Selection of formwork options when constructing high-rise buildings by AHP method (Case Study: Cao Lanh city, Vietnam)

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Abstract. Selecting the right construction formwork solution is vital to the success of a construction project. It can help speed up the construction schedule, boost quality, reduce construction costs, and ensure the safety of workers on the construction site. Construction contractors should carefully consider the project's characteristics and their capacity when selecting the most suitable formwork solution. The Analytic Hierarchy Process (AHP) method is a decision-making tool that can be useful in selecting the best formwork solution for constructing high-rise buildings. The AHP method allows decision-makers to break down complex decisions into smaller, more manageable parts and to evaluate alternatives based on a set of criteria. The paper presents the process and propose the use of the method in selecting formwork options.

Keywords: AHP, formwork, high-rise buildings, criteria, aluminum formwork, steel formwork, wood steel formwork

1 Introduction

There have been many studies conducted on different formwork solutions used in construction works[1-4]. These studies have focused on various aspects of formwork, including cost-effectiveness, durability, safety, ease of installation and removal, and environmental impact [5-7].

Currently wood formwork is still the main solution for constructing high-rise buildings in Dong Thap province, especially in Cao Lanh city, as it is a widely used and cost-effective option. However, it is worth noting that as the speed of infrastructure and traffic development in the region increases, there may be a need for more efficient and durable formwork solutions to keep up with the pace of construction. The use of aluminum formwork in construction is also a good option, as it offers several advantages over traditional wood formwork. Aluminum formwork is lightweight, durable, and reusable, which can help reduce construction time and costs.[8, 9] It also provides a smooth and consistent finish, which can improve the quality of the finished structure.

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This study will to introduce the method selecting formwork options for high-rise building projects. The use of the Analytic Hierarchy Process (AHP) [10-12] as a multiple-criteria decision making method is a well-established technique that can help to prioritize and rank various formwork options based on a set of predetermined criteria.

2 Selection of formwork options by AHP method

AHP is a decision-making methodology that helps individuals and organizations make complex decisions by breaking them down into smaller, more manageable parts. AHP was developed by Thomas Saaty [13] and has become a widely used decision-making tool in various fields, including business, engineering, and social sciences.

The formwork selection was developed using the AHP. The four secondary level formwork selection factors were identified and their relative importance was determined through a questionnaire survey. Respondents were asked to compare the factors in a pairwise manner and rate their relative importance on a scale of 1 to 9, as suggested by Saaty[13] (table 1.). Using the input values from practitioners and the relative weights of the formwork selection factors, the model computes priority values (scores) and rankings of the alternatives. The practitioner can compare any number of formwork alternatives of their choice based on the constraints of the project for which the system is being selected. In general, the implementation of this research is illustratedin the following picture Flowchart.

Calculate the weight of each criterion by summing a pairwise comparison matrix using mathematical algorithms. This process helps determine the relative importance of each criterion. The next step is to evaluate each alternative based on how well each criterion is met. The score for each alternative is calculated by multiplying the weight of each criterion by the rating for that criterion, and then summing the results.

Table 1: Value point of comparative scale Source

Numerical Values	Definition
1	Equally important or preferred
3	Slightly more important or preferred
5	Strongly more important or preferred
7	Very strongly more important or preferred
9	Extremely more important or preferred
2, 4, 6 and 8	Intermediate values to reflect compromise

To build reinforced concrete high-rise buildings, there are many formwork technology solutions in Vietnam. Formwork is typically made of wood, steel, aluminum, or plastic materials and is assembled on-site based on the shape and size of the concrete structure being built. Experts recommend formwork options suitable for reinforced concrete high-rise buildings as follows:

- Project 1 (PA1): Using aluminum formwork
- Project 2 (PA2): Using profiled steel formwork
- Project 3 (PA3): Using industrial wood formwork
- Project 4 (PA4): Using natural wood formwork

Survering with 50 experts in the construction field to evaluate the selection of formwork solutions. Based on the analysis of the contractor's capacity and construction experience as well as the actual situation of the project, the experts have proposed four criteria for selecting the option:

C1: Optimal economic efficiency

- This criterion suggests that construction activities should be carried out in a way that minimizes costs and maximizes the return on investment. This can involve careful planning and resource allocation, as well as the use of efficient construction methods and materials.

C2: Mechanization, high-tech tools and equipment

- This criterion emphasizes the use of advanced technology and equipment in construction processes. By using machines and tools that are specifically designed for construction tasks, workers can complete tasks more quickly and with greater precision.

C3: Scientific organization of labor

- This criterion highlights the importance of organizing construction work in a logical and efficient manner. This involves careful planning and coordination of activities, as well as the use of specialized knowledge and expertise.

C4: Standardization and shaping of construction

- This standard involves the use of standardized construction methods and materials to ensure consistent quality and reliability in the finished product. By adhering to established standards, construction projects can be completed more quickly and with fewer errors or defects.

