

PERFORMANCE EVALUATION ON SELECTION OF FORMWORK SYSTEMS IN HIGH RISE BUILDINGS USING REGRESSION ANALYSIS AND THEIR IMPACTS ON PROJECT SUCCESS

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The selection of the formwork system for high rise building affects the entire construction project duration and cost. The study reports the factors influencing the selection of different formwork system in the construction of high rise buildings through structural questionnaire survey from the client, contractor, consultant, and interviews with expert members. Total of 40 technical factors was identified from the literature and 220 filled questionnaires were received from the respondent. Relative Importance Index method is used to find the topmost factors affecting the selection of formwork system. Additionally, from factor analysis 22 factors were identified to have a correlation with one another. Regression analysis reveals that duration of the project, maintenance cost, adaptability, and safety have impact on formwork selection across time, cost and quality. These findings could potentially increase the construction company's existing knowledge in relation to formwork selection.

Keywords: Formwork system; Factor analysis; Correlation; Regression analysis.

1. INTRODUCTION

Construction is one of the important sectors in the world. Construction involves huge investment and plays an important role in growth of several other sectors in economy. Globally construction of high rise buildings is increasing in order to save time and space. In construction industry formwork

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plays an important role. Formwork contributes a major part of cost in construction and gives shape to the fresh concrete and also support the fresh concrete to gain its strength to carry on its own weight [25]. Formwork cost 40 to 60% of structural work in construction. Formwork should have good quality in terms of strength, durability and rigidity and it should be safe to workers and concrete structures and should possess good efficiency in operation, easy to handle and should be economical. It should be strong enough to withstand the dead and live load. Therefore choosing a correct formwork becomes essential in construction. Incorrect selection of formwork will lead to increase in cost and time overrun in construction project. Different types of formworks are available in construction. Among which choosing an appropriate system of formwork is crucial factor in successful completion of project in term of time, cost, quantity and safety [14].

The advancement in technology and population increase leads to construction of high rise buildings in small area [29]. In high rise reinforced concrete building, selection of formwork system based on site condition is essential for project completion. An appropriate formwork system is always cost and labor effective. Formwork always determines the cycle per floor of high rise building which affects the construction cost and subsequent activities [30]. Selection of formwork for a construction is mostly based on experience or decided by the high level authority in an organization. This alone will not lead to selection of appropriate formworks. Hence it is necessary to find a tool which selects the most useful formwork for a construction site based on the constraints. Therefore choosing a correct formwork will reduce the time and cost of the construction.

2. FORMWORK SELECTION

Formwork systems are classified in many ways, according to size they are classified as small sized formwork and large sized formwork. According to location of use, it is classified as timber form and girder form, where timber is used for irregular frame structures and girder form and climb forms are used for wall and column structures, where aluminum form is used for repeated regular section. Based on materials of construction it is classified as timber, steel, aluminum and plastic formwork. According to nature of operation crane independent, crane dependent and tunnel type formwork system. There are different types of formwork available and are being used in the construction of reinforced concrete structure. A plywood form is the oldest type of the formwork used in the construction industry. This is used for small construction works. This method is more expensive in usage of labor, it is time consuming process, it is difficult to carry install and

dismantle. It has very poor surface finishing. Steel formworks are fabricated of thin steel plates. Different panels can be joined by clamps or bolts & nuts. These formworks are used in a place where reuse of shuttering is needed. These are stronger and durable. Aluminum formworks are made from high strength aluminum alloys. The panels are joined by pin of wedge arrangement system. These are light in weight and reuse of formwork is more. Installation and dismantling is very easy and have very good surface finish. Plastic formworks are very light in weight and can be installed easily and save time & money and are cost effective. The panels can be attached with each other with the help of locking handles. These are easier to clean and can be reused instantly and have good surface finish.

Selection of a formwork for a high rise building mainly depends on individual's experience or by the senior members of an organization and the availability of the formwork system. This type of selection may result in cost expensive or faculty selection. The owner of an organization aims to reduce the overall cost of the project with specified quality and safety. Since, formwork is a costly item in construction he must be involved in formwork selection system process. Designer should design the building in such a way that it should have more number of similar size structures so that formwork can be used repeatedly which will reduce the cost and increase the productivity.

