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Evaluation Of Implementation Strategies And Methods To Improve Efficiency In The Bagong Main Dam Project Trenggalek

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Abstract

Earthfill dam construction requires effective strategies to ensure structural safety, construction quality, and efficient use of time and resources. This study examines the construction strategy and implementation method of the Main Dam of the Bagong Dam Project, Indonesia, which is designed as a vertically zoned earthfill embankment with a length of 620 m, a crest width of 12 m, a crest elevation of +330 m, and a height of 82 m. The research focuses on the application of a zoning-based construction approach to improve construction efficiency under complex field condition. The results indicate that dividing the embankment into six functional zones enables systematic layer-by-layer construction and parallel work execution, resulting in a planned construction duration of 937 working days. The integration of material zoning, quality control procedures, and optimized equipment management ensured that all embankment layers achieved more than 95% of maximum dry density. Coordinated equipment utilization further improved productivity, allowing approximately 304,653 m^3 of embankment work to be completed within 53 working days during critical construction stages. In addition, the implementation of a structured safety management system supported the achievement of zero-accident construction performance. These findings demonstrate that the integration of zoning strategy, systematic construction sequencing, quality management, equipment planning, and safety control significantly enhances time and cost efficiency while maintaining construction quality. The proposed approach provides a practical framework for earthfill dam construction projects in Indonesia and other regions with similar geological and climatic conditions.

Keywords: Construction Strategy, Implementation Method, Main Dam, Efficiency

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INTRODUCTION

Dam development constitutes a critical component of Indonesia's national infrastructure strategy, serving essential functions in water storage, flood mitigation, agricultural irrigation, and hydropower generation. The country's climatic characteristics—especially prolonged dry seasons—underscore the necessity of reliable water storage systems to sustain socio-economic activities. In this context, the Bagong Dam Project in Trenggalek Regency represents a strategic governmental initiative designed to enhance regional water security and reduce flood risk.

Despite substantial experience in dam construction, Indonesia continues to face a set of unique challenges that differentiate its projects from those in many other regions. The nation's complex geological formations, high annual rainfall, and significant seismic exposure require rigorous engineering approaches and highly controlled construction methodologies, particularly for core embankment structures. Additionally, many dam sites are located in mountainous or remote areas, imposing logistical constraints on the transportation of materials and heavy equipment. Variable soil conditions, fluctuating water levels that must be regulated during construction, and strong dependencies on weather patterns necessitate adaptive, flexible, and efficient construction planning. These contextual factors exert considerable influence on embankment quality, project timelines, safety performance, and overall construction cost.

Existing literature has contributed important insights into the technical aspects of dam engineering, including core embankment design, slope stability, and material behavior. However, research that holistically examines construction strategies—integrating work zoning, quality control mechanisms, safety management procedures, and heavy equipment utilization—remains limited. Studies addressing quality management often lack explicit discussion of its implications for project duration, while analyses focusing on zoning arrangements rarely explore their broader effects on resource allocation or equipment efficiency, particularly under Indonesia's challenging field conditions. This demonstrates a clear research gap concerning comprehensive and context-specific evaluations of main dam construction methods.

The Bagong Dam's main embankment is designed as a vertical core structure with a crest length of 620 m, a crest width of 12 m, a crest elevation of +330 m, and a structural height of 82 m. As the primary hydraulic-retaining element, the core embankment requires strict adherence to construction procedures to ensure long-term stability and operational safety. Inadequate methods or improper sequencing pose substantial risks to structural integrity. Consequently, the formulation of an appropriate construction strategy—including equipment deployment planning, work zone delineation, quality assurance through quality plans, and safety enforcement through safety plans—is essential to achieving efficient progress, risk minimization, and cost optimization.

This study aims to systematically analyze the construction strategies and implementation methods employed in the Bagong Dam main embankment works. The analysis focuses on work zoning arrangements, quality management measures, safety protocols, and heavy equipment requirements with the objective of identifying an optimal balance between project duration and cost efficiency. The findings are expected to contribute to improved construction control practices, enhance planning accuracy in dam projects, and provide a pedagogical reference for the development of construction method documents and instructional materials in project planning education.

