FRAMEWORK FOR IDENTIFYING INFLUENCING FACTORS FOR STAY-IN-PLACE FORMWORK IN BRIDGE CONSTRUCTION

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The formwork system (FWS) adopted for construction is the most important and crucial part of any structure, as it contributes about 40% to 60% of the cost of concrete and 10% of the total cost of construction. Formwork activity also consumes 50% to 70% of the total time required in RC construction. Particularly in bridge construction, conventional FWS is used for the construction of the bridge's deck, which requires the assembly of multiple FWS components. Conventional FWSs for deck construction are time and labor-intensive. Recently, there is a rise in the use of Stay-in-Place (SIP) formwork for bridge superstructure construction. SIP FWS eliminates the use of falsework, resulting in a reduction in labor input and time. The present study attempts to identify influencing factors affecting the selection of SIP FWS over the conventional FWS in bridge deck construction using the Delphi method. Firstly, based on the literature review, 7 main factors and 28 sub-factors influencing the selection of SIP FWS are identified. Three rounds of the Delphi method are conducted to finalize the main factors and sub-factors by creating a questionnaire and gathering responses from 10 qualified experts. Subsequently, the main 7 factors (Flexibility, Economy, Quality, Safety, Completion Time, Local Condition, and Organizational Support) and 27 sub-factors are shortlisted. Cronbach’s alpha is calculated to check the internal consistency of the main factors. The proposed framework can be extended for estimating the acceptability of SIP FWS compared to the conventional FWS in the Indian Construction Industry.

Keywords: Lost formwork, Slab formwork, Bridge deck construction, Delphi method.

1 INTRODUCTION

Formwork is a temporary structure used to support concrete until it sets and gains strength to support its own weight. The primary purpose of formwork is to mold concrete in any required shape and support until it gets sufficient strength. The formwork cost contributes about 40% to 60% of the cost of the concrete skeleton and 10% of the entire construction cost (Shin 2011). Basu and Jha (2016) stated that time and cost are two significant constraints for the residential project. A good FWS can quickly complete the concreting activity, after which other successive activities may begin. Other aspects, such as safety, quality, and productivity, play a crucial role in selecting any FWS. The selection process of FWS for any construction process requires the judgment of formwork experts. This judgment of FWS selection depends upon various factors. Identifying such influencing factors is crucial for decision-makers to select the appropriate FWS. Emerging FWS gets a definite level of acceptability by the industry based on their ability to meet the
requirement. One of them is SIP formwork for bridge deck construction. There are many advantages of these SIP forms, including the elimination of falsework resulting in the reduction of labor cost, quality of construction, and ease of construction. In addition to that, as falsework for deck construction is eliminated, construction time and material cost for formwork can be reduced.

Considering the importance of SIP FWS in construction work, this study aims to identify the factors affecting the selection of SIP FWS. To gain better understanding of FWS in construction work, the following section review the literature and outline the gaps in existing research. Then, the sections include research methodology, data collection and analysis, and the conclusions.