3. METHODOLOGY AND QUESTIONNAIRE DEVELOPMENT

The formwork selection will have a great impact on project success and it needs a detailed study of completed research projects. This research needs a documented data of completed project. For that, a questionnaire survey method is used as a tool [23]. The overall outcomes of the project are identified from the selected professionals (client, contractor and consultant) from design and construction firms for formwork selection. The identification and understanding of the factors at the starting stage of the project plays an important role in successful project completion. The questionnaires were obtained from the previous research papers and from the expert members through pilot survey and interviews with construction professionals. The professionals provided valuable suggestions in framing the questionnaire, which was helpful in refining the factors in clearer language. The pilot survey and interviews resulted in 40 factors. In order to accurately identify the critical factors, several interviews were conducted with owners, contractors and consultants. The interviewers were selected based on their experience and organizational position and the same were conducted with individuals employed at senior managerial levels of their companies. Individual item reliability and convergent validity test was conducted to find the

validity and reliability of the factors. Totally 40 factors were identified and it was grouped into 5 main factors namely General, Structural aspects, Formwork aspect, Environmental aspects and cost. The respondents were requested to rate each factor using five point scale of 1 to 5, where 5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree and 1 = Strongly Disagree.

4. QUESTIONNAIRE DISTRIBUTION

The total questionnaire prepared is about 280 and is distributed among contractor firms, consultant firms and client firms. From them, about 220 filled questionnaire is received. About one hundred and twenty (120) questionnaires which is about 42.8% has been distributed to the contractor firms and the responses received from them is about ninety three (93) which is about 42.2% from the overall responses received. Similar to that about ninety (90) questionnaires which is about 32.1% has been distributed to the consultant firms and the responses received from them is about seventy (70) which is about 31.8% from the overall responses received. whereas about seventy (70) questionnaires which is about 25% has been distributed to the client firms and the responses received from them is about fifty seven (57) which is about 25.9% from the overall responses received

5. RANKING OF ATTRIBUTES

In need to determine the critical factor of the attributes for the different project attributes is to be calculated from the five-point scale used in the questionnaire. Each individual attribute such as the mean and standard deviation are not reliable statistics to access the overall rankings [6]. Thus the overall relative ranking of the attributes is based on the Relative Importance Index (RII) as in Eq. (5.1) and it is evaluated using the following formula [8].

Relative Importance Index

$$(5.1) \quad RII = \sum \frac{X_i * Y_i}{Z_i * 5}$$

where,

RII = Relative Importance Index

X_i = number of responses to the factors

Y_i = the value of rating

Z_i = total number of responses to the factor

The critical attributes represents the highest value as the most critical attributes and the lowest value as the less significant attributes. To make the meaningful interpretation of the ranking to the framed attributes, they are just grouped into four categories such as the top order($RII \geq 0.800$), second order($0.800 > RII > 0.700$), middle order($0.700 > RII > 0.600$), low order($0.600 > RII > 0.500$). There are six top order ranked attributes with $RII \geq 0.800$, twelve second order ranked attributes with $0.800 > RII > 0.700$, fourteen middle order ranked attributes with $0.700 > RII > 0.600$, Eight low order ranked attributes with $0.600 > RII > 0.500$.

Considering the total respondents, the attribute 'Accessibility to work' scored the highest rank with RII value of 0.874 followed to that Quality, Surface finish, Storage & formwork and Capital cost are in order with RII range of 0.866 to 0.807. The accessibility to work and quality are preferred to be the project success in real time whereas inconvenience surface finish and storage of formwork leads to the failure of the projects and it results in the increase of overall cost of the project.

Considering the second order group, the maintenance cost (with RII value of 0.728) and lifespan (with RII value of 0.774) is to explain about the general aspect considered in the project. As availability (with RII value of 0.744) and restoring requirements repetition (with RII value of 0.741) enables to achieve the effective formwork system in project which tends to the project success. Followed by the previous factors the labour cost (with RII value of 0.754) and layout of the structure (with RII value of 0.794) are another important factor categorized in the second order category depending upon the RII values.

Considering the middle order group the insufficient instruction about handling is considered to be the highest ranking order in the middle order group with RII value of 0.693. The factors such as transportation cost (with RII value of 0.688) and duration of the project (with RII value of 0.688) is likely to explain the completion of project with the effective formwork system. Followed to that the factors including the building dimension(with RII value of 0.666), building height(with RII value of 0.614), type of formwork(with RII value of 0.668), labour efficiency(with RII value of 0.668) are also categorized under the middle order group with the RII values of range (0.693 to 0.607)

Considering the low order group the formwork material is selected as a highest ranking order in the low order group with RII value of 0.597. The factors followed to that area of floor (with RII value of 0.585), number of floors (with RII value of 0.562), weight of the formwork (with RII value of 0.553) is considered for an efficient completion project. The low order group indicates the lowest critical factor. Thus through the questionnaire survey conducted with Contractor firms, Construction firms, client firms the various factors are deducted and analysed to find the critical factor among the list of factors.

