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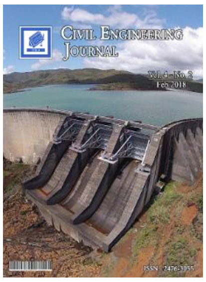

Technical Evaluation of Integrated Wall and Roof Formwork System and Its Comparison with Ordinary Concrete Building Construction Method

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Abstract

Nowadays, the development of construction industry is one of the development indices of countries. On the other hand, development of construction industry is more urgent than ever with increased population and consequently, increased desire for urbanization. Considering the inadequacy of traditional and conventional systems for mass housing production, the approach to use modern industrial methods of building along with new technology and observance of the latest technical standards is critical. Therefore, the present study aimed to investigate and compare construction method of reinforced concrete cast in-situ walls and slabs with the conventional method of constructing concrete structures using MSP software. Studies show that the integrated wall and ceiling molding technique has been used since the late 1970s in the construction of high-rise residential towers. Currently, integrated wall and ceiling molding system is used as one of the methods in the construction of buildings with load-bearing wall and concrete ceiling. This method brings about improvements in quality, earthquake resistance, reduced run-time, reduced cost, quick return on investment, saving on materials consumption, reduced labor, eco-friendliness, sustainability and longer durability, reduced resource consumption, integrated structure, fire resistance, high flexibility, and employee safety.

Keywords: Monolithic Concrete System; Modern Technology; MSP Software.

1. Introduction

With the end of the WWII, the first problem countries faced war devastations. The extent of the destruction was so high that it was not possible to provide the housing needed by the war-torn and homeless people easily. At this time, industrial countries thought of producing housing as well as other industrial goods in a massive and industrial manner, a method that could help countries pass from the housing crisis [1].

As one of the pioneers of industrialization, Japan was the first country to manufacture housing in an industrial way. According to the US Department of Housing and Urban Development, at the end of the twentieth century, Japan was qualitatively and sometimes quantitatively the world's first-grade industrial country. Of course, Japan has made several plans to achieve its goals in the field of housing industrialization, one of the most interesting of which was the reduction of units' size by construction of units of 20 square meters in the years after WWII. The infrastructure of the units gradually increased proportionately with the improvement of the economic situation. In addition, Japan provided the context for massive housing companies with long-term bank loans. By developing comprehensive plans, it managed to construct 30 million residential units in 1965 [1].

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Moving towards industrialization requires the parallel progress of all industries. Here, as an ancient industry, the construction industry requires special attention since huge sums of national capital are spent on it each year, However, it has not made significant progress compared to other industries [2].

The global experience has shown that when a large number of buildings and housing is needed, mass production in the industrial ways can only be achieved targeting, planning, managing and coordinating growth of the affiliated industries. Industrialization is a relatively time-consuming process, which requires long-term engineering-cultural thinking, and is a policy that everybody must work to expand [3].

2. Literature Review

Due to the implementation of raft foundation as well as the lower weight of the structure in this system, the structure can be erected where the soil features smaller load-bearing capacity [4]. Due to the integration of the roof and wall in the integrated roof and wall formwork system, its seismic performance is better than the concrete structures constructed based on common methods [5]. The performance of this system is about 55% to 80% better than the other ordinary systems of concrete structures' construction in earthquakes [6]. Due to its integrated performance, the increase in the structure's degree of uncertainty and greater delay in the formation of the plastic hinges in the members and, resultantly, the higher capability of tolerating the forces and buckling, the integrated roof and wall formwork system delivers an appropriate performance in earthquake [7]. The investigation of the behaviors of the structures constructed based on integrated roof and wall formwork system in 6.7-Richter earthquake in San Fernando, the US, in 1971 and 7.8-Richter earthquake in Chile in 1985 indicated that the buildings constructed based on this system have sustained the lowest damage in contrast to the commonly built concrete buildings [8].

The researches carried out regarding the integrated roof and wall formwork system suggest that the implementation of such systems can bring about reductions in construction time and cost, lower masonry wastes, more consistency with the environment and a more precise prediction of the costs [9]. Also, the fast and easy instruction capability of these systems to the human resources, saving in the consumed resources, reduction of the human resources volume, decrease in stagnancy of the capital and more rapid return on capital are enumerated inter alia the advantages of these systems [10]. The reduction in the human resources and appropriate thermal and acoustic performance are amongst the other advantages of this system [11]. The other researches are indicative of the idea that the system causes a reduction by 13% in the number of the laborers [2] and decreases the time duration of utilizing tower crane [12]; moreover, a reduction by 30% can be brought about in the masonry materials wastes [13].