METHOD

The formulation of an implementation method plays a crucial role in the construction of large-scale projects such as the main dam (central-core zoned embankment) of Bagong Dam. A well-prepared method provides a structured overview of how the project begins and proceeds until completion, ensuring that construction is executed with accuracy in terms of quality, cost, and time. In practice, it is often necessary to employ innovative solutions to address challenges arising from field conditions that differ from initial design assumptions. To systematize this process, a flowchart of strategy development and implementation was prepared in Figure 1.

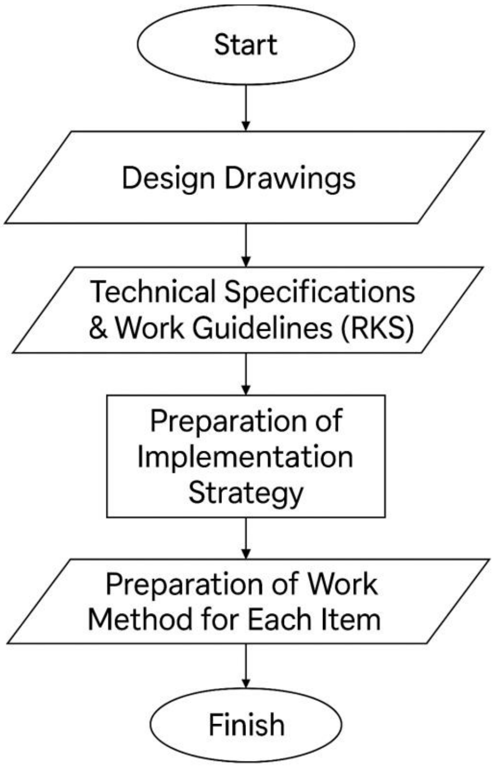

Figure 1. Flow Chart of Strategy Development and Implementation Method

The stages include: (1) collecting data in the form of design drawings, technical specifications, and the Bill of Quantities (BOQ); (2) formulating effective and efficient strategies and implementation methods for each task, considering environmentally friendly practices, the logical sequence of work, and respective work volumes; and (3) preparing visualizations of the implementation process to support field execution and monitoring.

Purposive sampling was used to define the scope of analysis by selecting construction activities that significantly influence project performance. The selection criteria included large work volumes, intensive use of heavy equipment, and high sensitivity to productivity, cost, and construction duration. Based on these criteria, earthfill placement, compaction works, and heavy equipment operations were selected as the main focus of the study, while ancillary works were excluded.

Alternative implementation strategies were formulated by modifying the baseline construction method based on field conditions, contractor practices, technical guidelines, and relevant literature. The strategies differ in terms of equipment combinations, work sequencing, and resource allocation. All strategies were developed using identical design parameters, work volumes, and site constraints to ensure comparability.

Each implementation strategy was evaluated using scenario-based analysis. Fixed parameters included total work volume, working hours, and site geometry. Variable parameters included equipment productivity rates, equipment configurations, and operational sequences. These scenarios were used to simulate construction duration, unit cost, and productivity performance.

Data analysis was conducted using descriptive and comparative quantitative methods. Descriptive analysis was used to establish baseline productivity, construction duration, and unit cost values. Comparative ratio analysis was applied to evaluate differences between the baseline and alternative strategies, expressed as percentage changes in productivity, cost efficiency, and time efficiency. The statistical treatment was limited to descriptive and comparative analysis, as the study focuses on performance evaluation rather than hypothesis testing.

Validity was ensured through data triangulation using project documents, field observations, and benchmark values from relevant literature. Reliability was strengthened by recalculating productivity values using standardized references, such as the Caterpillar Performance Handbook, and by consulting experienced field engineers. This study focuses on the main dam body construction and excludes ancillary structures, such as spillways and intake towers.

RESULT AND DISCUSSION

In the implementation of the Main Dam construction of the Bagong Dam Project, Trenggalek Regency, a strategic approach was applied to achieve optimal quality, cost, and time performance. The construction strategy for the Main Dam was designed using a zoning system, which divides the dam body into six distinct zones, namely: Zone 1 (Core Clay), Zone 2 (Filter), Zone 3 (Transition), Zone 4 (Random Fill), Zone 5 (Rock Fill), and Zone 6 (Rip-Rap). Each zone has a specific function and material composition that together ensure the dam's structural stability and hydraulic performance, as illustrated in Figures 2 and 3, which show the overall dam layout and zoning configuration that support efficient construction sequencing and parallel work execution. Beyond its structural role, this zoning configuration enables construction activities to be carried out in parallel while maintaining a controlled and logical work sequence, thereby supporting the research hypothesis that structured work zoning enhances construction efficiency in large-scale earthfill dam projects.

