Table 1. Mix ratio of the design combinations

Cement (kg/m³)	Silica fume (%)	Sand (kg/m³)	Glenium 54 (%)	Steel fiber (%)	W/C (%)
920	15	946.8	4	0.5	23

Figure 2. Impact test apparatus

In this paper, three case studies are studied by using the eight slab design combinations as input data after grouping them into three main groups; each group had four slab combinations. Grouping process was conducted on the basis of serviceability loads requirements. In other words, samples of each group were selected depending on the minimum required impact load, and the maximum demanded deflection. Succeeding that, the optimization is performed on each group to find out the optimal slab design combination with the least cost, time, and weight as sought by designers of these slabs.

4.1 First case study

For this case, the minimum required impact load is 6 kN, and the maximum corresponding deflection is 0.55 mm. Optimization process is performed on four slab samples to get the optimal solution: least cost, best time, and least weight with meeting the required serviceability loads. The investigated slab samples are: design combination no. 2, S2, had 60 mm thickness and 0.5% steel fiber as shown in Figure 3, design combination no. 3, S3, had 80 mm thickness and 0.5% steel fiber, design combination no. 6, S6, had 40 mm thickness, 0.5% steel fiber, and 1 mm steel stiffener, and design combination no. 7, S7, had 40 mm thickness, 0.5% steel fiber, and 2 mm steel stiffener. In the design combination S6 and S7, two steel plates with thickness of 1 mm and 2 mm, respectively, were put on the bottom face of the slabs. The steel plates were installed by using epoxy ET-HP and put on the slab to constitute plus shape as shown in Figure 4. Therefore, in this case, the parameters: slab thickness and steel stiffener with existing steel fiber are searched to specify their influences on the final cost, time, and weight of slabs construction. The estimated total cost (including cost of concrete ingredients, steel fiber, steel stiffener, epoxy, and cost of labor) for the slab design combinations S2, S3, S6, and S7 per one cubic meter is $480.352, $643. 44, $766.5, and $783. 984, respectively. The estimated total time for the slab design combinations S2, S3, S6, and S7 per one cubic meter is 7.03 hr, 9.38 hr, 4.69 hr, and 4.69 hr, respectively.

The total required quantity of slabs was assumed to be 10000, and after running LINDO the outputs of optimization after performing 78 iterations showed that slabs S2 and S6 are the optimal slabs in quantities of 338 and 9662, respectively. The amount of objective function no. 1 and 2 is $193532 and 1220 hr, respectively. The corresponding total weight for the obtained cost and time is 540000 kg. The minimum obtained impact load is 6.18 kN, and the maximum deflection is 0.521 mm. Next, after conducting a number of trials on the model by decreasing the maximum allowable weight, it was noticed that decreasing weight by 2.41% led to increasing cost by 1.25% and decreasing time by 1.63%. Figures 5-7 illustrate the relation between cost, time, and weight for the slab design combinations S2, S3, S6, and S7.

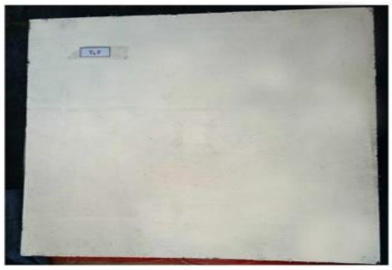

Figure 3. Slab design combinations S2 and S3

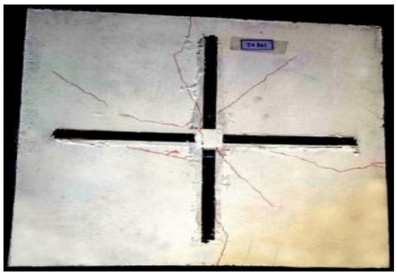

Figure 4. Slab design combinations S6 and S7

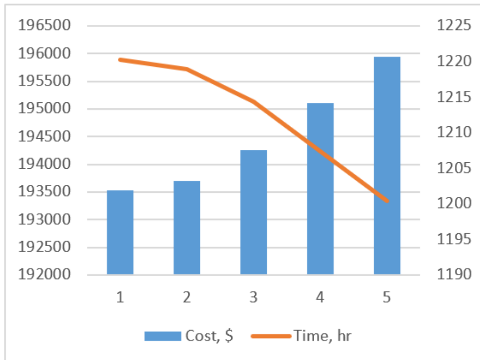

Figure 5. Cost and time relationship of the slab design combinations S2, S3, S6, and S7