In case of exercising a proper management style, an 80-percent saving can be witnessed in the construction time [14]. The system causes an increase in the safety and reduction of the execution risks as compared to the ordinary methods of concrete structure construction [15]. In this system, a 300-m2 storey can be built only in two days [16]. Also, the system can be implemented with a brief instruction of the vernacular workforce who can subsequently build a storey in one day [17]. In France, it took only 640 hours to build 65 building blocks each with 20 apartment units, 120 square meters in area, for the total construction of which about 40000 cubic meter of concrete was consumed [18]. Due to the same reason, the system drew the attentions of the majority of the mass-constructors in Nigeria [19].

The masonry use of the system is about 15% to 22% lower than the customary concrete skeletons. According to the fact that the internal and external walls are erected in an integrated manner, there will be no need for brick-laying in such a manner that about 62% reduction in time will be brought about in a five-storey building in comparison to the ordinary concrete structures in which brick-laying is an integral part [20]. In this method, the walls are made thicker and the useful spaces of the buildings are wider [21]. The wall thicknesses can be increased up to 100 mm [22] as a result of which the structure weight will be decreased considerably [23]. In integrated wall and roof formwork system, the concrete and rebar uses, on average, are 0.5 cubic meter and 35 kg/m2 to 40 kg/m^2 of the foundation, respectively [3]. Also, the system offers a good performance against water infiltration to the building [24] and it delivers a good consistency to the various climatic conditions [25].

In this system, the walls' surfaces are perfectly smooth [26]. The formwork enjoys a long useful life due to its being properly utilized and they can even be applied in numerous and later projects [27]. These formworks can be reportedly used for a thousand times [28]. The increase in the building's life and reduction of masonry wastes are inter alia the other merits of the integrated roof and wall formwork [29]. The increase in the building life to about 200 years and a 15 to 20-percent reduction in the building weight in contrast to the customary concrete structure construction methods are amongst the other benefits of this industrial method [30]. Of course, the system only suffers from the high price of the formwork and the impossibility of making changes in the structure during the formwork installation; furthermore, the construction of units in few numbers is not economically justified [31]. The implementation of the method for a number of units lower than 500 is not cost-effective [24].

3. Methodology

Library research was the method of choice to gather the data required in the current research paper. The data collection instrument has been the use of the extant information and documents. The present study firstly makes use of a descriptive method to analyze the qualitative data and explore the integrated wall and roof formwork system and then the acquired workshop information and the structural maps of a nine-storey concrete building will be employed as inputs to MSP software. In the end, a comparison will be made based on the data and outputs of MSP software between the integrated wall and roof formwork system and the customary concrete structure system in terms of the concrete, rebar, human workforce and consumed machinery (Figure 1).

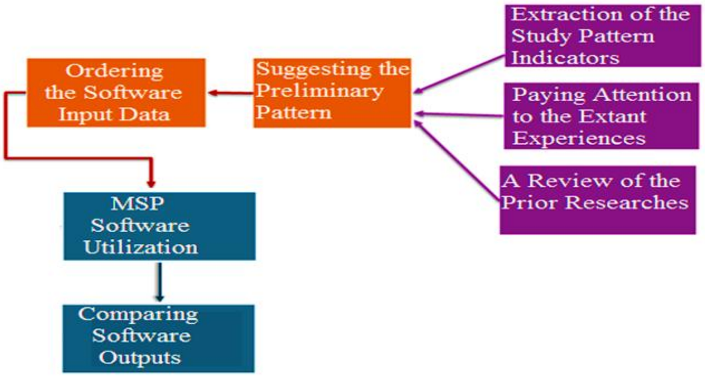

Figure 1. Flowchart of the study method stages

3.1. The Necessary Prerequisites for Defining and Implementing the Activities in MSP

3.1.1. The Necessary Prerequisites for the Implementation of the Activities in Ordinary Concrete Buildings Method

The necessary prerequisites for performing the activities in the customary concrete building construction method are summarized in Table 1. In This table specifies the amounts of the resources needed as inputs to MSP software according to the type of the resource, its unit and the maximum amount existent for every resource for the implementation of the activities pertinent to the ordinary concrete structure construction. Based on these input data, the basis and foundation of the software are formed.