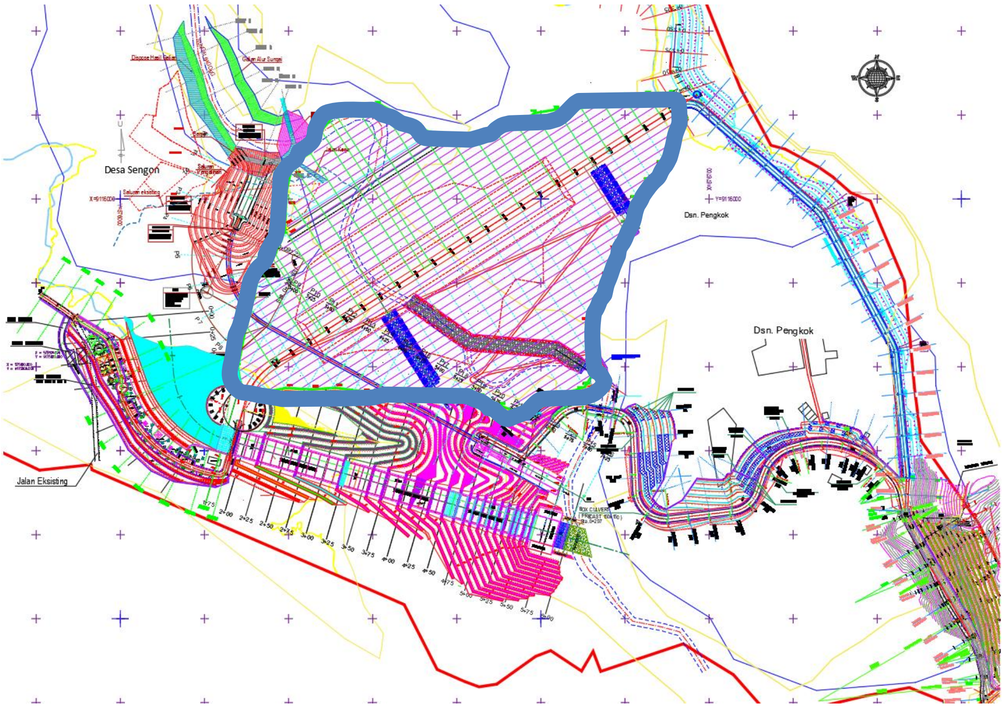

Figure 2. Layout Plan of the Main Dam Embankment

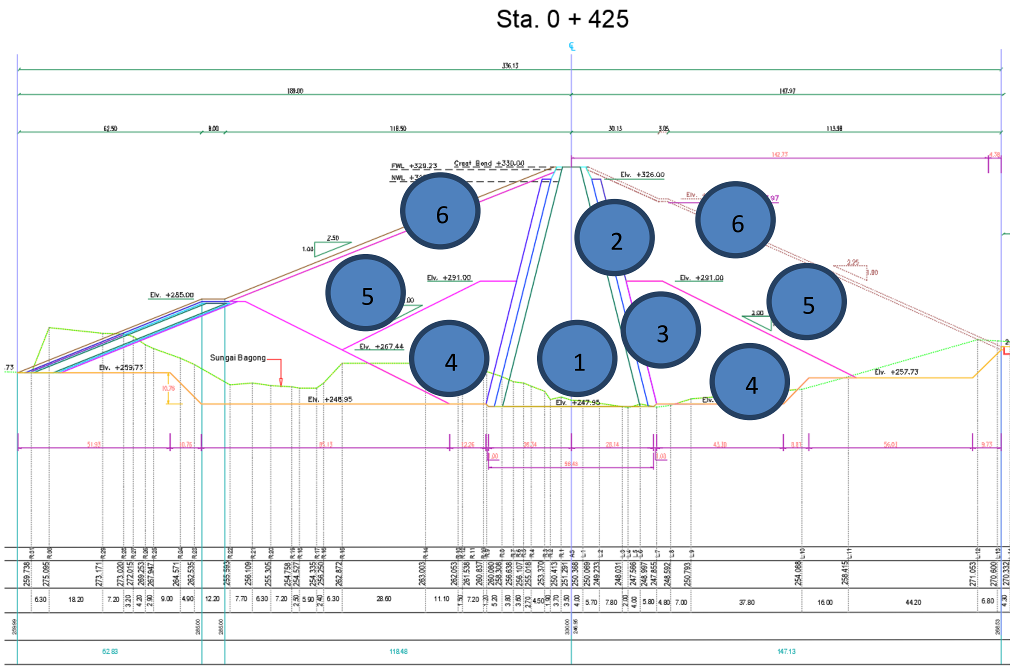

Figure 3. Zoning Division of the Main Dam

The main dam body was divided into six construction zones, each with a dedicated construction method tailored to its engineering function. The results indicate that dividing the embankment into distinct zones allows layer-by-layer construction while maintaining balanced elevations across the dam body. This approach minimizes material sloughing, rehandling, and corrective work, which are common sources of schedule delays in embankment construction. As summarized in Table 1, each zone is assigned a specific material type and construction method, enabling quality control and productivity to be managed independently for each work segment. Based on this zoning strategy, the planned construction duration for the main dam was established at 937 working days, reflecting a realistic and achievable schedule under site-specific constraints. The zoning system also facilitates systematic quality assurance, as each zone follows predefined material specifications, layer thickness requirements, and compaction standards.

Table 1. Main Dam Construction Zones

Zone	Material	Function and Construction Method
Zone 1 – Core (Clay	Impermeable clay	Serves as the watertight element of the dam. Material is spread in layers of approximately 30 cm, cleaned from organic matter, moistened to optimum water content, and compacted using a sheepfoot roller to achieve a minimum of 95% of maximum dry density (MDD).
Zone 2 – Fine Filter	Fine sand	Functions as a filter to prevent migration of fine clay particles. Each layer is about 40 cm thick, spread using bulldozers, and compacted with a vibro roller.

Zone 3 – Coarse Filter (Transition)	Coarse gravel	Acts as a transition between fine filter and rock layers. Layers are 40 cm thick and compacted with vibro rollers.