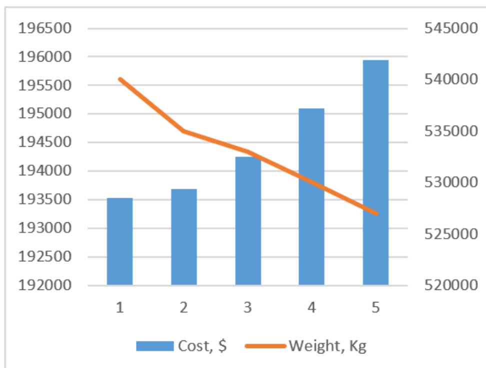

Figure 6. Cost and weight relationship of the slab design combinations S2, S3, S6, and S7

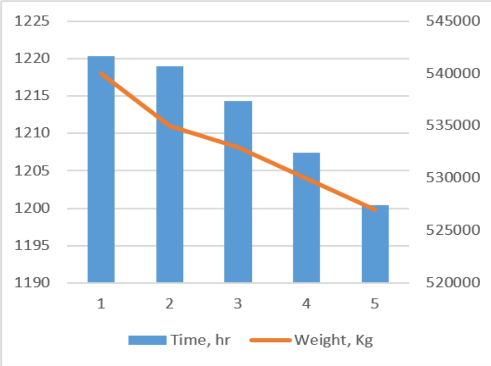

Figure 7. Time and weight relationship of the slab design combinations S2, S3, S6, and S7

4.2 Second case study

In this case, the minimum allowable impact load is 6 kN, and the maximum acceptable deflection is 1.2 mm. For this case, four samples of slabs are used as input data to obtain the optimal solution, which are least cost, best time, and least weight with satisfying the serviceability loads. The modeled four slabs for this case are: design combination no.1, S1, had 40 mm thickness and 0.5% steel fiber, design combinations no. 6 and 7, S6 and S7, with details explained in case no.1, and design combination no.10, S10, had 40 mm thickness, zero percent of steel fiber, and two layers of reinforcement with 6 mm diameter and distributed at 100 mm c/c as illustrated in Figure 8.

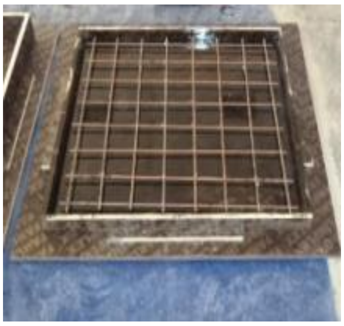

Figure 8. Slab design combinations S10

In this case, the parameters: steel stiffener and reinforcement with and without existing of steel fiber are explored to find out their effect on specifying the cost, time, and weight of construction. The estimated total cost per one cubic meter (including cost of concrete ingredients, steel fiber, steel stiffener, epoxy, reinforcement, and cost of labor) of the slab design combination S1 and S10 is $320.4 and $447.07, respectively. The estimated total time of the slabs S1 and S10 per one cubic meter is 4.69 hr and 8.59 hr.

After setting the required total quantity, which is the same in the first case, LINDO was run. The outputs of the run model after performing 10 iterations showed that the slab S10 is the optimal slab design combination. The amount of objective function no. 1 and 2 is $114000 and 2200 hr, respectively. The corresponding total weight is 550000 kg. The minimum achieved impact load is 7.8 kN, and the maximum deflection is 1.144 mm. Moreover, lowering the maximum acceptable limit of weight for this case by 3.64% resulted in increasing cost and decreasing time of construction by 62% and 39.2%, respectively. Figures 9-11 show the relation between cost, time, and weight for the slab design combinations S1, S6, S7, and S10.

