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Original Article

Evaluating the Selection Criteria of Formwork System (FS) for RCC Building Construction

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Abstract *- Formwork System (FS) selection for reinforced cement concrete (RCC) members is a crucial factor in finishing the project successfully, as it is necessary for improved productivity and faster construction of the projects. The present study assessed the criteria influencing the formwork system selection in the construction of residential buildings. From the literature and past studies conducted on selecting the formwork system, a total of 24 influencing factors were identified. The formwork suitability is analyzed using Statistical Package for Social Sciences (SPSS). Furthermore, using the performance indicators used in the formwork system analysis, a total of 5 influencing factors were indicated as being the primary determinant of formwork selection. The remaining 19 factors were omitted because they did not have a major influence. The surface finish, capital cost, durability, labor cost, repetition, and wastage are the top 5 factors which are identified as having a significant impact on formwork system selection. This study examines the different existing formwork technology with recently invented FS, such as aluminum formwork and the jump formwork system, that are not often used in India, to determine which formwork system is most effective and appropriate for the projects under consideration. To better understand this, the hypothetical building projects employing traditional formwork were considered to compare newly developed formwork with conventional formwork systems considering the key selection criteria analyzed. The results offer a better understanding of the influencing factor affecting the formwork system selection in Mumbai City. They will help construction professionals improve productivity in terms of cost saving faster construction, expanding the existing knowledge regarding formwork selection systems, and decreasing formwork waste.*

Keywords *- Construction projects, Reinforced concrete formwork systems, Selection criteria, Traditional formwork, Newly emerging formwork.*

1. Introduction

In the building industry, concrete is a crucial building material [1,2,3,4,5]. It has been widely utilized in the construction of infrastructure development, commercial, and residential projects due to its strength and durability properties, which allow for any form, regardless of the intricacy of the geometry, as well as its excellent building characteristics, including structure performance, low cost, accessibility, and sustainability. Formwork is required to hold the concrete in place temporarily until it can stand on its own (Sai and Aravindan 2020- 6). It shapes the concrete to fit various forms used in construction, which often vary depending on the needs of the building. The realization of geometry and improvement of concrete elements' strength properties are significantly aided by formwork [7,8,9]. Numerous formwork systems have been employed in various projects throughout the long history of formwork use. Considering factors including surface quality, building time, structural geometry, safety, and the cost is important when designing and choosing a formwork system [10,11,12,13,14]. The FS used during construction significantly impacts the surface quality of the concrete structure and finished geometry [15]. Therefore, before construction begins, it is important to carefully evaluate the FS's selection criteria and fundamental requirements [16, 17]. A formwork system should, first and foremost, should be of high quality and should be maintained in the building process, including rigidity, durability, and strength. [18, 10].

Cost is a significant consideration when choosing a formwork system [19,20,21]. This covers the cost of the materials, labour used in constructing, assembling, and dismantling the formwork, handling tools required, and the cost of the release agents used to remove the formwork [22]. The cost of the FS for structures which are constructed from cast-in-place concrete can account for up to 50% of the

total cost of the project [23]. As a result, while choosing and designing a formwork system, it is crucial to consider material savings and the potential for formwork reuse. Additionally, the formwork material's sensitivity to the weather condition would increase the maintenance costs and shorten its useful life. Utilizing materials with adequate resistance to severe damage and corrosion is generally advised. Additionally, the design of a formwork system must consider the formwork's ergonomics and adaptability [24]. Modern formwork engineering techniques may drastically cut costs and material waste while raising the likelihood of a project succeeding [43].

Additionally, the chosen FS may significantly affect the building construction project's total time, as well as its safety and quality [26, 27]. As a result, as reinforced concrete building advances, formwork engineers must develop new formwork systems to provide solutions [28]. Several factors, some of which are interrelated, may be taken into consideration while choosing the formwork system [44]. Modern integrated evaluation techniques can be applied to solve the various constriction-related problems with maintaining sustainability [30,31,32,33,34]. Suppose a reinforced concrete building is constructed using traditional formwork. In that case, the project cannot be regarded as successfully completed efficiently and on time which may result in the client, contractor, and stakeholders' dissatisfaction with the project's quality specifications or estimated completion date [35].

