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Research Paper

Study of Alternative Formwork Methods for Concrete Retaining Wall Structures: Kali Bekasi Flood Control Project, Package 7

Arief Kurniawan[1], Krishna Suryanto Pribadi[2], Fitri Suryani[3]

[1]*Master Student, Civil Engineering Study Program, Universitas Persada Indonesia Y.A.I, Jakarta Indonesia*

[2]*Lecturer, Civil Engineering Study Program, Universitas Persada Indonesia Y.A.I, Jakarta Indonesia*

[3]*Lecturer, Civil Engineering Study Program, Universitas Persada Indonesia Y.A.I, Jakarta Indonesia*
Corresponding Author: Arief Kurniawan

ABSTRACT: *Formwork selection is a critical construction management decision because it affects construction cost, duration, productivity, concrete surface quality, workability, occupational safety, and project risk. This study evaluates three alternative formwork systems for reinforced concrete retaining walls in the Bekasi River Flood Control Project Package 7 in Indonesia: conventional formwork, semi-system formwork using hollow steel box frames, and Doka system formwork. A sequential explanatory mixed methods design was employed. Quantitative analysis compared construction cost, productivity, and implementation time, while questionnaire-based assessment was used to evaluate visual quality, ease of implementation, and occupational safety. Risk identification and evaluation were subsequently conducted using a Probability Impact Matrix, followed by qualitative interpretation through field observations, semi-structured interviews, and project documentation. The quantitative results indicate substantial differences among the alternatives. The total estimated formwork cost was IDR 13.195 billion for the conventional system, IDR 19.169 billion for the semi-system, and IDR 18.591 billion for the Doka system. Although conventional formwork had the lowest initial cost, the Doka system obtained the highest performance scores for time, visual quality, ease of implementation, and occupational safety. The mean scores for time were 3.37, 3.41, and 3.77, while visual quality scores were 2.83, 2.98, and 3.69 for conventional, semi-system, and Doka formwork, respectively. Ease of implementation scores were 2.97, 3.07, and 3.83, whereas occupational safety scores were 2.91, 2.92, and 3.43. Integration of the quantitative and qualitative findings indicates that Doka formwork provides the most balanced performance for repetitive retaining wall construction despite its higher initial investment. The findings suggest that formwork selection for flood control infrastructure should consider multidimensional project performance rather than initial cost alone.*

KEYWORDS: *formwork system; retaining wall; construction productivity; construction cost; construction safety; risk management; mixed methods; flood control infrastructure*

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I. INTRODUCTION

Formwork is a temporary construction system used to shape and support fresh concrete until the concrete achieves sufficient strength. Its selection has direct implications for construction cost, duration, productivity, safety, structural geometry, and surface quality. Recent studies have emphasized that formwork selection is inherently a multi-criteria decision because the most economical alternative is not necessarily the most productive, safest, or highest-performing alternative [1,2].

The development of modular and prefabricated formwork systems has provided alternatives to conventional timber-based systems. Standardized systems can reduce repetitive manual work and improve dimensional consistency, while their economic advantages become more apparent when the formwork is reused over multiple construction cycles [1,3]. Nevertheless, system formwork commonly requires higher initial investment and greater dependence on material availability, technical planning, and specialized installation procedures.

The selection problem becomes more complex in infrastructure projects where construction conditions differ substantially from conventional building projects. Retaining walls along rivers, for example, are often constructed under restricted working space, variable ground conditions, water level fluctuations, limited access, and repetitive structural geometries. Therefore, selecting a formwork system solely according to initial cost may produce a suboptimal construction strategy.

The Bekasi River Flood Control Project Package 7 was developed as part of the flood control strategy for the Bekasi River. The project includes river normalization, bank reinforcement, and construction of retaining wall structures. The research site includes several retaining wall geometries with wall heights ranging from 3.0 to 5.0 m. The retaining wall work is therefore repetitive but also affected by site-specific riverbank conditions. The thesis underlying this study identifies three alternative formwork systems: conventional formwork, semi-system formwork using hollow steel box frames, and Doka system formwork.

The research problem is not simply which formwork system is cheapest. Rather, it concerns which alternative provides the most appropriate balance among cost, time, productivity, concrete visual quality, ease of implementation, occupational safety, and risk. This perspective is consistent with recent formwork selection literature, which identifies cost, project duration, quality, local conditions, safety, formwork characteristics, and performance as interrelated selection criteria [2,3].