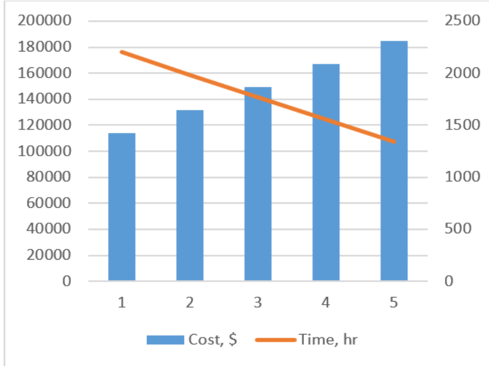

Figure 9. Cost and time relationship of the slab design combinations S1, S6, S7, and S10

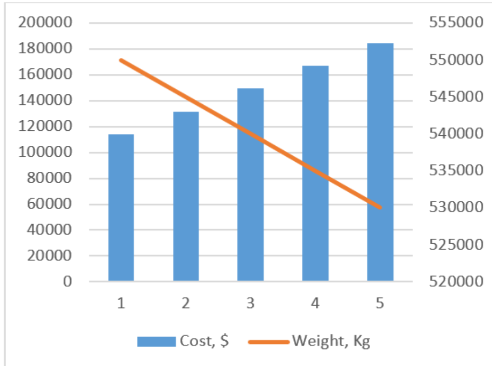

Figure 10. Cost and weight relationship of the slab design combinations S1, S6, S7, and S10

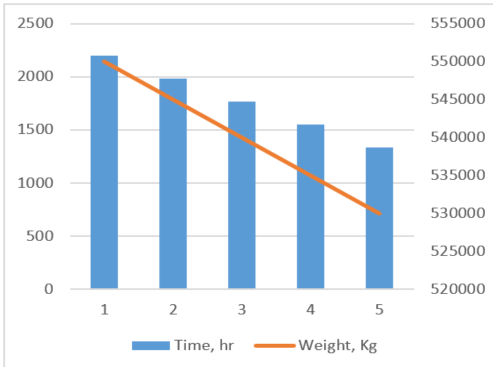

Figure 11. Time and weight relationship of the slab design combinations S1, S6, S7, and S10

4.3 Third case study

The minimum allowed impact load and the maximum permitted deflection for this case are 6.5 KN and 0.3 mm, respectively. The used slab design combinations for this case are design combinations no. 2 and 3 with details mentioned in case no. 1, design combination no. 4, S4, had 40 mm thickness and 1% steel fiber, design combination no. 5, S5, had 40 mm thickness and 2% steel fiber. In this case, the examined parameters are slab thickness and steel fiber ratio to know their impact on the total cost, time, and weight. The estimated total cost and time per one cubic meter of the slabs S4 and S5 are $325.625, $335.55, 4.69 hr, and 4.69 hr, respectively.

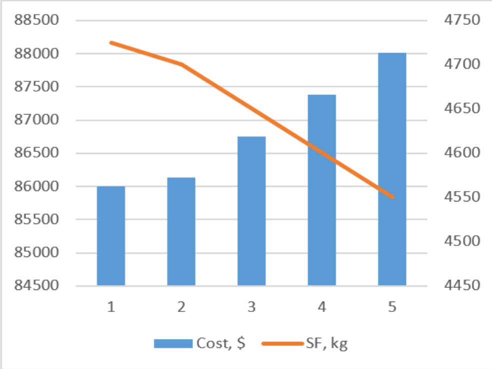

Figure 12. The relationship between cost and SF availability of the slab design combinations S2, S3, S4, and S5

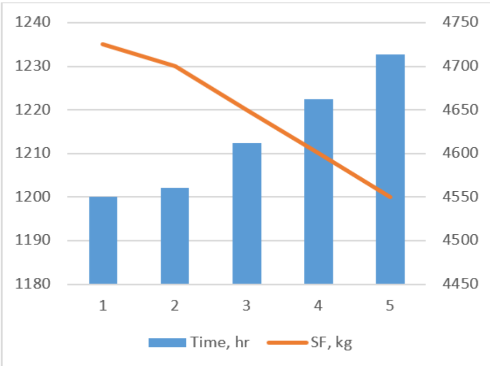

Figure 13. The relationship between time and SF availability of the slab design combinations S2, S3, S4, and S5