2 LITERATURE REVIEW

In recent years, selecting an appropriate FWS is critical in any construction project. In this regard, several studies have explored the selection of FWS for construction projects. Elazouni et al. (2005) listed a variety of factors for estimating the acceptability of the new four systems by identifying six factors, including quantitative factors (construction time and cost) and qualitative factors (quality, safety, expected familiarity, and flexibility). Hanna (1989) identified four main factors (Building design, local condition, job specification, and supporting organization), twelve sub-main factors, and 38 factors that influence the FWS selection. Basu and Jha (2016) include two more factors, quality of formwork and available site characteristics in the above four factors. Terzioglu et al. (2022) introduced a structural equation modelling approach for selecting FWS criteria for building construction projects and identified 5 main factors: structural design, performance indicators, local conditions, cost, and formwork system (FWS) and formwork fabricators (FWF) characteristics. Tam et al. (2007) identifies building height, structural system, site circumstances (accessibility, make-up space, neighboring buildings, or utilities), building form, equipment availability, and concrete finish as selecting factors. Bank et al. (2009) developed a model construction and design specification for thin non-participating permanent formwork panels, also termed as lost formwork, composed of FRP or FRC with or without reinforcement for use in the construction of concrete slabs, particularly highway bridge decks. Based on this study, FRP or FRC panels may be used in bridge deck construction as SIP formwork if employed according to the model specification. Gai et al. (2013) examines the ductility of FRP SIP structural FWS supporting concrete slabs. Nelson and Fam (2014) tested working of SIP FWS for concrete bridge decks on a bridge with girders, diaphragms, and monolithic connectors. Hanus et al. (2009) used SIP form built with FRP to build and strengthen a hypothetical military bridge deck. The literature review explores that most of the studies mentioned above have identified the factors for selecting the formwork system for residential and industrial construction. However, no such studies are available on identifying the factors for the SIP formwork used in bridge construction. Therefore, there is a need to identify factors and develop a framework that can help in selecting the SIP formwork system for bridge deck construction.

Further in the aforementioned studies, approaches such as surveys, interviews, and group brainstorming sessions are required for research that includes confounding multiple factors. However, compare to these above-mentioned conventional approaches, the Delphi method is more accurate (Lad et al. 2022). In this connection, the Delphi method can be preferred to identify and shortlist the factors. The Delphi method uses well-designed questionnaires, and enables researchers to get highly trustworthy information from qualified experts. It is also a systematic and interactive research approach for acquiring the opinions of a group of independent experts by reviewing the opinions of experts given in the previous round. This way, a consensus is reached, which provides anonymous feedback throughout numerous rounds. Ameyaw et al. (2016) reviewed 88 studies published between 1990 and 2012 in the construction engineering and management (CEM) industry
that used Delphi and other quantitative methodologies. Hallowell and Gambatese (2010) explain the process of Delphi method, and asserted that researchers in CEM often turn to the Delphi method because it can reveal extremely reliable data from experienced professionals by using surveys that have been carefully designed. Hallowell and Gambatese (2010) gave researchers a standardized framework for using the Delphi method in attentive studies. Chan et al. (2001) developed a multi-attribute model using the Delphi approach by conducting four rounds of Delphi surveys. The Delphi exercise’s iterations enabled the experts to change the utility factors weighting and project them beyond their own personal perspectives, which leads to a more reliable outcome. In addition to discussing the challenges of conducting a Delphi survey, the efficiency of the Delphi technique is assessed. The criteria and utility factors derived from the Delphi survey are then used to construct a procurement selection model. This way Delphi method can be a useful method to analyze factors.

3 RESEARCH METHODOLOGY

Following a thorough assessment of the literature, the following research methodology is developed and it is shown in Figure 1.

The first step of this study is to identify the influencing factors for SIP FWS through an extensive literature review. Following the factor identification, in step 2, guidelines for selecting qualifying experts are prepared. Based on these guidelines, experts (also called as Delphi panelists) are selected to conduct the Delphi rounds. In step 3, the first round of the Delphi method is conducted in which identified influencing factors are discussed with qualified experts, and feedback is obtained. In Step 4 the second round of the Delphi method, wherein a 6-point Likert scale questionnaire is formed and forwarded to qualified experts for collecting the response. In step 5, the result is interpreted from the data collected from the questionnaire. Various statistical parameters are established and calculated for the response collected from the questionnaire. Statistical parameters are calculated to measure if desired consensus is achieved or not. If the desired consensus is not achieved, responses shall be collected again with the help of a questionnaire. Step 6, the third round of the Delphi method is conducted, where the result of the second round is discussed with the experts, and their opinion is obtained to finalize the factors to develop the framework. In step 7, if all the experts agree with the result of 2nd round, then factors are finalized, and a framework can be developed for SIP FWS.