Table 1. The necessary prerequisites for the implementation of the activities in the customary concrete structure construction method

Resource Name	Initials	Group	Max. Units
Concrete work expert	Individuals	Human resources	7
Rebar binder	Individuals	Human resources	6
Assistant rebar binder	Individuals	Human resources	9
Ironsmith	Individuals	Human resources	4
Assistant ironsmith	Individuals	Human resources	5
Lifter	Unit	Machinery	5
Electrician	Individuals	Human resources	12
Assistant electrician	Individuals	Human resources	12
Brick-wall layer	Individuals	Human resources	12
Assistant concrete mason	Individuals	Human resources	7
Mechanical shovel-with driver	Unit	Machinery	5
Concrete pump-with driver	Unit	Machinery	5
Surveying machinery	Series	Instruments	3
Floor insulation equipment	Series	Instruments	4
Mixer truck-with driver	Unit	Machinery	5
Scaffold	Square meter	Instruments	2100
Ceramic tile worker	Individuals	Human resources	7
Stonemason	Individuals	Human resources	8
Assistant Stonemason	Individuals	Human resources	12
Glazier	Individuals	Human resources	3
Assistant glazier	Individuals	Human resources	5
Insulation worker	Individuals	Human resources	7
Assistant insulation worker	Individuals	Human resources	8
Concrete formwork	Square meter	Instruments	320
Formwork finisher	Individuals	Human resources	6
Formwork finisher assistant	Individuals	Human resources	6
Cabinet maker	Individuals	Human resources	3

Assistant cabinet maker	Individuals	Human resources	4
Professional laborer	Individuals	Human resources	12
Tile worker	Individuals	Human resources	18
Assistant tile worker	Individuals	Human resources	5
Truck-with driver	Unit	Machinery	7
Ductwork expert	Individuals	Human resources	7
Assistant ductwork expert	Individuals	Human resources	3
Plasterer	Individuals	Human resources	3
Assistant plasterer	Individuals	Human resources	21
Plumber	Individuals	Human resources	41
Assistant plumber	Individuals	Human resources	4
Carpenter	Individuals	Human resources	5
Assistant carpenter	Individuals	Human resources	3
Painter	Individuals	Human resources	4
Assistant painter	Individuals	Human resources	11
Surveying engineer	Individuals	Human resources	2
Bricklaying tools-shovel and pickax etc.	Series	Instruments	25
Painting tools	Series	Instruments	5
Vibrator	Unit	Instruments	3

- **Technical specifications of concrete structure constructed using the conventional method**

The technical specifications of the discussed customary concrete buildings required for evaluation and use in MSP software are as stated below:

- The building has nine floors.
- According to the map, the columns are in two C1 and C2 types, whose cross section is 50×50 cm for the column type C1 for the first three floors, 40×40 cm for the third two columns; and 35×35 cm for the third three floors. For the column type C2, the column section is 60×45 cm for the first three floors, 60×40 cm for the second three floors, and 60×35 cm for the third three floors.
- Rebar placement in the columns above sections is based on Figure 4.
- Implementation of foundation is in strip form.
- Foundation molding is of a height of 70 cm, and in the form of a brick.
- The interior of the molds is covered with plastic to prevent the absorption of concrete.
- All concretes are at least of grade 350 kg per cubic meter.
- The execution of moldings of columns, beams and sub-beams is made of metal.
- The height of all walls in the floors is 2.96 meters and is 20 cm wide.
- All ceilings are made of joints and blocks.

Figure 2. shows how the rebar is put in columns in a concrete building in a conventional manner.

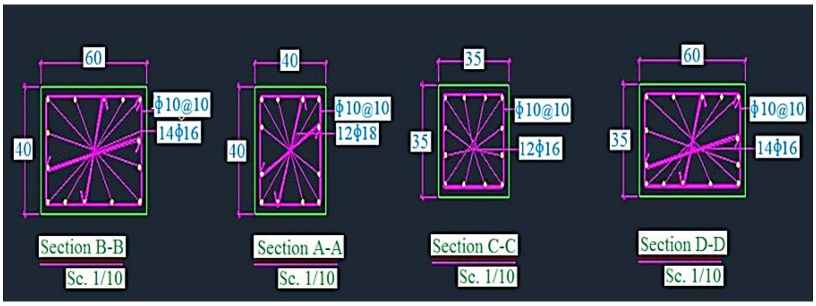

Figure 2. Putting rebar in columns

3.1.2. The Necessary Prerequisites for the Implementation of the Activities in the Integrated Wall and Roof Formwork Method

The necessary prerequisites for the implementation of the activities in the integrated wall and roof formwork are presented in Table 2.