Accordingly, this study aims to:

1. compare the construction cost, duration, and productivity of conventional, semi-system, and Doka formwork;
2. compare visual concrete quality, ease of implementation, and occupational safety among the three alternatives;
3. identify and evaluate dominant risks associated with each formwork system; and
4. determine the optimal formwork alternative through integrated multi-criteria evaluation.

The contribution of this study lies in integrating objective construction performance with practitioner-based assessments and risk information. Unlike a conventional cost-time comparison, the study uses a sequential explanatory mixed methods design to explain why differences in quantitative performance occur under actual riverbank construction conditions.

II. LITERATURE REVIEW

2.1 Formwork system selection

Formwork system selection is a multi-criteria construction decision. Terzioglu et al. [2] identified that formwork selection is influenced by conflicting criteria and professional perspectives. Their subsequent structural equation modelling study demonstrated relationships among formwork characteristics, structural design, local conditions, cost, and project performance [3].

Li et al. [1] further emphasized that modern formwork selection should consider safety, cost, structural geometry, construction time, surface quality, flexibility, fabrication, and environmental implications. Consequently, formwork should be evaluated as part of the overall construction system rather than as an isolated temporary material.

Recent research also confirms the importance of systematic multi-criteria evaluation. Worku [4] developed an integrated multi-criteria decision-making model for formwork material selection and demonstrated that economic and performance criteria should be considered jointly rather than independently.

2.2 Conventional formwork

Conventional formwork generally uses plywood, timber, nails, screws, and manually assembled supports. Its principal advantage is flexibility because the panel can be adjusted directly to different geometries and field conditions. However, conventional formwork is relatively labour intensive and may require longer fabrication, installation, and dismantling processes.

The thesis data indicate that conventional formwork is advantageous in terms of initial investment and material availability but tends to have lower productivity and greater material waste when compared with more standardized systems.

2.3 Semi-system formwork

Semi-system formwork combines panel materials with hollow steel box frames. The steel frame increases panel rigidity and allows repeated use. This configuration provides an intermediate solution between the flexibility of conventional formwork and the standardization of system formwork.

Recent comparative research has shown that semi-system formwork can provide economic advantages under specific structural configurations, although the optimal alternative depends on the work element and project conditions [5].

2.4 Doka system formwork

Doka is a modular system formwork characterized by standardized components and repeated use. In the investigated project, the system includes components such as waling, tie brackets, connecting pins, lifting brackets, beams, tie rods, and supporting components. The system is configured according to the retaining wall geometry and reused across construction cycles.

The project data indicate that repeated use is an important economic mechanism for system formwork. The Doka components are designed for repeated application, while some consumable or semi-consumable components have different expected reuse cycles.