From the literature, it can be observed that there are several types of FS in the construction industry which should be properly selected in India by considering important factors. Several past studies pointed out that various types of formwork system (FS) utilized in construction projects is the major factor for the success of building construction project in terms of construction cost, quality, and speed of the projects. The study's main objective is to evaluate formwork selection criteria in reinforced concrete construction and comparatively evaluate the traditional and newly emerging formwork system in concrete construction considering the evaluated selection criteria of reinforced concrete construction.

2. Materials and Methods

The present study evaluates the criteria which affect the formwork system selection in residential building construction projects. Fig. 1 shows the flow chart of the methodology used to evaluate the formwork system (FS) selection. From the literature review, a total of 24 technical factors were identified which can influence the FS selection of RCC. Then, 53 filled questionnaires related to the formwork system (FS) selection of reinforced concrete (RC) were received from the respondent who is in practice in Mumbai City. The questionnaires are analysed using Statistical Package for Social Sciences (SPSS). The following 5-point Likert scale has been used for the analysis of the questionnaires.

The mean, mode, median, standard error, and mean score index are used as performance indicators. Mean Score Index (MSI) [36,37,38,39] is employed to understand the relative influence of the factors considered. The 5-point likert scale was utilized to evaluate the weightage of each factor considered [40,41,42]. The formula for calculating the Mean Score Index (MSI) (performance indicators) is given below.

$$Mean\ Score\ Index\ (MSI) = \frac{\Sigma W}{(A\ X\ N)} \quad (2.1)$$

Where,
N is the number of respondents,
A is the highest weightage,
W is the weightage given by respondents to each factor.

The formula used to calculate the Standard Deviation (performance indicators) is given below.

$$Standard\ Deviation\ (\sigma) = \sqrt{\frac{\Sigma\ (X-\mu)}{N}} \quad (2.2)$$

Where,
N is the total number of observations
μ is the population mean
X is the value in the data distribution

The formula used to calculate the Standard error (performance indicators) is given below.

$$Standard\ Error\ (SE) = \frac{\sigma}{\sqrt{n}} \quad (2.3)$$

Where,
σ is the standard deviation
n is the number of samples

Additionally, 5 factors that have a dominant influence on the choice of formwork were identified through factor analysis, and the remaining 19 factors were omitted since they had little influence. Initial cost, Durability, Labour Cost, Wastage of formwork material, and repetition were found to be the top 5 criteria significantly influencing formwork choices. This study compares and evaluates the current FS technology with newly emerging FS, including jump formwork systems and aluminum formwork, which are not widely used in India, to determine which technique is most effective and appropriate for the project under consideration.

Table 1. 5-point Likert scale used for understanding the importance of factor

Point 1	Point 2	Point 3	Point 4	Point 5
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