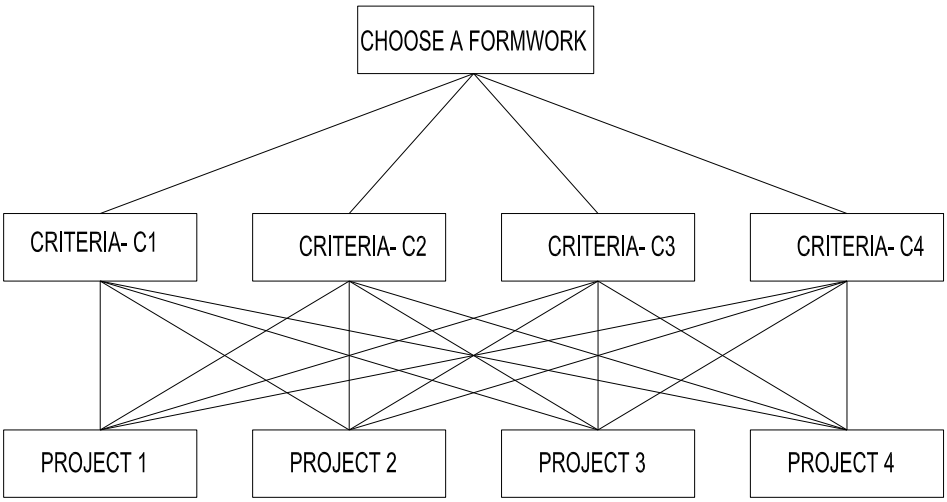

Fig. 1. Diagram describing the problem of hierarchical analysis

3 Calculation results

From the general opinions of experts on the priority of the criteria, we set up a pairwise comparison matrix in Table 2.

Table 2. Comparison of Criteria Pairs

Criteria	C1	C2	C3	C4
C1	1	4	3	6

C2	1/4	1	1/3	3
C3	1/3	3	1	5
C4	1/6	1/3	1/5	1
Sum	1.75	8.33	4.53	15

Calculating the data according to the AHP method, the weights of the criteria are shown in Table 3.

Table 3. Weight of criteria when comparing pairs

Criteria	C1	C2	C3	C4	Weight of criteria (w_i)
C1	0.57	0.48	0.66	0.40	0.528
C2	0.14	0.12	0.07	0.20	0.134
C3	0.19	0.36	0.22	0.33	0.276
C4	0.10	0.04	0.04	0.07	0.062

With the number of criteria n=4 then RI=0.9. We can calculate the following metrics:
Consistency vector of criteria:

$$f_i = \sum_{i=1}^{n} \left(\sum a_{ij} x w_i \right) x \frac{1}{w_i}$$

$$\lambda_{max} = \frac{\sum_{i=1}^{n} f_i}{n}$$

Table 4. Consistency vector of criteria

Weight	0.528	0.134	0.276	0.062	Sum	Consistency vector (f_i)
Criteria	**C1**	**C2**	**C3**	**C4**		
C1	0.53	0.54	0.83	0.37	2.26	4.28
C2	0.13	0.13	0.09	0.18	0.54	4.05
C3	0.18	0.40	0.28	0.31	1.16	4.21
C4	0.09	0.04	0.06	0.06	0.25	4.06

$$\lambda_{max} = (4.28 + 4.05 + 4.21 + 4.06)/4 = 4.15$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4.15 - 4}{4 - 1} = 0.049$$

$$CR = \frac{CI}{RI} = \frac{0.049}{0.9} = 5.5\% < 10\% \text{ (ok)}$$

Continuing to calculate the priority of the options according to each criterion, we set up the corresponding matrices with the size equal to the number of proposed solutions.
Since there are 4 comparison criteria, it is necessary to calculate 4 matrices with the data obtained from the expert consultation interview. Set up the calculation matrix for criterion C1 (optimal economic efficiency):

Table 5. Priority matrix of options for criterion C1

Criteria	PA1	PA2	PA3	PA4
PA1	1	3	5	7
PA2	1/3	1	3	5
PA3	1/5	1/3	1	2
PA4	1/7	1/5	1/2	1
Tổng	1.68	4.53	9.50	15.00

Calculate the weights for the options according to C1 criterion and shown in Table 6.

Table 6. Weight of alternatives according to criteria C1

Criteria	PA1	PA2	PA3	PA4	Weight of criteria (w_i)
PA1	0.60	0.66	0.53	0.47	0.563
PA2	0.20	0.22	0.32	0.33	0.267
PA3	0.12	0.07	0.11	0.13	0.108
PA4	0.09	0.04	0.05	0.07	0.062

With the number of criteria n=4 then RI=0.9. Calculating similar to the steps above, we have:

$$\lambda_{max} = 4.069$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4.069 - 4}{4 - 1} = 0.023$$

$$CR = \frac{CI}{RI} = \frac{0.023}{0.9} = 2.5\% < 10\% \text{ (ok)}$$

Similarly, synthesize expert advice and make table 3.6 for criterion C2

Table 7. Priority matrix of options for criterion C2

Criteria C2	PA1	PA2	PA3	PA4
PA1	1	5	6	8
PA2	1/5	1	3	4
PA3	1/6	1/3	1	2
PA4	1/8	1/4	1/2	1
Tổng	1.49	6.58	10.50	15.00

Calculate the weights for the options according to C2 criterion and shown in Table 3.7.