4 DATA COLLECTION AND ANALYSIS

According to the first step of the research methodology, seven main factors and 28 sub-factors are identified through a literature review as shown in Table 1. Ten experts are identified as eligible and selected for conducting Delphi rounds. The selection of these 10 experts was based on the
satisfying at least three out of the following six criteria: (i) minimum three years of experience in SIP formwork system; (ii) minimum four years if bachelor in civil engineering degree or master’s in construction management/structural engineering; (iii) professional registration such as registered engineer/licensed engineer; (iv) primary or secondary author of at least three pre-review journal articles; (v) invited to present at a conference or training program; and (vi) member or chair of a nationally recognized committee, society/council. Then, those probable factors are discussed with selected experts, and 7 main factors and 28 corresponding sub-factors are agreed by them after the first round of the Delphi method.

Table 1. List of influencing factors for SIP FWS.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Sub-Factors</th>
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<tbody>
<tr>
<td>F1 Flexibility</td>
<td>F1.1 Type of Bridge, F1.2 Shape, F1.3 Size</td>
</tr>
<tr>
<td>F2 Economy</td>
<td>F2.1 Initial Investment, F2.2 Transportation Cost, F2.3 Fabrication cost, F2.4 Fabrication cost, F2.5 Potential reuse, F2.6 Scrap value</td>
</tr>
<tr>
<td>F3 Quality</td>
<td>F3.1 Concrete finish, F3.2 Compaction technique, F3.3 Curing technique</td>
</tr>
<tr>
<td>F4 Safety</td>
<td>F4.1 Working environment, F4.2 Degree supervision, F4.3 Risk assessment, F4.4 Safety measures taken,</td>
</tr>
<tr>
<td>F5 Completion time</td>
<td>F5.1 Cycle time, F5.2 Erection time, F5.3 Stripping time, F5.4 Setting time of concrete</td>
</tr>
<tr>
<td>F6 Local condition</td>
<td>F6.1 Exposed condition, F6.2 Cost of labor, F6.3 Quality of labor, F6.4 Working space (urban or sub-urban), F6.5 Yard facility</td>
</tr>
<tr>
<td>F7 Organization Support</td>
<td>F7.1 Available capital, F7.2 Equipment and machinery, F7.3 Head of support</td>
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</table>

In the second round, a developed questionnaire is sent to those selected experts to collect responses for each factor on a 6-point Likert scale. Lad et al. (2021) advocated that neutral should not be considered in Likert scale to have convenient response without requiring cognitive effort. To assess the consensus of the response given by experts, certain statistical parameters are established. Parameters like mean, median, absolute deviation (AD)- median, coefficient of variation (CV), and data range are calculated, and the result of these statistical parameters are shown in the Table 2. Further, to shortlist the factors, the limits of absolute deviation (AD)- median, coefficient of variation (CV) should be stated and it can be based on the requirement of a particular study (Lad et al. 2021). Therefore, in this study absolute deviation (AD)-median, coefficient of variation (CV), and the range of data should be less than 0.50, 0.25 and 4, respectively. Hence, no main factors are eliminated from the study. For the factors to be internally consistent, the reliability test is conducted by calculating Cronbach’s Alpha. Hair et al. (2018) stated that value of Cronbach’s Alpha shall be more than 0.6 for all factors and sub-factors. Further, value of 0.6 is acceptable for indicating consistency using Cronbach’s alpha determination (Patel and Jha 2017). As a result, the sub-factor scrap value from the main factor economy is eliminated. Finally, 7 main factors and 27 sub-factors are shortlisted based on Cronbach’s Alpha value.