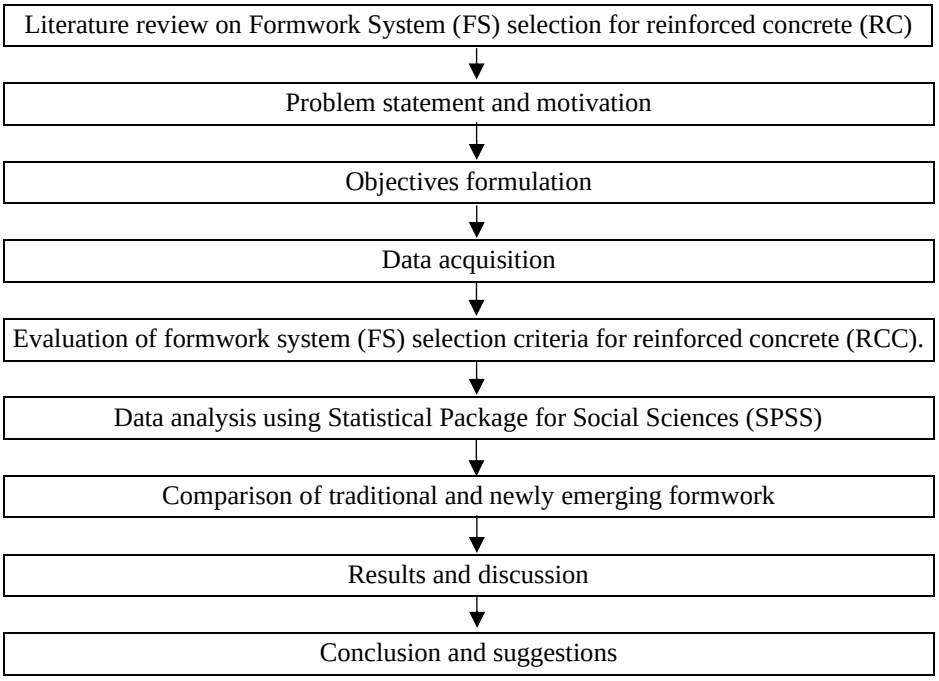

Fig. 1 Flow chart of the methodology used to evaluate the formwork system (FS) selection

To further understand this, the hypothetical building construction project utilizing aluminum and traditional formwork was analyzed and then used to compare the formwork systems with respect to the 5 main factors identified through a questionnaire survey. Finally, a comparison of current FS technology with newly emerging formwork systems, such as aluminum formwork and jump FS, is conducted to determine which method is suitable for the projects under consideration.

2.1. Data Acquisition and Preparation

From the literature review, a total of 24 technical factors were identified which can influence the formwork system (FS) selection of reinforced concrete (RC). The identified criteria for the formwork system (FS) selection of reinforced concrete (RC) are durability and time consumption of various types of formwork systems, labour cost and skills for various types of formwork systems, the concrete quantity for formwork, steel quantity, shuttering, de shuttering, floors number, area of a floor, floor height, weather condition, the initial cost of the formwork system, transportation cost of the formwork system, maintenance cost of the formwork system, the potential reuse of the formwork system in the other project, resiliency, compatibility, safety, and flexibility, weight, size, technical support, BIM support, floor plate, and grade of concrete. Then, 53 filled questionnaires related to the formwork system (FS) selection of reinforced concrete (RC) were received from the respondent who is in practice in Mumbai City.

3. Results and Discussion

The analysis of the formwork system for reinforced concrete members through the analysis of the questionnaire survey is described in the following sections. The essential criteria from the literature review are listed in Table 2 as questions with their analysis utilizing the Mean Score Index (MSI), performance indicators, Ranking, Standard Deviation, and Standard Error.

The evaluation of the mean score index of the questionnaire survey ranges from additional analysis of the questionnaire survey's standard deviation and standard error, which range from. The standard deviation of a dataset measures the variance from the mean. It is calculated as the square root of the variance. The standard deviation in the field of formwork systems demonstrates the variances in experience based on the projects and site circumstances.

Future research might therefore examine the thorough examination of the formwork selection method in Mumbai City in more detail. Cost, durability, repetition, labour costs, and formwork material waste are the primary influencing factors affecting the selection of forms in the Mumbai City region, according to an analysis of the critical factors using the Mean Score Index (MSI), Ranking, Standard deviation, and Standard error (Table 2). Tables 3, 4 and 5 show examples of the analysis of each question through cumulative percent, valid percent, frequency, and percent.

Table 2. presents a summary of the main elements gleaned from the literature review as questions with performance indicators.