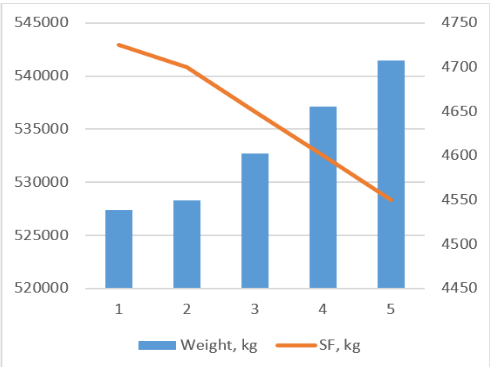

Figure 14. The relationship between weight and SF availability of the slab design combinations S2, S3, S4, and S5

After running LINDO, the outputs revealed that the slab S5 is the optimal one after performing 10 iterations. The objective function amounts of no.1 and no.2 are $86000 and 1200 hr, respectively. The total weight is 527400 kg. The minimum obtained impact load and maximum deflection for this case are 6.93 kN and 0.291 mm, respectively. Next, for this case, the maximum achieved weight was lowered to check its effect on cost and time, but the same outputs were obtained. The major reason for this is the main dominator in controlling cost, time, and weight in this case is steel fiber availability. Lowering steel fiber availability by 3.7% led to increasing all of cost, time, and weight of construction by 2.3%, 2.7%, and 2.7%, respectively. Figures 12-14 show the relation between steel fiber availability with all of cost, time, and weight for the slab design combinations S2, S3, S4, and S5.

5. RESULTS DISCUSSION

Three case studies are researched in this study by running a developed model with two objective functions: minimization cost and time of construction. The set objective functions are restricted by a number of constraints like ingredients quantities, minimum impact load, maximum deflection, and deadloads. The input data of the developed model comprised details of eight design combinations with a variety of design parameters, such as slab thickness, steel fiber ratio, thickness of steel stiffener, and reinforcement. Hence, what was intended from developing such a model is saving cost and time of construction, reducing deadload of the construction elements, and satisfying the structural requirements. The explored case studies had different structural requirements, and at the same time different outputs of cost, time, and DEA load were obtained.

Regarding cost of construction, the achieved amount of construction cost in the three case studies are $193533, $114000, and $86000, respectively, see Figure 15. Therefore, the lowest cost was obtained in the third case study, although higher requirements of serviceability loads are demanded in this case comparing with the requirements in the case studies no. 1 and 2. Based on that, the saved money in the case studies no.1 and no.2 by considering cost in case no.3 as a reference is $107533 and $28000, respectively.

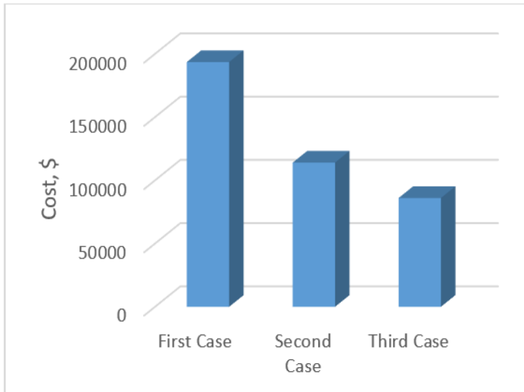

Figure 15. Cost of construction in the three case studies

Concerning time of construction, the least provided time was in case no. 3. The amount of time in the three cases are 1220, 2200, and 1200 hr as shown in Figure 16. The saved time in hours in the case studies no.1 and no.2 with taking case no.3 as a reference is 20 and 1000, respectively.

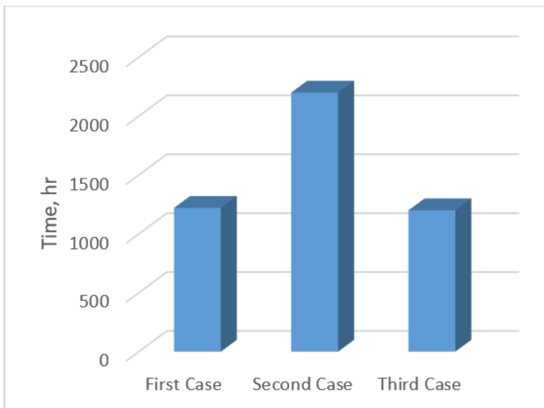

Figure 16. Time of construction in the three case studies

Referring construction deadload, in the case no.3, the least deadload was provided. The amount of deadload in kilogram in the three case studies are 540000, 550000, and 527400, respectively, see Figure 17. Therefore, the saved amount of construction deadload in the cases no. 1 and 2 in kilogram is 12600 and 22600, respectively.