Table 2 specifies the required resources as inputs to the software in terms of the type of the resources, the units and the maximum available amounts for the implementation of the concrete structure construction method based on integrated roof and wall formwork. These resources and their required amounts form the basis and foundation of the software data.

Table 2. The necessary prerequisites for the implementation of the concrete structure construction based on integrated roof and wall formwork

Resource Name	Initials	Group	Max. Units
Concrete work expert	Individuals	Human resources	5
Rebar binder	Individuals	Human resources	4
Assistant rebar binder	Individuals	Human resources	6
Ironsmith	Individuals	Human resources	3
Assistant ironsmith	Individuals	Human resources	4
Tower Crane	Unit	Machinery	1
Electrician	Individuals	Human resources	10
Assistant electrician	Individuals	Human resources	10
Brick-wall layer	Individuals	Human resources	10
Assistant concrete mason	Individuals	Human resources	5
Mechanical shovel-with driver	Unit	Machinery	3
Concrete pump-with driver	Unit	Machinery	3
Surveying machinery	Series	Instruments	1
Floor insulation equipment	Series	Instruments	2
Mixer truck-with driver	Unit	Machinery	3
Scaffold	Square meter	Instruments	1500
Ceramic tile worker	Individuals	Human resources	5
Stonemason	Individuals	Human resources	6
Assistant Stonemason	Individuals	Human resources	10
Glazier	Individuals	Human resources	1
Assistant glazier	Individuals	Human resources	2
Insulation worker	Individuals	Human resources	4
Assistant insulation worker	Individuals	Human resources	4
Concrete formwork	Square meter	Instruments	210
Formwork finisher	Individuals	Human resources	4
Formwork finisher assistant	Individuals	Human resources	4
Cabinet maker	Individuals	Human resources	1
Assistant cabinet maker	Individuals	Human resources	4
Professional laborer	Individuals	Human resources	10
Tile worker	Individuals	Human resources	15
Assistant tile worker	Individuals	Human resources	3
Truck-with driver	Unit	Machinery	5
Ductwork expert	Individuals	Human resources	5
Assistant ductwork expert	Individuals	Human resources	1
Plasterer	Individuals	Human resources	1
Assistant plasterer	Individuals	Human resources	19
Plumber	Individuals	Human resources	38
Assistant plumber	Individuals	Human resources	5
Carpenter	Individuals	Human resources	5
Assistant carpenter	Individuals	Human resources	1
Painter	Individuals	Human resources	2
Assistant painter	Individuals	Human resources	3
Surveying engineer	Individuals	Human resources	1
Bricklaying tools-shovel and pickax etc.	Series	Instruments	22
Painting tools	Series	Instruments	5
Vibrator	Unit	Instruments	3

- **Technical specifications of building method with reinforced concrete cast In-situ walls and slabs**

The technical specifications of the discussed integrated roof and wall formwork system required for evaluation and use in MSP software are as described below:

- The building has nine floors.
- The foundation is raft.
- In the entire floor, a lean concrete layer of grade 150 kg per cubic meter is used.
- All moldings are made of metal mold.
- The height of the foundation mold is 70 cm.
- Foundation rebar is made as reinforcing mesh up and down.
- Dowel bar is seen in all walls.

- The height of all walls in the floors is 2.96 meters.
- All walls have a thickness of 20 cm.
- All concretes, except for lean concrete, are of grade of at least 350 kg per cubic meter.
- The walls are reinforced in the form of mesh in two rows.

Figure 3. shows the molding of the walls in the integrated wall and ceiling system.