Sr. No.	Critical factors identified from the literature review in the form of questions	Mean Score Index (MSI)	Ranking	Standard Deviation (σ)	Standard Error
1	Is durability affects the selection of a formwork system?	0.856	1st	29.376	4.113
2	Do repetitions affect the selection of the formwork system?	0.84	2nd	28.830	4.037
3	While selecting a formwork system, are wastage measures required?	0.816	3rd	28.010	3.922
4	Are high safety measures required for traditional formwork?	0.812	4th	27.868	3.902
5	While selecting a new emerging formwork system, is project cost affected?	0.776	5th	26.634	3.729
6	Are transportation costs affected while selecting the formwork system?	0.764	6th	26.220	3.672
7	Does flexibility is affected while selecting the formwork system?	0.752	7th	25.811	3.614
8	Does labour costs affect by the formwork system?	0.744	8th	25.543	3.577
9	Is maintenance cost more in a traditional formwork system?	0.724	9th	24.860	3.481
10	Does steel quantity affect when selecting the formwork system?	0.724	10th	24.855	3.480
11	Does the structural system affect when selecting a formwork system?	0.7	11th	24.031	3.365
12	While selecting the formwork system, does concrete weight affects it?	0.7	12th	24.038	3.366
13	Does floor area is affected by the selection of the formwork system?	0.684	13th	23.487	3.289
14	Does sustainability is affected by traditional formwork systems and new emerging formwork systems?	0.668	14th	22.945	3.213
15	Does BIM help while selecting the formwork system?	0.66	15th	22.666	3.174
16	For installing New Emerging Formwork, does on-site high-rate equipment is required?	0.652	16th	22.403	3.137
17	Does weather condition affect the selection of the formwork system?	0.652	17th	22.398	3.136
18	Does building location affect during the selection of the formwork system?	0.632	18th	21.705	3.039
19	Does building height affect selecting the formwork system?	0.588	19th	20.200	2.829
20	Does skilled labour required for the new emerging formwork system?	0.576	20th	19.801	2.773
21	Do technical support requires for selecting the formwork system?	0.572	21st	19.669	2.754
22	For installing Traditional formwork, does on-site low-rate equipment is required?	0.56	22nd	19.234	2.693
23	Does the change in the floor plate design implicate the selection of the formwork system?	0.556	23rd	19.109	2.676
24	Do the grade of Concrete affect while selecting the formwork system?	0.544	24th	18.696	2.618

Table 3. Does the change in the floor plate design implicate the selection of a formwork system

Sr. No.	Scale	Frequency	Percent	Valid Percent	Cumulative Percent
1	Strongly Disagree	10	18.9	19.6	19.6
2	Disagree	9	17.0	17.6	37.3
3	Neutral	14	26.4	27.5	64.7
4	Agree	16	30.2	31.4	96.1
5	Strongly Agree	1	1.9	2.0	98.0
6	Error	1	1.9	2.0	100.0
7	Total	51	96.2	100.0	-
8	Missing	2	3.8	-	-
9	Final Total	53	100.0		

Table 4. Skilled labour is required for the new emerging formwork system

Sr. No.	Scale	Frequency	Percent	Valid Percent	Cumulative Percent
1	Strongly Disagree	9	17.0	17.6	17.6
2	Disagree	9	17.0	17.6	35.3
3	Neutral	18	34.0	35.3	70.6
4	Agree	7	13.2	13.7	84.3
5	Strongly Agree	7	13.2	13.7	98.0
6	Error	1	1.9	2.0	100.0
7	Total	51	96.2	100.0	-
8	Missing	2	3.8	-	-
9	Final total	53	100.0	-	-

Table 5. Does floor area affect the selection of the formwork system?

Sr. No.	Scale	Frequency	Percent	Valid Percent	Cumulative Percent
1	Strongly Disagree	1	1.9	2.0	2.0
2	Disagree	9	17.0	17.6	19.6
3	Neutral	15	28.3	29.4	49.0
4	Agree	18	34.0	35.3	84.3
5	Strongly Agree	7	13.2	13.7	98.0
6	Error	1	1.9	2.0	100.0
7	Total	51	96.2	100.0	-
8	Missing	2	3.8	-	-
9	Final total	53	100.0	-	-

According to the analysis of the questionnaire survey, the five characteristics have the most influence on the choice of formwork system (FS) for reinforced concrete construction. To choose the best formwork system, these criteria are examined in-depth. The description of the analysis is shown in part after that.