6. FACTOR ANALYSIS

Factor analysis helps in identifying the most important factors from number of possible causes. In this study Kaiser-Meyer-Olkin test and the Bartlett's test of specificity [32] is used for factor analysis. Kaiser-Meyer-Olkin is the ratio of squared correlation between the variables to the squared partial correlation between the variables. The value of Kaiser-Meyer-Olkin varies from 0 to 1. If Kaiser-Meyer-Olkin values are close to 1 it indicates the correlations are more compact and reliable factors. The factors that having Kaiser-Meyer-Olkin value greater than 0.50 is considered for analysis in reference 40 factors were considered for Kaiser-Meyer-Olkin analysis from which 22 factors are found to have correlation with one another, which is shown in the Table 2 and remaining 18 factors are excluded from the factor analysis since they do not have significant correlation with other factors. Bartlett's test confirming that there is a correlation matrix is an identical matrix, with a significance value <0.001 . The principal component analysis is adopted to reduce the highly correlated formwork selection factor into smaller number of key factors. Five principal components were extracted from the identified 22 factors as shown in the table 2. The principal components were extracted by specifying the minimum initial eigenvalue of 1.0. The five components, which cumulatively explain 68.10% of the total variance and all the factor loadings were greater than 0.5.

To test the agreement among the respondent spearman's rank correlation was used among the three respondents shown in table 2. A high correlation coefficient indicates strong agreement among the respondents in ranking the factors. The table 3 shows the correlation coefficient for the three pairs of respondents, namely Client/Contractor, Client/Consultant and Consultant/Contractor. The analysis shows the strong correlation among the three pairs of the respondent on ranking the formwork system selection, as all the pairs showed the significant loadings of 84.6%, 80.2% and 76.1% respectively.

Table 1: Factor Analysis

Description of factor and attributes	Factor loading	Variance Explained	Cumulative
Factor 1: General aspects			
Quality	0.971	19.50%	19.50%
Safety	0.962		

Availability	0.873		
Adaptability	0.818		
Duration of project	0.809		
Factor 2: Structural aspect			
Accessibility to work	0.987	16.30%	35.80%
Type of structure	0.944		
Building dimensions	0.652		
Factor 3: Formwork aspect			
Load carrying capacity	0.934	13.20%	49.00%
Type of formwork	0.911		
Lifespan	0.837		
Weight of formwork	0.816		
Construction cycle time	0.707		
Factor 4: Environmental aspect			
Exposure to environment	0.862	10.70%	59.70%
Site condition	0.829		
Climate condition	0.778		
Insufficient instruction about handling	0.694		
Storage of formwork	0.560		
Factor 5: Cost aspect			
Capital cost	0.951	8.40%	68.10%
Maintenance cost	0.807		
Labor cost	0.674		
Transportation cost	0.619		

Table 2: Spearman rank correlation coefficient

Test	Client/Contractor	Client/Consultant	Consultant/Contractor
Spearman rank correlation coefficient	0.846	0.802	0.761

7. EXPLANATION ON CIRITICAL ATTRIBUTES

7.1 SELECTION BASED ON GENERAL ASPECTS

The Table 1 shows the attributes which relates to the factor based on the factor loading value. Factors are categorized based on total variance; from that general aspect has the highest range of total variance with a value of 19.50% under this five most important attributes affiliated with formwork selection. Under the general aspect, the first attribute that affords to the formwork selection is quality (with factor loading=0.971) is found to achieve superior surface finish of any concrete. The second attribute that comes in formwork selections is safety (with the factor loading=0.962) which provide proper access and working platform arrangements to ensure workmen safety. Availability (with the factor loading =0.873)has to be checked and purchased or rented in prior, adaptability (with the factor loading = 0.818) has to be checked while purchasing the formwork and duration of project (with the factor loading = 0.809) has to be kept in mind and formwork has to be maintained and stored in care are the remaining three attributes which has the ability to learn from experience, provides an effective solution in development and completion of project on time.