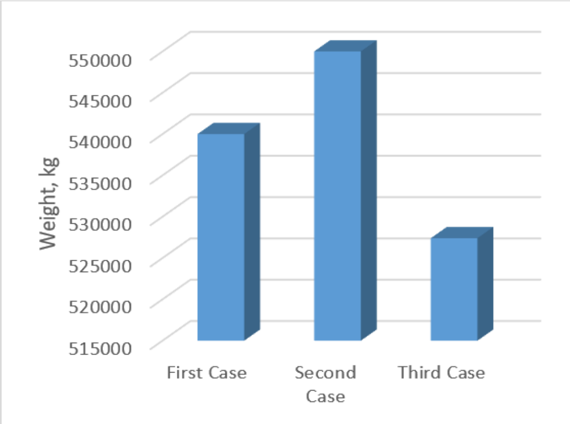

Figure 17. Weight of construction in the three case studies

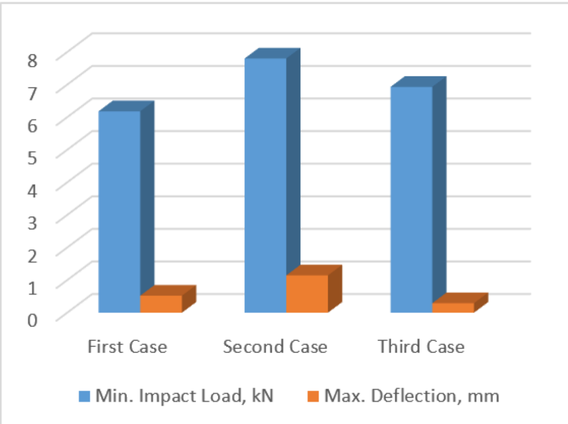

Figure 18. Impact load and deflection in the three case studies

Impact load and deflection, the least amount of deflection was provided in the case no. 3. The amount of deflection in the three cases in millimeter are 0.521, 1.144, and 0.291, respectively. In case no.3, the provided load was the second highest load as shown in Figure 18. The impact load in the three cases in kilonewton is 6.18, 7.8, and 6.93, respectively.

As it is clear from the previous results that the optimal design parameter that provides the least cost, time, and deadload of construction with providing almost the highest impact load and least deflection is steel fiber ratio of 2%. Usage steel fiber in enough percentage in concrete neglects the need for increasing slab thickness, usage steel stiffener, and disregards the necessity for reinforcement. While design parameters: reinforcement and slab thickness with steel fiber showed less optimality with variable outputs of cost, time, and weight depending on the maximum permitted limit of weight.

6. CONCLUSION

Construction industry is a fundamental contributor to the development of countries, but at the same time, executed projects in this sector usually consume more money than the planned money and need more time than the estimated one. These frequently faced problems in construction media by the involved parties in projects construction who are owners, contractors, and architects call for considering techniques, such as optimization technique, to complete projects execution within the budgeted money and specified days in projects contract. For that purpose, a multi-objective mathematical model with linear and binary constraints is developed to specify the optimal design parameters of a number of concrete slabs with different design parameters. Eight concrete slabs that are designed to provide a resistance to impact loads were considered for this study. The investigated slabs had different design parameters, such as different slab thicknesses, steel fiber contents, steel plates thicknesses, and reinforcement. All slabs were subjected to impact load from the same height and by the same weight to record their strength to impact loads and their deflection values. After that, the explored slabs were deeply studied and quantified to specify their ingredients quantities and their construction cost and time. Then, the obtained input data and the developed model were run in LINDO 6.1 software to recognize the optimal design parameters. The outputs of the run software showed that steel fiber content and steel fiber availability play an essential role in specifying slabs construction cost. Time, and weight. Steel fiber content led to avoiding the need to increasing slabs thickness, using steel plates, and/or providing a substitute to reinforcement with meeting the structural requirements. The thing that results in reducing slabs dimensions, slabs concrete ingredients, and slabs weight, consequently savings in cost, time, and weight of construction are achieved. Therefore, when steel fiber availability is reduced, an increment in cost time, and weight was noticed.

