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Research Paper

Comparative Study of Various Vertical Formwork Systems and Preparation of Formwork Selection Model Using Fuzzy Logic

Engineering

KEYWORDS : Vertical Formwork systems, Fuzzy logic, Knowledge base, selection factors, MATLAB

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ABSTRACT

Formwork system plays an important role in any construction project. Formwork system consumes large portion of total project cost. In India, selection of formwork is done on the basis of decision of project manager or experienced person. The decision maker may have restricted experience or unaware of new advancements in formwork systems. The probability of suitable selection is very less as the person selecting formwork system may or may not consider all factor in selecting formwork system. Comparison of the systems, considering advantages and limitations of each system is necessary. It needs to integrate all the information into one database. In proposed study of formwork selection, important factors affecting selection of vertical formwork system are found out by conducting questionnaire survey. Calculation of importance index was carried out, to find most important factor affect selection of vertical formwork system. Comparative analysis of different formwork systems was carried out on the basis of selected important factors. On the basis of comparative analysis, knowledge base is prepared. Finally, the knowledge base is automated by using fuzzy logic.

1. Introduction

Formwork system is very important element of any construction project. Formwork costs around 20% of total project cost [8]. Special attention must be given to selection of most suitable formwork system. In India, conventional wooden formwork system use everywhere, because of its low initial cost. Conventional wooden formwork system may affect economy, during actual construction operation due to wastages and high labour cost. Formwork system may be defined as "the system of support for freshly placed concrete as well as supporting members, hardware and necessary bracing" [5]. Classification of formwork is done mainly in two categories, horizontal formwork system and vertical formwork system [1]. In India, formwork is selected by referring to any formwork expert. There are no clear cut guidelines for formwork selection, as every construction project is different from each other. Formwork expert may have restricted experience [6]. Completely dependence on opinion of single person may lead to wrong decision. Nowadays, various new formwork systems are available in market. These systems have many advantages such as higher floor cycle rate, lower material wastage, large number of reuses, low maintenance cost and provides smooth concrete finish [6]. In the proposed study, Instead of selecting individual vertical formwork system, vertical formwork systems in combinations are studied. The objective is to find whether vertical formwork systems in combination will be the optimal solution or not. By studying various methods through literature review, it can be said that fuzzy logic is suitable for the preparation of proposed formwork selection model [1].

2. Vertical Formwork Systems

In the proposed research, various vertical systems are used in combination. Combinations of formwork systems are made such that all possible vertical structural members of varying geometry can be cast. Following are the vertical formwork systems used to make combinations.

2.1. *Wooden Formwork System*
2.2. *Panel Formwork System*
2.3. *System Column Formwork*
2.4. *Slip Formwork*
2.5. *Tunnel formwork*

3. Factors Affecting Selection of Formwork System

There are many factors, which have effect on selection of formwork system. Awad S Hanna et al. (1992) have carried extensive research on formwork selection and found the factors which affects formwork selection. The study grouped those factors into four major categories as building design, job specifications, local condition and supporting organisation. Each category included there related primary factors. Through literature review, a total of 29 factors were found which affect the selection of formwork system [1]. The proposed research is on vertical formwork system only. Therefore, it is necessary to shortlist factors which are more significant in vertical formwork selection. Considering complexity of proposed model and studying previous selection models, it was found that top five factors can be consider in proposed model. To find out the importance level of the factors, questionnaire survey was conducted [4]. In the questionnaire, each factor is represented against various importance levels. Importance levels are represented using five point likert scale. Targets for the questionnaire survey included project managers, engineers, formwork experts and contractors. Data was collected and analysed by calculating importance index of each factor. To calculate importance index following formula was used [4].

$$\text{Importance index} = \frac{\sum i\ vi \times fi}{n}$$

vi = score of each factor
fi =frequency of response
i = given respondents changes from 1 to*n*
n = total number of responses

After t-he analysis importance index of each factor was found. Importance index shows the average score of each factor. Top five factors with highest importance index were shortlisted for the preparation of model [1]. Shortlisted factors are building shape, potential refuses, floor cycle rate, initial cost of formwork system and labour cost.

4. Knowledge Base Preparation

Knowledge base contains all the raw data which expert system use while performing any operation [7]. In the proposed research, knowledge base is prepared in tabulated format by representing formwork system combinations against shortlisted factors. Based on literature and the interview survey carried out during the course of research, knowledge base, is prepared. In knowledge base information about various formwork systems and their performance characteristics are recorded. Table no. 1 shows the knowledge base.