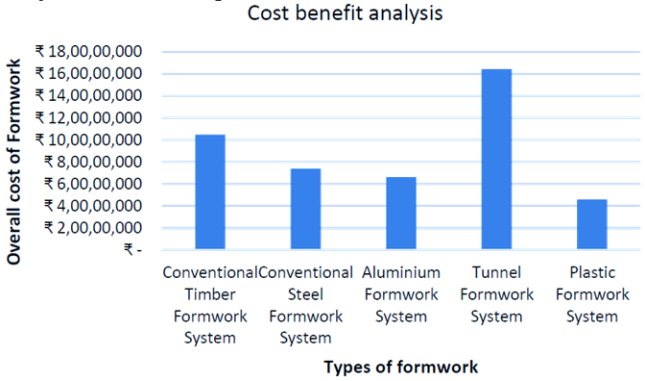

Fig. 2 Cost Benefit Analysis

3.1. Cost-Benefit Analysis

The questionnaire analysis shows that initial formwork costs, formwork system reuse, maintenance, and storage costs impact formwork prices.

The cost-benefit analysis for the type of formwork system is shown in Fig.2.

Fig. 2 shows the highest cost required for the tunnel formwork system, followed by the conventional timber FS, conventional steel FS, aluminum FS and plastic FS.

Table 6. formwork system's durability

Sr.No	Types of Formwork Systems	Durability
1.	Conventional Timber Formwork System	Low
2	Conventional Steel Formwork System	Average
3	Aluminium Formwork System	High
4	Tunnel Formwork System	Very High
5	Plastic Formwork System	High

3.2. Durability Analysis

Table 6 shows the formwork system's durability. The typical timber formwork system is less durable than other formwork systems. The tunnel formwork system's high level of durability makes it possible to reuse it for another project.

3.3. Repetition of the Formwork

Fig. 3 shows the number of times the different formwork systems can be used. It is clear that the tunnel formwork system can be used 500 times which makes it the most repetitive formwork system, followed by the aluminum formwork system (300 times), plastic formwork system (120 times), conventional steel formwork, and conventional timber formwork system.