REFERENCES

[1] Yavari, M.S., Du, G., Pacoste, C., Karoumi, R. (2017). Environmental impact optimization of reinforced concrete slab frame bridges. Journal of Civil Engineering and Architecture, 11(4): 313-324. https://doi.org/10.17265/1934-7359/2017.04.001

[2] Shabbab Al Hammadi, M. (2016). Study of delay factors in construction projects. International Advanced Research Journal in Science, Engineering and Technology, 3(4): 87-93. https://doi.org/10.17148/IARJSET.2016.3420

[3] Nyantakyi, E.K., Obiri-Yeboah, A., Obeng-Ahenkora, N.K., Domfeh, M.K., Mohammed, G.A. (2020). Investigating occupational health and safety of workers on selected construction sites in the Sunyani Municipality, Ghana. Journal of Safety Engineering, 9(1): 1-8. https://doi.org/10.5923/j.safety.20200901.01

[4] Sambasivan, M., Soon, Y.W. (2007). Causes and effects of delays in Malaysian construction industry. International Journal of Project Management, 25(5): 517-526. https://doi.org/10.1016/J.IJPROMAN.2006.11.007

[5] Koushki, P.A., Al-Rashid, K., Kartam, N. (2005). Delays and cost increases in the construction of private residential projects in Kuwait. Construction Management and Economics, 23(3): 285-294. https://doi.org/10.1080/0144619042000326710

[6] Abusafiya, H.A., Suliman, S.M. (2017). Causes and effects of cost overrun on construction project in Bahrain:

Part I (ranking of cost overrun factors and risk mapping). Modern Applied Science, 11(7): 20-27. https://doi.org/10.5539/MAS.V11N7P20
[7] Assaf, S.A., Al-Hejji, S. (2006). Causes of delay in large construction projects. International Journal of Project Management, 24(4): 349-357. https://doi.org/10.1016/j.ijproman.2005.11.010
[8] González-Vidosa, F., Yepes, V., Alcalá, J., Carrera, M., Perea, C., Payá-Zaforteza, I. (2008). Optimization of reinforced concrete structures by simulated annealing. Simulated Annealing, Vienna, Austria, pp. 307-320.
[9] Tang J., Zhang M., Tang H., Chen Y. (2015). Research on cost management of construction project based on activity-based costing. In International Conference on Civil, Materials and Environmental Sciences. pp. 51-54. https://dx.doi.org/10.2991/cmes-15.2015.15
[10] Barbole, A.N., Nalwade, Y.D., Parakh, S.D. (2013). Impact of cost control and cost reduction techniques on manufacturing sector. Indian Streams Research Journal, 3(5): 1-8.
[11] Yavari, M.S., Pacoste, C., Karoumi, R. (2016). Structural optimization of concrete slab frame bridges considering investment cost. Journal of Civil Engineering and Architecture, 10(9): 982-994. https://doi.org/10.17265/1934-7359/2016.09.002
[12] Alreshaid, K.H., Mahdi, I.M., Soliman, E. (2004). Cost optimization of reinforced concrete elements. Asian Journal of Civil Engineering (Building and Housing), 5: 161-174.
[13] Sarma, K.C., Adeli, H. (1998). Cost optimization of concrete structures. Journal of Structural Engineering, 124(5): 570-578. https://doi.org/10.1061/(ASCE)0733-9445(1998)124:5(570)
[14] Deb, K. (2011). Multi-objective optimisation using evolutionary algorithms: An introduction. In Multi-Objective Evolutionary Optimisation for Product Design and Manufacturing, pp. 3-34. https://doi.org/10.1007/978-0-85729-652-8_1
[15] Jaimes, A.L., Martınez, S.Z., Coello, C.A.C. (2009). An introduction to multiobjective optimization techniques. Optimization in Polymer Processing, pp. 29-57.
[16] Muteb, H.H., Habeeb, G.M., Al Zahid, M.A.A. (2012). Experimental investigation of reactive powder concrete slab with steel stiffener under impact load. International Journal of Civil and Structural Engineering, x(x): 259-272.