5. Fuzzy Logic Model

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In this paper, model is prepared using fuzzy logic. Fuzzy logic has a unique ability to handle imprecise data. Imprecise data cannot be expressed in exact numeric figures, but it can be expressed in terms of linguistic values [1]. Linguistic values are less precise than a numeric values but has ability to express imprecise data. As discussed earlier, formwork selection is complex task and factors in selection process are ill defined to describe. For the preparation of fuzzy logic model it is need to define input, output variables and decision rules.

5.1. Fuzzy input variables

Fuzzy logic model consists of fuzzy input variables, fuzzy output variables and fuzzy rules. As discussed earlier, top five important factors with higher degree of importance were selected. These important factors were selected as fuzzy input variables. It was difficult to define varying values of input variables with crisp set, as in crisp set there is boundary limitation. Solution to this problem was fuzzy set. So, the concept of fuzzy set was adopted to define values of input variables. To cover universe of all varying values, input variables were expressed in membership functions as low (L), medium (M) and high (H) [1]. Ranges of the membership function were decided on the basis of various literature and interview survey carried out in Pune city. Trapezoidal section was adopted to represent membership function as shown in Fig.1. As trapezoidal is best suited to represent value distribution for the proposed study. Each factor need to be expressed in numeric form to suit fuzzy logic model.

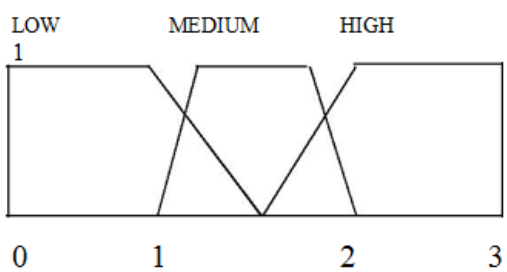

Figure 1: Trapezoidal membership function

In the selected factors, one factor building shape is qualitative factor, as it represents quality of structure. This qualitative factor can be represented in terms of shape regularity index as shown in table no. 2.

Table 2: Membership function of Qualitative factor

Membership functions →	LOW	MEDIUM	HIGH
Qualitative factors ↓			
Building shape	Building is regular	Building is semi-regular	Building is irregular

All other factors are quantitative factors, which are easy to define. Table no. 3 shows the representation of quantitative factors.

Table 3: Membership function of Quantitative factors

Membership functions →	LOW	MEDIUM	HIGH
Quantitative factors ▼			
Potential reuses	Less than 10 reuses	Between 10 to 50 reuses	More than 50 reuses
Floor cycle rate	Higher than one floor per 5 days	Between one floor per 4 to 5 days	Lower than one floor per 2 days
Initial cost of formwork system	Higher than 20% of total project cost	Between 10% to 20% of total project cost	Lower than 10% of total project cost
Labour cost	Higher than 5% of total project cost	Between 2% to 5% of total project cost	Less than 2% of total project cost

Table 1 : Knowledge-Base for Vertical Formwork Selection

Formwork system	Conventional wooden	Conventional wooden	System column formwork	Panel formwork	Tunnel formwork
combinations	formwork system	formwork	+	+	
		+	Panel formwork	Slip form	
Factors		Panel formwork			
	(It is suitable for RCC	(Panel formwork system	(With system column	(Staircase shaft, lift shaft,	(With tunnel formwork
	columns, lift shaft, staircase	can be used where wooden	formwork RCC columns of	shear wall and concrete	advance new load bearing
	shaft staircase, retaining	system may limit in	various sizes and footing	core [for high rise] can be	structures can be construct.)
	wall)	strength, height, or time	columns can be cast and	cast with slipform all other	
		limit)	with panel formwork all	members can be cast with	
			other members can be cast)	panel formwork)	
Building shape	Any type of variation in	Adaptability with variation	Adaptability with variation	Adaptability with variation	Adaptability with variation
	building shape can handle ,	in shape is good [6]	in shape is medium[6]	in shape is low[6]	in shape is very low[6]
	adaptability with variation				
	in building shape is good[6]				
Potential reuses	less than 10[4]	Wooden formwork: less than 10[4]	In combination up to 50 [6]	Panel formwork: up to 50 [6]	Up to 1000 reuses [1]
		Panel formwork: 40 to 50 [6]		Slipform : up to 100 [1]	
Floor cycle rate	One floor per week [4]	One floor per 6 days [4]	One floor per 4 days [6]	One floor per 2 days [6]	One floor per day [1]

Initial cost of formwork	Maximum 8% of total	Maximum 12% of total	Maximum 17% of total	Maximum 25% percentage	Up to 30% of total cost
system	project cost	project cost	project cost	of total project cost	
Labour cost	Up to 8% of total project cost	Up to 5% of total project cost	3% of total project cost	Up to 1% of total project cost	0.5 % of total project cost

Table 1 : Knowledge-Base for Vertical Formwork Selection

5.2. Fuzzy output variables

All five formwork system combinations were considered as fuzzy output variables, as the fuzzy logic model will give output as the one of the vertical formwork system combination. The output will give suitability of the vertical formwork system with respect to governing factors. Suitability cannot be explained precisely. Hence, fuzzy output variables need to be defined in terms of membership functions. Then the Fuzzy output variables will give their suitability, expressed in terms of poor, fair and good as membership function.