7.2 SELECTION BASED ON STRUCTURAL ASPECTS

The second factor depending on total variance is structural aspect with a total variance value of 16.30%, three important attributes lies under this category. From which accessibility to work(with the loading factor =0.987) explained the expediency for the working environment. Following to that the second attribute that is the type of structure (with the loading factor =0.944) which relates with member constructed separately or the members put together. Next to that the third attribute that affords to formwork selection is building dimension (with the factor loading =0.652) states that varying in size and shape results in the requirement of different type of formwork.

7.3 SELECTION BASED ON FORMWORK ASPECTS

The third factor that related to formwork aspect comprising five attributed with total variance value of 13.20%. The load carrying capacity (with the factor loading =0.934) which help labour to work in the heights and to lift the materials required for construction from the ground level to the higher levels. Followed to that the second attribute, is type of formwork (with the factor loading =0.911)

which is categorized as vertical formwork and horizontal formwork results in the construction of wall, column, beam and slab. Lifespan of formwork (with the factor loading =0.837) which is treated as an important factor results in the reuse of the formwork effectively, which reduces the cost of the project. The fourth attribute that leads to formwork selection is weight of formwork (with the factor loading =0.816), which influences the shuttering and de-shuttering process. Construction cycle time (with the factor loading =0.707), represents the formwork that can be reused number of times effectively with proper maintenance.

7.4 SELECTION BASED ON ENVIRONMENTAL ASPECTS

The fourth factor having five important attributes with total variance value of 10.70%, exposure to environment (with the loading factor =0.862), indicates if the formwork is subjected to repeated exposure results in the variation of size and leads to replacement of formwork. Followed to that the second attribute is site condition (with the loading factor =0.829), it relates with the accessibility to construction site. Climatic condition is the third attribute (with the factor loading =0.778), which formwork is highly sensitive to weather conditions that leads to the increase in the cost and time duration of project. The fourth attribute that affects the formwork selection is insufficient instruction about handling (with the factor loading =0.694), the insufficient instruction leads to the damage in the formwork materials and requires replacement of the formwork and further leads to cost overrun. The fifth attribute is storage of formwork (with the factor loading =0.560), improper storage leads to damage and theft of formwork.

7.5 SELECTION BASED ON COST ASPECTS

The final major factor cost aspect with total variance value of 8.40%, in which four important attributes lies under this category. From cost aspect category the first attribute that affects the formwork selection is capital cost (with the factor loading =0.951) which is the total cost or the one-time expenses of the project, any issues may lead to the significant changes in the project cost. Followed to that second attribute of formwork is maintenance cost (with the factor loading =0.807), includes types of repair and storage of formwork influence the maintenance cost which results in the increase in cost of the project. Labor cost (with the loading factor =0.674) is the attributes in which work like erecting, removing and cleaning results in the efficient completion of project within the proposed budget. Finally the last attribute that affords to formwork selection is

transportation cost (with the factor loading =0.619), Where the formwork is to be transported from the manufacturing unit to the work site and return back to the storage yard once the project is completed.

8. REGRESSION ANALYSIS

Regression analysis is the study of relationship between dependent and independent variables. The independent variables are grouped under the five factors as shown in the Table 3 the dependent variables that are associated with the project completion are cost, quality and time. Multiple regression models are developed to determine the quantitative impacts of the factors and the performance is measured by the equation in Eq.(8.1)

$$(8.1) \quad Y_i = \beta_0 + \beta_1\alpha_{1i} + \beta_2\alpha_{2i} + \dots + \beta_j\alpha_{ji} + \varepsilon_i$$

Where Y = value of dependent variables; β_0 = constant; β_1 to β_j = regression coefficient; α_1 to α_n = values of independent variables, ε_i = random error.

Spearman correlation test was carried to find correlation between the factors affecting formwork system selection. It is done to identify the independent variable having significant correlation with three criteria cost quality and time. The independent variables against dependent variables of cost, quality and time are entered one by one in regression analysis. The model is selected based on correlation strength which is a measure of goodness of fit for the model. The value of R^2 changes if new independent variables are added and adjusted R^2 will be measured in the model. The adjusted R^2 value and R^2 value will show how the model generalizes the independent strength of the dependent variables [11]. The Table 3 shows the value of all three derived model with reasonable strength. The regression model for cost is expressed in Eq. (8.2)

$$(8.2) \quad \text{Cost} = 2.321 + 0.463(\text{Capital cost}) + 0.453(\text{Maintenance cost}) + 0.399(\text{Transportation cost})$$

Capital cost (0.463) is found to have strong link with the time performance in formwork selection since major part of the construction cost is spent on formwork. The maintenance cost (0.453) in the formwork make the surface finish in smooth manner and it also prevents in purchase of new formwork. While the transportation cost have least impact on formwork selection since most of the

company have their own formwork but transport of formwork to different site will involve cost while further affect the cost performance of the project completion.