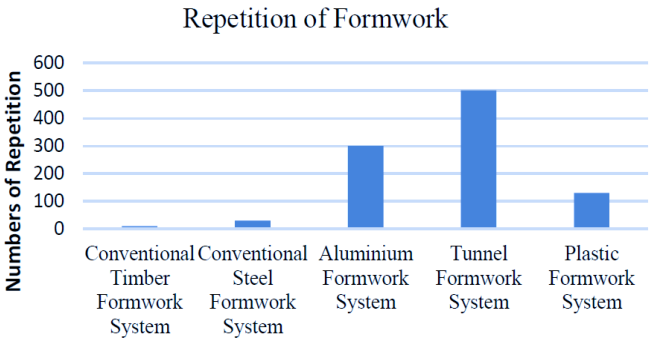

Fig. 3 Repetition of formwork

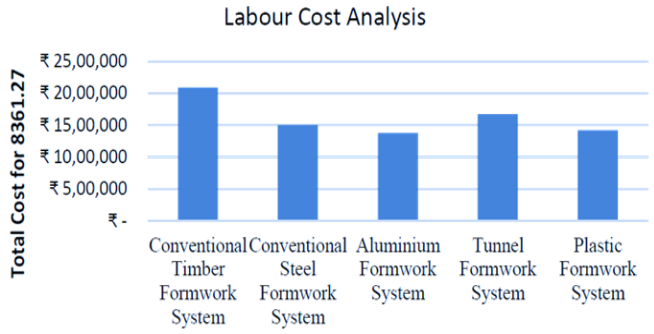

Fig. 4 Labour Cost analysis

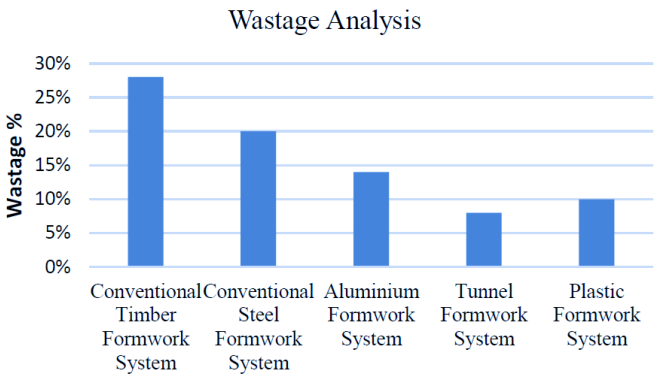

Fig. 5 Wastage analysis

3.4. Labour Cost Analysis

Fig. 4 shows the labour cost for the different types of formworks. In comparison to other formwork systems, the labour cost for timber formwork is higher, but no skilled labour is needed for it. The aluminum formwork system resulted in the least cost required for labour.

3.5. Wastage Analysis

Fig. 5 shows the wastage in different formwork systems, which can be high or low. While using the formwork wastage factor is most important because less wastage in the formwork system helps to earn more profit. Fig. 5 shows that using an aluminum formwork system (14 % wastage) on a project provides less wastage than timber formwork (28 % wastage), generating high wastage. The tunnel formwork system results in minimum wastage, but the cost of tunnel formwork is high.

As a result, using aluminum formwork can be advised based on its suitability and other factors like construction speed and the availability of skilled labour. The tunnel formwork is advised over aluminum if there are time restrictions on finishing the projects. When compared to an aluminum formwork system, conventional methods take longer.

While the price of an aluminum formwork system is 9% cheaper than that of a traditional formwork system. Therefore, using this recently developed form of FS, the project's cost and duration can be decreased. Although the newly emerged formwork is more expensive but takes longer, many still employ conventional methods because they believe they will be less expensive in the long run. In India, however, advanced techniques are employed for large-scale megaprojects.

For each project under consideration, it is necessary to do a selection study of the formwork system that has proven superior to the standard formwork system in terms of cost, durability, repetition, labour cost, and formwork material waste. Although the present study comprehensively evaluated the formwork system, some limitations are associated with the present research. The study was conducted only in Mumbai City is the first limitation.

However, there is a scope for conducting such type of study at the Country level like India. Second, the criteria employed in this study to choose formwork systems focused on residential building construction projects. Other formwork system selection criteria can be found and analyzed for various project categories, such as commercial, industrial, or infrastructure projects. Additionally, factor analysis can be carried out group-wise based on the quantitative datasets supplied in this research to effectively analyze the formwork system selection criteria and interpret the effect between the FS selection criterion grouping.

4. Conclusion

The analysis represents the comparisons of various types of FS, i.e., Jump system, Aluminum, conventional steel, and conventional timber, focusing on five important factors identified from the literature and survey analysis: cost, durability, repetition, labour cost, and wastage of formwork material. The analysis shows that the aluminum formwork and tunnel formwork can be employed over the traditional formwork as they proved better in terms of speed of construction, long-term cost, and less wastage. If there are time constraints in completing the projects, the tunnel formwork is recommended over aluminium. When compared to an aluminium formwork system, conventional methods take more time. The long-term cost of an aluminium formwork system is significantly lower than that of a traditional formwork system. Therefore, employing the aluminum and tunnel formwork system can minimise the duration and cost of the residential construction project.

Although the aluminum and tunnel formwork proved beneficial in long-term use considering all the major influencing factors, in many places, the traditional formwork system is used because there is a perception that the cost of newly emerging formwork is more and therefore prefer the traditional type of formwork, however for massive concreting construction projects the newly emerged formwork is used in India. Therefore, it is required to conduct the formwork system selection analysis for each project under consideration, which proves better than the conventional formwork system by considering cost, durability, repetition, labour cost, and wastage of formwork materials. The results offer a better understanding of the criteria affecting FS selection in Mumbai City, and they will be helpful for construction professionals to make successful plans, expand the body of knowledge regarding formwork selection, and maybe cut down on formwork waste. Compared to conventional techniques, using modern formwork techniques allows for the quicker casting of large elements, saving time and labour.

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