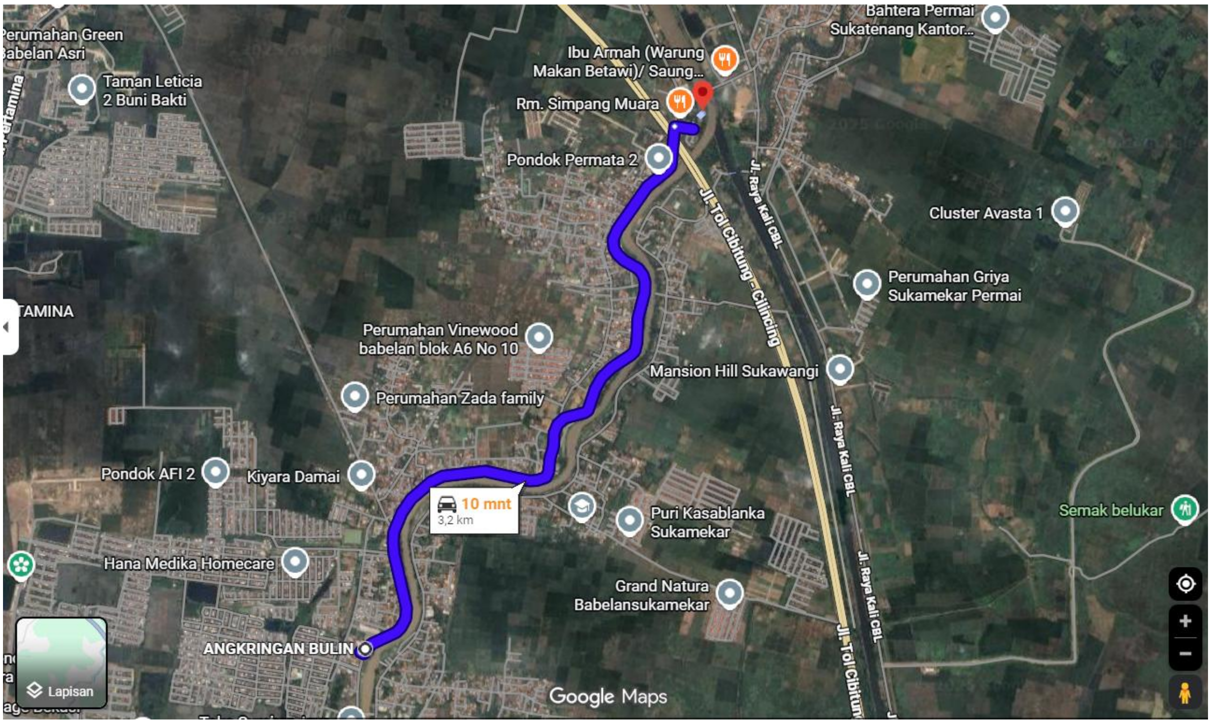

Figure. Aerial photo of the Bekasi River flood control project alignment, Package 7
(Source: Google Maps)

III. RESEARCH METHODOLOGY

3.1 Research design

This research employed a **Sequential Explanatory Mixed Methods** design consisting of a quantitative phase followed by a qualitative phase. The quantitative strand was used to compare the performance of the three formwork alternatives, whereas the qualitative strand was used to explain the differences observed in the quantitative findings.

The integration logic was therefore **QUAN → QUAL → Integration**. Quantitative results informed the selection of issues requiring deeper qualitative explanation. Indicators with relatively low scores, dominant risks, and substantial differences between alternatives became the focus of interviews and field observations.

This approach is consistent with the explanatory sequential mixed methods model, in which quantitative findings inform subsequent qualitative data collection and the final integration of findings [6,7].

3.2 Research location and alternatives

The research was conducted on the retaining wall work of the Bekasi River Flood Control Project Package 7. Five retaining wall types were considered, with wall heights of 3.0, 3.5, 4.0, 4.5, and 5.0 m.

The alternatives were:

1. conventional formwork;
2. semi-system formwork using hollow steel box frames; and
3. Doka system formwork.

The comparison was conducted over equivalent construction stages, including fabrication, installation, pre-pour inspection, concrete casting, dismantling, concrete inspection, cleaning, and reuse preparation.

3.3 Data collection

Primary data consisted of field observations, interviews, and questionnaire responses. Secondary data consisted of the project RAB, shop drawings, unit price information, and other project documents.

The questionnaire respondents were practitioners directly involved in the project, including contractor personnel and supervision consultants. The respondent groups included project management, site operation, field supervision, team leadership, river engineering, safety personnel, and field inspection personnel.

3.4 Quantitative analysis

The quantitative analysis consisted of:

1. formwork volume calculation;
2. material requirement calculation;
3. labour productivity calculation;
4. construction duration calculation;
5. formwork cost calculation;
6. descriptive analysis of questionnaire results; and
7. weighted comparison of the alternatives.

Productivity was determined from construction output relative to effective working time. Cost was calculated from material and labour requirements. The cost analysis considered the total requirement for the investigated retaining wall types.

3.5 Qualitative analysis

Qualitative data were collected through semi-structured interviews, field observation, and project documentation. The data were reduced, organized into thematic matrices, interpreted, and verified.

The qualitative strand focused specifically on explaining quantitative differences, including ease of implementation, concrete visual quality, safety, and dominant risk conditions.

3.6 Risk analysis

Risk identification was conducted using literature review and expert judgment. Risk analysis employed a Probability Impact Matrix, with risk score calculated as:

$$\textbf{Risk Score} = \textbf{Probability} \times \textbf{Impact}$$

Five major risk groups were considered: cost, time, quality, occupational safety, and technical risk. The risk assessment was subsequently used to identify dominant risks and formulate mitigation strategies through practitioner interviews.