The regression model for quality is expressed in Eq. (8.3)

$$(8.3) \quad \text{Quality} = 2.675 + 0.465(\text{Quality}) + 0.487(\text{Adaptability}) + 0.398(\text{Type of formwork}) + 0.498(\text{Safety})$$

The quality of formwork (0.465) has the highest impact on formwork selection in quality performance. If the formwork quality is poor then the strength and durability of concrete will not be achieved in proper manner. The adaptability (0.487) is an important aspect to get a smooth surface finish and provide a uniform structure. The type of formwork (0.398) being used in the building construction plays significant role in the construction, it gives a definite and neat surface finish to the structure. However the safety (0.498) plays a crucial role in quality performance, thus it has to be considered as an important aspect in the selection of the formwork. The regression model for time is expressed in Eq. (8.4)

$$(8.4) \quad \text{Time} = 2.411 + 0.478(\text{Construction cycle test}) + 0.418(\text{duration of project}) + 0.377(\text{Climatic condition})$$

As seen, duration of project (0.418) plays a major role in the completion of the project, which affects the delivering of the building to the owner. The selection of the formwork should be of suitable climate condition (0.377) for the extensive use of the formwork. Construction cycle time (0.478) has to be considered as important factor since; it helps in completion of project at the earliest.

Table 3: Multiple Regression Analysis

Variable	B coefficient	SE	t-value	sig.(p)	(R ²)/ADJUSTED R ²
Time performance					
Constant	2.411	0.256	2.543	0.001	0.3572/0.3829 F=6.822 P=0.0001 Durbin Watson= 1.865
Construction cycle time	0.478	0.023	2.678	0.054	
Duration of project	0.418	0.025	1.867	0.048	
Climate condition	0.377	0.115	1.245	0.036	

Cost performance					
Constant	2.321	0.267	2.387	0.001	0.3448/0.3598 F=7.454 P=0.0001 Durbin Watson= 1.848
Capital cost	0.463	0.265	1.845	0.047	
Maintenance cost	0.453	0.027	2.154	0.025	
Transportation cost	0.399	0.017	2.201	0.037	
Quality performance					
Constant	2.675	0.243	2.51	0.001	0.3678/0.3876 F=7.699 P=0.0001 Durbin Watson= 1.823
Quality	0.465	0.243	2.145	0.012	
Adaptability	0.487	0.016	2.013	0.031	
Type of formwork	0.398	0.019	1.578	0.046	
Safety	0.498	0.254	1.745	0.031	

9. CONCLUSION

This study identified the factors affecting the selection of formwork system in high rise buildings and the correlation between the factors. Client, Contractor and Consultant participated in a survey intended to identify and rank the major factors influencing selection of formwork system in high rise buildings. Among 40 factors Accessibility to work, quality, surface finish, storage of formwork, capital cost, safety, layout of structures, lifespan, exposure to environment and labor cost are the top 10 major factors identified in the survey. Based on the factor analysis 31 out of 40 factors were further categorized into 5 group's namely general aspects, structural aspects, formwork aspects, environmental aspects and cost aspects. As a result of this analysis more is known regarding the formwork systems selection factors in high rise buildings. Spearman's rank correlation coefficient was carried out to test of agreement of respondent which shows a strong level of agreement among the three pairs of the respondent to the survey. It demonstrates the validity and reliability of information and findings from the research. The regression modeling highlighted the relational links between selected key attributes the outcome of the project is based on time, cost and quality success. Constructions cycle time, duration of the project and climate condition were found to have a strong influence on the time performance. Similarly, maintenance cost, transportation cost and capital cost were found to have influence on the cost performance and the quality, safety, type of formwork and adaptability have a strong significant influence on the quality performance. Hence the regression modeling has been clear that cost, time and quality performances in the projects are valued through the attributes in the formwork selection process.

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LIST OF TABLES

Table 1: Factor Analysis

Table 2: Spearman rank correlation coefficient

Table 3: Multiple Regression Analysis

Received 30.03.2019

Revised 27.05.2019