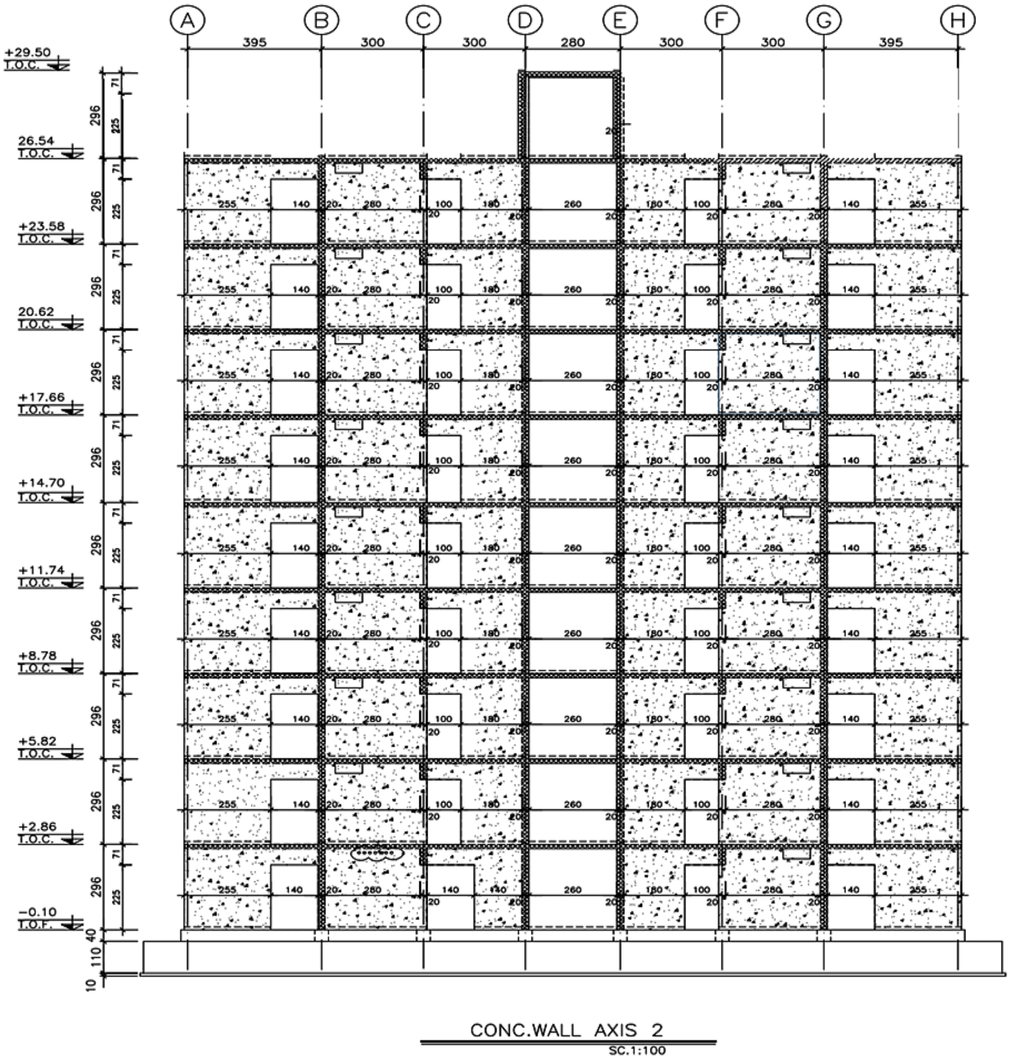

Figure 3. Wall molding plan [32]

4. Introducing the Building Method with Reinforced Concrete Cast In-situ Walls and Slabs

Nowadays, various molding systems have been introduced into engineering communities based on a variety of concrete construction methods. Given the ever-growing need of society for massive, cheap, fast and secure housing, it is inescapable to move towards industrial construction methods and use of appropriate construction techniques. For this purpose, many molding systems have been developed to achieve the goal of housing industrialization, each with its own advantages and disadvantages. Among all the mass construction systems, the construction of a concrete structure with integrated molds is the only system that allows the simultaneous execution of the walls in all directions of the building plan, and does not have any restrictions on the height of the ceilings and the width of the span, allowing easy construction of parking spaces. Over the past four decades, the system has widely been used by mass producers all over the world, and so far, there have been many technical reviews by mold designers. Building method of reinforced concrete cast in-situ walls and slabs system, as well as other industrial methods, are justifiable regarding four criteria of time reduction, cost reduction, quality improvement, and labor safety [21].

In this system, called building method of reinforced concrete cast in-situ walls and slabs reinforced, reinforced concrete walls are used as load bearing elements and ceilings are made as in situ reinforced concrete slab. Due to the simultaneous construction of all external and internal walls and their involvement with the floor and ceiling, the structure is integrated and the concrete walls and slabs of the floor act as a single unit against the lateral forces of the wind and earthquake. Figure 4. illustrates an example of wall reinforcement in a building constructed through in situ concrete technique with integrated wall and ceiling mold [3].