In the third round of Delphi method, all shortlisted factors and sub-factors are discussed with the experts to obtain their consensus. All the shortlisted factors and sub-factors were agreed by the experts. Thus, 7 main factors and 27 sub-factors are finalized after implementation of Delphi method. The first factor Flexibility characterized features of formwork system that make the system acceptable for different size and shape of bridge components. This also incorporates the formwork's flexibility, which comprises design flexibility, connection flexibility, flexibility in size variation, and strength. Economy includes different cost incurred in this FWS. Quality factor includes quality of concrete in terms of concrete finish, compaction technique and curing method used for construction. Safety factors describes the risk associated and safety measures taken for
work associated with this FWS. Completion time factor includes time required for erection, stripping, and setting time of concrete. Local conditions like local formwork practices, weather conditions and site condition play vital role in choosing this FWS. Organizational support to use this FWS for bridge deck construction is necessary in terms of financial support, making available qualified workers and machinery.

Table 2. Result of statistical parameters after second round of the Delphi method.

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</thead>
<tbody>
<tr>
<td>Flexibility</td>
<td>5.1</td>
<td>0.57</td>
<td>5</td>
<td>0.11</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>0.36</td>
<td>0.00</td>
<td>0.29</td>
<td>0.93</td>
</tr>
<tr>
<td>Economy</td>
<td>5.3</td>
<td>0.48</td>
<td>5</td>
<td>0.09</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>0.42</td>
<td>0.00</td>
<td>0.21</td>
<td>0.745</td>
</tr>
<tr>
<td>Quality</td>
<td>5.5</td>
<td>0.85</td>
<td>6</td>
<td>0.16</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>0.7</td>
<td>0.00</td>
<td>0.65</td>
<td>0.783</td>
</tr>
<tr>
<td>Safety</td>
<td>5.4</td>
<td>1.35</td>
<td>6</td>
<td>0.25</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>0.96</td>
<td>0.00</td>
<td>1.64</td>
<td>0.947</td>
</tr>
<tr>
<td>Completion time</td>
<td>5.2</td>
<td>0.92</td>
<td>5</td>
<td>0.18</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>0.64</td>
<td>0.5</td>
<td>0.76</td>
<td>0.915</td>
</tr>
<tr>
<td>Local condition</td>
<td>4.7</td>
<td>1.06</td>
<td>5</td>
<td>0.23</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>0.68</td>
<td>0.00</td>
<td>1.01</td>
<td>0.738</td>
</tr>
<tr>
<td>Organization Support</td>
<td>4.6</td>
<td>0.84</td>
<td>5</td>
<td>0.18</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>0.68</td>
<td>0.5</td>
<td>0.64</td>
<td>0.721</td>
</tr>
</tbody>
</table>

5 CONCLUSIONS

This study identified factors and develop a framework for the SIP FWS using the Delphi method. As new FWS are introduced to formwork experts and decision-makers, it becomes crucial to identify such factors that can be considered while selecting FWS. Particularly for SIP FWS, 7 main factors and 28 sub-factors are identified through the literature review, which are the influencing factors. These factors are finalized by conducting three rounds of the Delphi method. Statistical parameters like AD-median, Covariance, and range data are calculated to measure the consensus. As a result of calculating these parameters, a sub-factor scrap value got eliminated from the study in the second round of Delphi. Finally, 7 main factors and 27 sub-factors are finalized, which are the influencing factors for SIP FWS in Indian construction industry.

The proposed framework exclusively identifies influencing factors and corresponding sub-factor for SIP FWS only. The proposed framework can be useful in selecting the SIP formwork over the conventional formwork system in terms of economy, quality, safety, flexibility, completion time, local condition, and organization support. The limitation of the present study is that the develop framework is only applicable to the bridge deck construction. Before the framework could be used to assess quantitatively, it is essential to determine the relative weights of the 7 factors and their sub-factors. For this, the research is required to propose a qualitative approach for quantifying the SIP FWS in Indian construction industry. Further studies can also develop similar framework for other special type of FWS.

References


1 M-Mean, SD-Standard Deviation, Med.-Median, CV-Coefficient of Variance, R-Range of Data (Max.-Min.), ADM-Absolute deviation (Mean), AD Med.- Absolute Deviation (Median), V-Variance.