Table 8. Weight of alternatives according to criteria C2

Criteria	PA1	PA2	PA3	PA4	Weight of criteria (w_i)
PA1	0.67	0.76	0.57	0.53	0.634
PA2	0.13	0.15	0.29	0.27	0.210
PA3	0.11	0.05	0.10	0.13	0.098
PA4	0.08	0.04	0.05	0.07	0.059

With the number of criteria n=4 then RI=0.9. Calculating similar to the steps above, we have:

$$\lambda_{max} = 4.129$$

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{4.129 - 4}{4-1} = 0.043$$

$$CR = \frac{CI}{RI} = \frac{0.043}{0.9} = 4.8\% < 10\% \text{ (ok)}$$

Continue to consult experts to calculate and tabulate the priority of options for C3 criterion as follows:

Table 9. Priority matrix of options for criterion C3

Criteria	PA1	PA2	PA3	PA4
PA1	1	2	5	6
PA2	1/2	1	4	4
PA3	1/5	1/4	1	2
PA4	1/9	1/4	1/2	1
Sum	1.87	3.50	10.50	13.00

Calculate the weights for the options according to C3 criterion and shown in Table 10.

Table 10. Weight of alternatives according to criteria C3

Criteria	PA1	PA2	PA3	PA4	Weight of criteria (w_i)
PA1	0.54	0.57	0.48	0.46	0.511
PA2	0.27	0.29	0.38	0.31	0.311
PA3	0.11	0.07	0.10	0.15	0.107
PA4	0.09	0.07	0.05	0.08	0.071

With the number of criteria n=4 then RI=0.9. Calculating similar to the steps above, we have:

$$\lambda_{max} = 4.066$$

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{4.066 - 4}{4-1} = 0.022$$

$CR = \frac{CI}{RI} = \frac{0.022}{0.9} = 2.5\% < 10\%$ (Đạt yêu cầu)

Finally, we collect expert opinions and tabulate the priority of the options for C4 criterion

Table 11. Priority matrix of options for criterion C4

Criteria	PA1	PA2	PA3	PA4
PA1	1	3	6	7
PA2	1/3	1	5	6
PA3	1/6	1/5	1	3
PA4	1/7	1/6	1/3	1
Sum	1.64	4.37	12.33	17.00

Calculate the weights for the options according to C4 criterion and shown in Table 12.

Table 12. Weight of alternatives according to criteria C4

Criteria	PA1	PA2	PA3	PA4	Weight of criteria (w_i)
PA1	0.61	0.69	0.49	0.41	0.548
PA2	0.20	0.23	0.41	0.35	0.298
PA3	0.10	0.05	0.08	0.18	0.101
PA4	0.09	0.04	0.03	0.06	0.053

With the number of criteria n=4 then RI=0.9. Calculating similar to the steps above, we have:

$$\lambda_{max} = 4.227$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4.227 - 4}{4 - 1} = 0.076$$

$CR = \frac{CI}{RI} = \frac{0.076}{0.9} = 8.4\% < 10\%$ (Đạt yêu cầu)

After calculating the above weighted data, we can set up table 3.12 which summarizes the following calculation results:

Table 13. Summary of calculation results

Project	Criteria				Weight of criteria	
	C1	C2	C3	C4		
Project 1	0.563	0.634	0.511	0.548	C1	0.528
Project 2	0.267	0.210	0.311	0.298	C2	0.134
Project 3	0.108	0.098	0.107	0.101	C3	0.276
Project 4	0.062	0.059	0.071	0.053	C4	0.062

Multiplying the two matrices shown in Table 3.12 together, we have the results of evaluating the optimal choice as the one with the largest value as follows:

Project 1= 0.56
Project 2 = 0.27
Project 3 = 0.11
Project 4 = 0.06

4 Conclusion

Choosing the right formwork solution for a high-rise building involves a complex decision-making process that requires considering various criteria with different priorities. Each project has its unique design, schedule plan, and construction technology, which can make it challenging to find a single formwork solution for all projects. One approach to addressing this challenge is to use the Analytic Hierarchy Process (AHP), which is a multi-criteria decision-making method that can help determine the relative importance of different criteria and identify the best formwork solution based on those criteria

Survey results at ongoing works in Cao Lanh city (Dong Thap) show that the use of aluminum formwork solutions in construction is encouraged by many experts to be selected. While the initial investment cost of aluminum formwork may be high, the long-term benefits and cost savings can make it a viable option for construction projects. Creating companies that specialize in leasing formwork systems can help smaller construction companies access this technology and promote sustainable construction practices.

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