5.3. Fuzzy decision rules

Now, that the Fuzzy input and fuzzy output variables are defined, to regulate this complex data the decision rules should be define. Fuzzy decision rules includes all possible output values of membership function for each value of membership function of input variables.

5.4. Fuzzy logic model preparation

Fuzzy logic model can be prepared in Fuzzy Logic Tool box of the MATLAB. Table no. 4 showing all possible suitability scores can feed as fuzzy knowledge base for the preparation of model. Figure no. 2 shows how to define input and output variables. Figure no. 3 shows membership function editor in which each input and output variable can defined with respect to its range and shape of membership function. Figure no. 4 shows fuzzy decision rule editor, in which rules can be enter in model. Figure no. 5 shows fuzzy logic model output interface, in which we can actually check output results for the given input values.

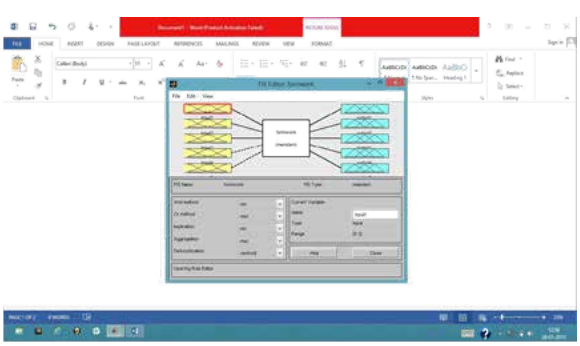

Figure 2: Input and output variables in MATLAB

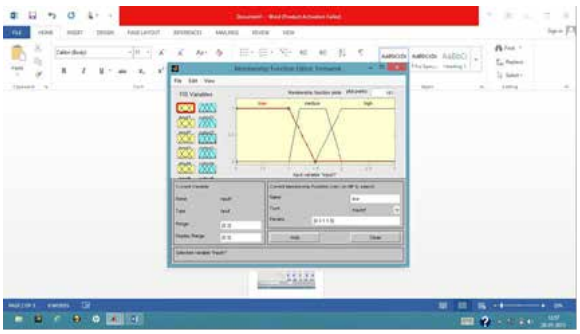

Figure 3: Membership function editor

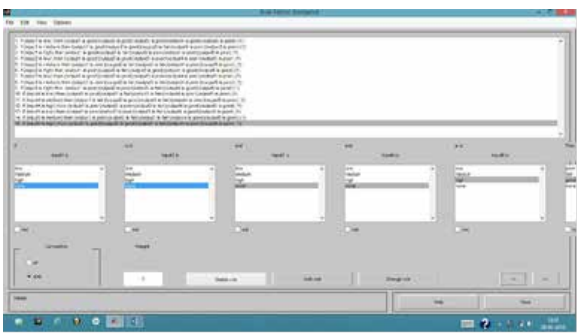

Figure 4: Fuzzy logic decision rules editor

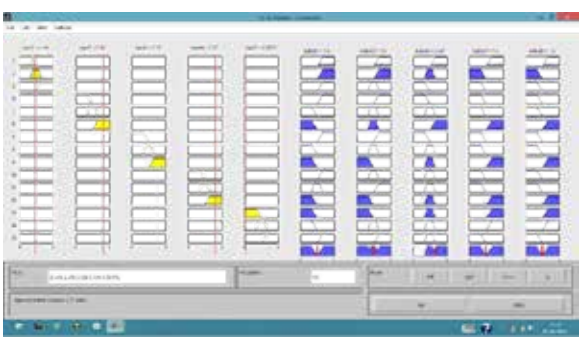

Figure 5: Fuzzy logic model output

6. Conclusion

In the proposed research, fuzzy logic model was prepared. The model predicts the best suited formwork system combination, depending upon the factors affecting the particular building project in selection of formwork system. Initially, questionnaire survey was carried out to find most important factors. Total five most important factors were shortlisted. Knowledge base is prepared using selected factors and formwork system combinations. Finally, fuzzy logic model is prepared to automate the process. This model overcomes the ambiguity in formwork selection process. This model processes itself and gives result like a formwork expert.

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