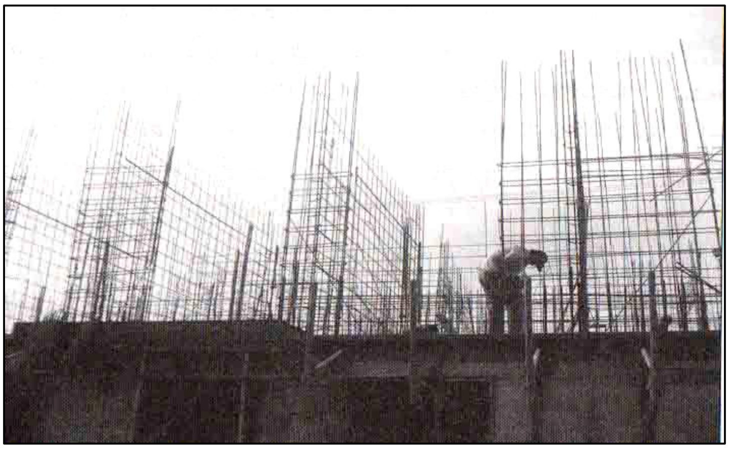

Figure 4. An example of wall reinforcement in in a building constructed through in-situ concrete technique with integrated wall and ceiling mold [3]

The resulting structural system derived from this methodology is one of the best-known systems in accordance with international regulations. In other words, in this system, which lacks the construction frame for vertical loading, the reinforced concrete load bearing walls, besides bearing vertical loads, act as shear walls to counter the lateral forces. The system under discussion is abundantly adapted to different architectural designs, and with the smooth construction of reinforced concrete walls, the next steps can be minimized for thinning and facade. Figure 5. shows the molding of the load bearing walls in the integrated wall and ceiling mold system [3].

Figure 5. Molding of the load bearing walls [21]

Another desirable feature in this system is the appropriateness of this construction method for massive house building and construction of 5 to 15-story buildings. Although the initial investment cost for the preparation of the mold and equipment in this system is relatively high, the system can economically be considered as efficient and justifiable as the number of repetitions in the use of molds and accessories increases. Obviously, this will be achieved when quality implementation is coupled with the correct management and control of the project. Figure 6. shows an example of the completed building according to the integrated wall and ceiling mold method [3].

Figure 6. An example of a completed building made using integrated in-situ concrete molding [3]

5. Result and Discussion

5.1. MSP Software Output to Build a 9-Story Concrete Building Using Integrated Wall and Ceiling Mold System and Conventional Method

In this section, the outputs of the MSP are examined. Concrete, rebar, labor and machinery used in the project will be presented separately for both methods of the construction of nine-story concrete building, i.e. integrated wall and ceiling mold system and conventional method, which will lead to a closer examination and comparison of the advantages of integrated wall and ceiling molds compared to conventional concrete structures.

5.2. Concrete Used

The used in the integrated molding according to Figure 7. is 1868.15 m^3 but in the conventional method 1228.52 m3. In fact, the amount of concrete used in the integrated wall and ceiling mold system will be 34.24% higher due to the implementation of raft foundation as well as the reinforced concrete used in the construction of external walls and most internal walls. However, due to the reduction of other project costs and the shorter construction time using the integrated wall and ceiling mold system, the higher cost of concrete in this method will be fully compensated for and will have economic justification.

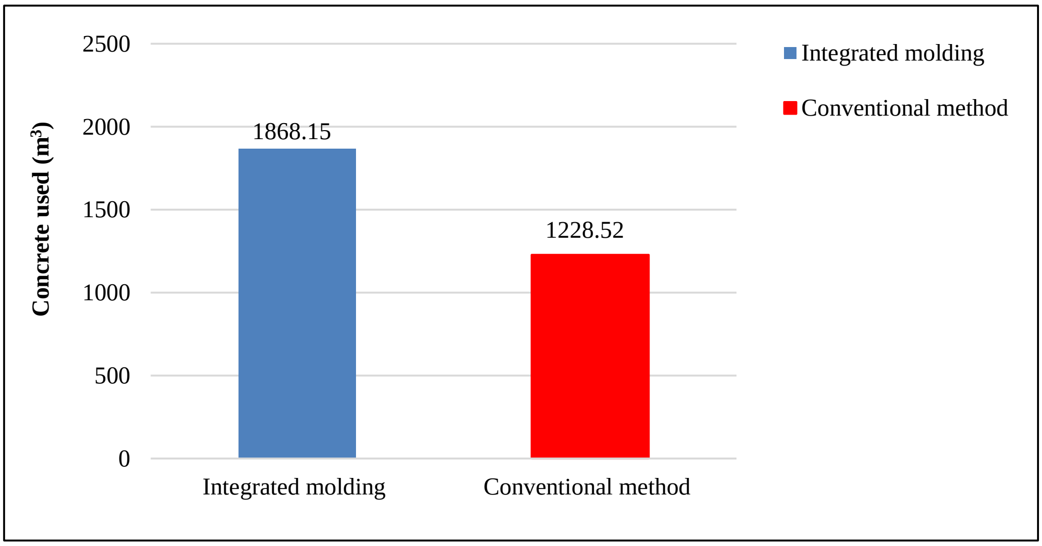

Figure 7. The concrete used in a concrete nine-story building using integrated wall and ceiling mold system and conventional mold