3.7 Integrated decision model

The final evaluation used six criteria:

Criterion	**Weight**
Cost	20%
Time	20%
Visual quality	20%
Ease of implementation	10%
Occupational safety	10%
Risk	20%
Total	**100%**

The weighting scheme follows the decision framework developed in the thesis.

Each alternative was normalized and weighted according to the established criteria. The highest overall score was interpreted as the optimal formwork alternative.

IV. RESULT AND DISCUSSION

4.1 Construction cost

The total estimated formwork cost for the five retaining wall types was:

Formwork system	Total cost (IDR)
Conventional	13,194,722,910.80
Semi-system hollow steel box	19,168,866,631.11
Doka system	18,591,106,522.49

The conventional system had the lowest total cost. The semi-system was approximately 45.28% more expensive than the conventional system, whereas the Doka system was approximately 40.90% more expensive than conventional formwork. However, the Doka system was approximately 3.01% less expensive than the semi-system.

The cost results therefore demonstrate an important trade-off. Conventional formwork provides the lowest initial expenditure, while Doka provides better economic positioning than the semi-system when applied to the complete project scope.

4.2 Time performance

The mean time-performance scores were:

Time indicator	Conventional	Semi-system	Doka
Fabrication and installation	3.14	3.14	3.86
Reuse cycle	3.43	3.43	3.71
Dismantling	3.43	3.43	3.71
Mobilization and lifting	2.86	3.00	3.71
Weather factor	4.00	4.00	3.86
Mean	**3.37**	**3.41**	**3.77**

The Doka system achieved the highest overall time score. The advantage is associated with standardized components, structured assembly, and repeated use.

4.3 Visual concrete quality

The visual quality scores were:

Visual quality indicator	Conventional	Semi-system	Doka
Surface flatness	2.71	3.14	3.71
Joint tightness and leakage resistance	2.57	2.71	3.71
Dimensional precision	3.00	3.14	4.14
Surface texture and porosity	2.57	2.57	3.43
Visual consistency	3.29	3.29	3.43
Mean	**2.83**	**2.98**	**3.69**

Doka demonstrated the highest visual quality score, particularly in dimensional precision, surface flatness, and joint performance.

4.4 Ease of implementation

The mean ease-of-implementation scores were 2.97 for conventional formwork, 3.07 for semi-system formwork, and 3.83 for Doka. The Doka system therefore achieved the highest perceived ease of implementation.

This finding is particularly relevant because ease of implementation is not equivalent to low initial cost. A formwork system may be inexpensive but require more manual adjustment, greater dependence on worker skill, or more complex field modification.

4.5 Occupational safety
The occupational safety scores were:

Method	Mean safety score
Conventional	2.91
Semi-system	2.92
Doka	3.43

Doka achieved the highest safety score. The result indicates that standardization and more structured assembly can contribute to safer work execution, although site-specific hazards remain important.
The research also identified risks associated with unstable supports, falling components, worker injury during panel modification, and formwork failure during concrete casting.

4.6 Risk analysis

The risk analysis identified several dominant risks across the alternatives. Examples include:
- delayed material procurement;
- delayed panel fabrication;
- additional cost caused by damaged formwork components;
- worker injury caused by manual or electrical tools;
- instability of bracing or scaffolding on soft riverbank soil; and
- formwork failure caused by fresh concrete pressure and vibration.

For the Doka system, the riverbank support instability remained a high-risk issue with a risk score of approximately 10.1, demonstrating that system standardization does not eliminate site-specific geotechnical and environmental risks.
The mitigation strategy therefore requires not only appropriate formwork selection but also inspection of supporting conditions, procurement monitoring, equipment inspection, control of concrete placement rate, and HSE supervision.

V. INTEGRATED RESULT AND DISCUSSION

The integrated findings demonstrate that no single criterion independently determines the optimal formwork system. Conventional formwork performs best when initial expenditure and flexibility are prioritized. Semi-system formwork provides an intermediate technological solution, combining greater rigidity and reuse with relatively moderate system complexity. Doka, however, demonstrates the strongest overall performance when time, quality, ease of implementation, safety, reuse, and risk are considered jointly.

The most important finding is the apparent contradiction between **cost minimization and overall optimization**. Conventional formwork has the lowest total cost, yet Doka is identified as the optimal alternative through the multi-criteria assessment. This does not imply that Doka is economically cheaper in absolute terms. Rather, it indicates that the higher initial cost is compensated by superior performance in other criteria.