Zone 4 – Random Fill	Mixed soil and small rock	Provides the main body mass for slope stability. 154ayer sup to 50 cm thick are continuously compacted using vibro rollers.
Zone 5 – Rock Fill	Large rock from quarry	Forms the outer supporting layer. Each layer is about 100 cm thick, spread with excavators, and leveled using bulldozers.
Zone 6 – Rip-Rap (Protection)	Large broken rock	Protects the slope surface from erosion and wave action. Placed after 3–4 layers of rock fill are completed, using excavators and manual workers to interlock the rocks.

Material zoning directly influences both structural performance and construction efficiency. As shown in Table 1, the core zone utilizes impermeable clay to control seepage, while filter and transition zones ensure internal stability, and rockfill and rip-rap zones provide slope stability and erosion protection. Controlled layer thicknesses 30 cm for clay, 40 cm for filter materials, and up to 100 cm for rockfill combined with appropriate compaction equipment ensured that all embankment layers achieved more than 95% of Maximum Dry Density (MDD).

Figure 4. Clay Filling

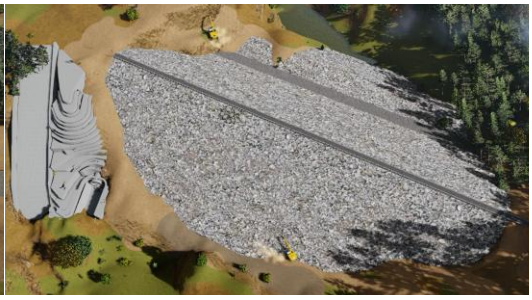

Figure 5. Main dam Fill Work

Quality control results demonstrate that the zoning strategy supports consistent quality achievement while reducing the risk of rework. Field density and moisture content tests were conducted for each layer, and the results were used to adjust compaction procedures in subsequent layers. Trial embankments were executed prior to full scale construction to optimize compaction parameters, including equipment type, number of passes, and optimum moisture content. The close agreement between laboratory test results and field measurements confirms the reliability of the adopted construction methods and reinforces the hypothesis that systematic zoning and quality control contribute to efficient and predictable construction outcomes.