5.3. Rebar Used

On the basis of Figure 8, the amount of rebar used in the construction of nine-story concrete building using integrated wall and ceiling mold system is 128611.42 kg, whereas the rebar used in the conventional method is 196773.52 kg. In other words, the use of rebar in the integrated wall and ceiling mold system is 34.64% less than the conventional one.

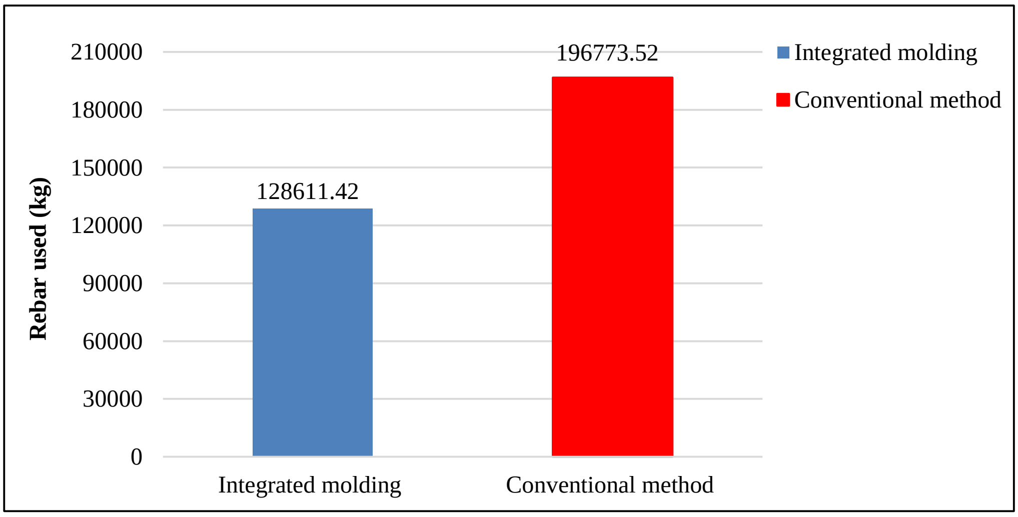

Figure 8. The rebar used in a concrete nine-story building using integrated wall and ceiling mold system and conventional mold

5.4. Labor Used

According to Figure 9, the labor required for the construction of nine-story concrete building using integrated wall and ceiling mold system is 43448.63 hours, whereas in the conventional method, it is 55719.08 hours, which will lead to a total reduction of 22.03% in the labor. Reducing labor will increase the efficiency of buildings and reduce the human hazards such as death, injury, and disability during work.