This finding is consistent with recent literature emphasizing that formwork selection involves conflicting criteria rather than a single cost-minimization objective [1,2,4]. The result also agrees with studies demonstrating that standardized and reusable formwork can improve productivity and reduce the economic disadvantages associated with higher initial investment [4,5].

The quantitative results provide evidence that Doka has superior performance in time, visual quality, ease of implementation, and safety. The qualitative interpretation explains the mechanism underlying these differences. Standardized components reduce the need for repeated field fabrication and adjustment, while the modular configuration supports more consistent installation and dismantling. The reuse mechanism also becomes more beneficial as the number of repetitive retaining wall segments increases.

This relationship is important for flood control infrastructure because the project contains multiple retaining wall types and repeated construction segments. The value of a reusable system therefore depends on the number of construction cycles rather than only on the initial procurement cost.

The mixed methods integration further indicates that safety should not be interpreted merely from questionnaire scores. The Doka system obtained the highest perceived safety score, but the risk analysis still identified high-risk conditions associated with unstable riverbank supports and fresh concrete pressure. Thus, **higher perceived safety does not mean zero risk**. Instead, the two strands indicate that standardized formwork can reduce certain operational risks while site conditions continue to generate residual risks.

Integrated Joint Display

Quantitative finding	Qualitative explanation	Integrated interpretation
Doka had the highest time score	Standardized components and structured installation reduce field adjustment	Doka is advantageous for repetitive construction cycles
Doka had the highest quality score	Higher dimensional precision and more rigid panels improve alignment and surface consistency	Standardization supports quality consistency
Doka had the highest ease score	Installation and dismantling follow a defined system	Systemization reduces manual adaptation
Doka had the highest safety score	More structured assembly and stable components improve work organization	System formwork can reduce operational exposure
Conventional had the lowest cost	Simple materials and manual fabrication reduce initial expenditure	Conventional remains suitable when initial cost and flexibility dominate
Doka still had high site-specific risks	Riverbank soil, lifting activities, and concrete pressure remain hazardous	Formwork technology reduces some risks but does not replace site-specific risk control

The integrated interpretation therefore produces a meta-inference that would not emerge from either quantitative or qualitative analysis alone: **Doka is optimal not because it minimizes every individual criterion, but because its performance profile provides the most balanced solution for repetitive retaining wall construction under constrained riverbank conditions.**
This finding also supports the broader literature on formwork selection. Formwork systems should be evaluated according to project-specific combinations of cost, performance, construction conditions, structural geometry, safety, and reuse potential rather than through a single economic criterion [2,3,4].

VI. CONCLUSION

This study evaluated conventional, semi-system hollow steel box, and Doka formwork for reinforced concrete retaining wall construction in the Bekasi River Flood Control Project Package 7 using a sequential explanatory mixed methods approach.

The conventional system provided the lowest total formwork cost at approximately IDR 13.195 billion. The semi-system and Doka systems required approximately IDR 19.169 billion and IDR 18.591 billion, respectively. Therefore, Doka was approximately 3.01% less expensive than the semi-system but approximately 40.90% more expensive than conventional formwork within the investigated project scope.

Despite its higher initial cost, Doka achieved the strongest performance in time, visual quality, ease of implementation, and occupational safety. Its mean scores were 3.77 for time, 3.69 for visual quality, 3.83 for ease of implementation, and 3.43 for safety, compared with lower scores for the conventional and semi-system alternatives.

The risk analysis showed that Doka had fewer dominant risks than the conventional and semi-system alternatives, although high-risk conditions remained, particularly related to riverbank support instability, material procurement, lifting activities, and fresh concrete pressure.

The integrated findings demonstrate that formwork selection should not be based on initial cost alone. For retaining walls with large volumes, repetitive geometries, and strict construction schedules, the Doka system provides the most balanced overall performance. The system is particularly appropriate when productivity, concrete quality, safety, reuse, and schedule reliability are prioritized.

The principal managerial implication is that contractors and project owners should evaluate formwork as a strategic construction system rather than merely as a temporary material. The economic value of modular formwork increases with repetitive use, while its technical advantages become more significant when project duration, quality consistency, and safety are critical.

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