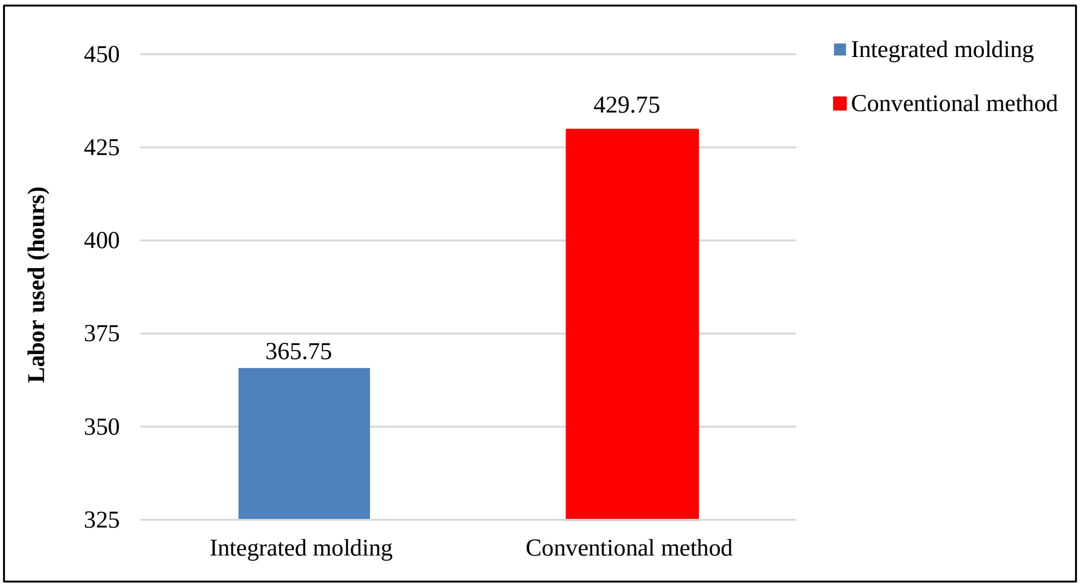

Figure 9. The labor in a concrete nine-story building using integrated wall and ceiling mold system and conventional mold

5.5. Machinery Used

According to Figure 10, it was determined that the whole machinery used in the construction of nine-story concrete building through integrated wall and ceiling mold system is 645.03 hours, whereas it is 5574.66 hours in the conventional method. In fact, the use of the integrated wall and ceiling molding method will reduce 88.43% of the total machinery used.

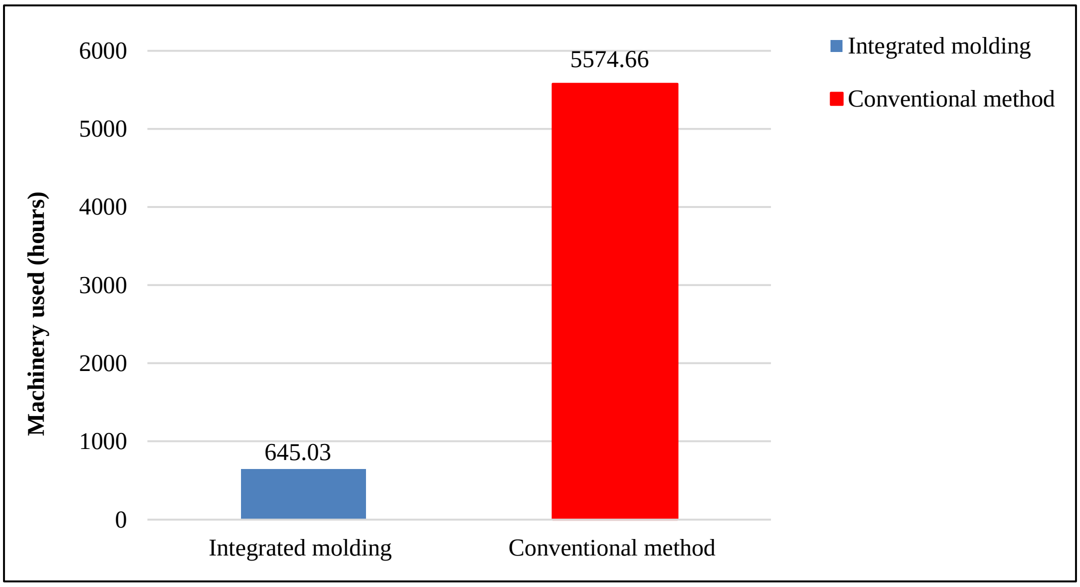

Figure 10. The machinery in a concrete nine-story building using integrated wall and ceiling mold system and conventional mold

6. Conclusion

Industrialized construction of the buildings can be finished in a smaller time than the traditional methods of construction due to the simultaneous and parallel production and installation of the formwork; but, the initial investment costs in industrialized construction of the buildings is higher than the traditional methods. Since a considerable part of the implementation costs are incurred for the purchase of the materials, masonry and tools required in the industrial building construction system, the proper allocation of the credits in the onset of the implementation operation can provide for the control of the implementation cost increase as a result of the lengthening of the construction time and the effect of the inflation rate thereon. This way, the finished price of the building can be lowered. In general, in construction projects, the integrated wall and roof formwork system as compared to the common methods of concrete building construction is in a greater compliance with the industrialized construction scales because many of the activities like the implementation of the internal and external walls in the entire stretches of the building plan in every storey along with the buried ducts installed therein are all undertaken within a single activity and simultaneously and the other activities such as the implementation and completion of the building facade and joinery and masonry works are decreased to their minimums and this, per se, brings about a reduction in cost, construction time, consumed masonry, machinery and human workforce.

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