Table 2. Heavy Equipment Management

Material	Function and Construction Method
Excavator	Menggali dan memuat material (loading)
Dump Truck	Mengangkut material (hauling) antar zona atau dari borrow area
Wheel Loader	Membantu loading material ke dump truck
Bulldozer	Menyebar dan meratakan material timbunan (spreading)
Motor Grader	Melakukan perataan akhir (leveling) dan pembentukan profil lereng
Water Tank Truck	Membasahi timbunan untuk mencapai kadar air optimum
Vibro Roller	Melakukan pemadatan tiap layer material timbunan

The execution methods were structured into several main construction stages, ensuring systematic progress and optimal use of resources:

a. Excavation Work

Excavation was performed mechanically using excavators, bulldozers, and dump trucks. Excavated material was either stockpiled or transported to spoil areas. For hard rock, a hydraulic breaker was used. The sequence consisted of area demarcation, excavation, loading, hauling, and surface finishing.

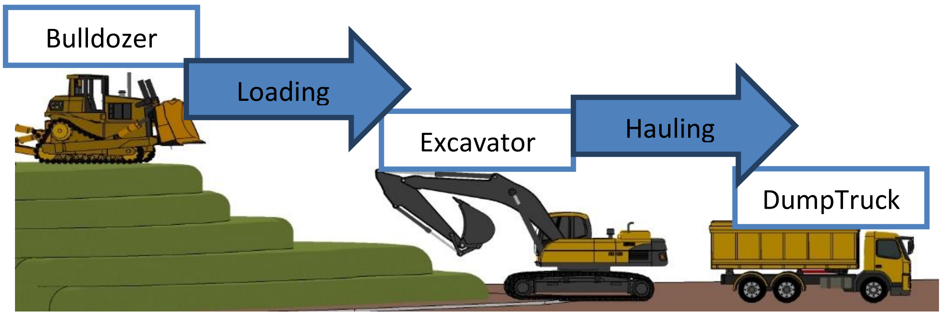

Figure 6. Excavation Work

Figure 7. Visualization of Excavation Work

b. Dewatering and Drainage
   Temporary drainage channels and pumping systems were installed to manage seepage and rainfall water. Embankment protection and diversion channels were built on both sides of the cofferdam to keep the working area dry and stable during construction.
c. Cofferdam and Main Dam Embankment
   Embankment construction started from the clay core (Zone 1), followed by fine and coarse filters (Zones 2–3), random fill (Zone 4), rock fill (Zone 5), and rip-rap (Zone 6). Each layer was placed with a thickness ranging from 30 cm to 100 cm depending on material type. Compaction was performed according to the results of trial embankment and field density testing. The filling of each zone was carried out alternately and in parallel to maintain consistent elevation and minimize differential deformation.
d. Grouting Work
   Grouting was carried out on the foundation beneath Zone 1 using the downstage method. Each borehole was flushed, tested with water pressure tests, and injected with a cement-water mix under pressure. The process reduced rock permeability and increased the watertightness of the foundation. Before injection, a 1 m thick grout cap was constructed to prevent grout leakage during the injection phase.

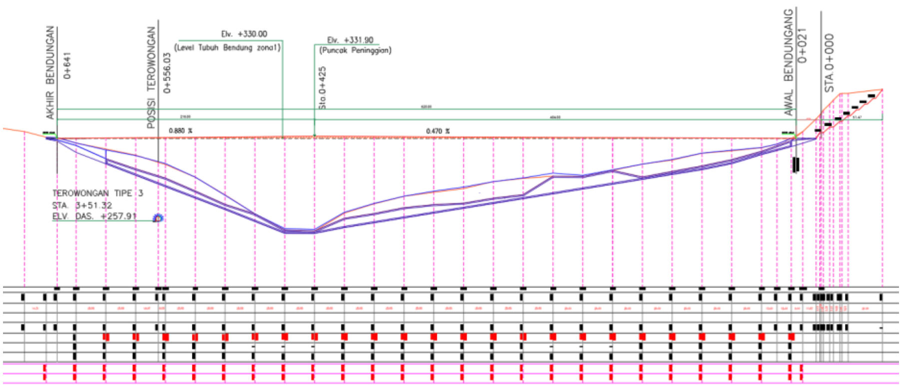

Figure 8. Grouting Work

e. Crest Construction (Dam Top Layer)
After the dam body was completed, the crest was constructed as an access and inspection road. The sequence included the lower base layer, upper base layer, prime coat, asphalt base course (AC-BC), and asphalt wearing course (AC-WC). Asphalt mixture was produced in the Asphalt Mixing Plant (AMP), transported by dump trucks, laid using an asphalt finisher, and compacted with vibratory and pneumatic rollers to achieve smoothness and density.

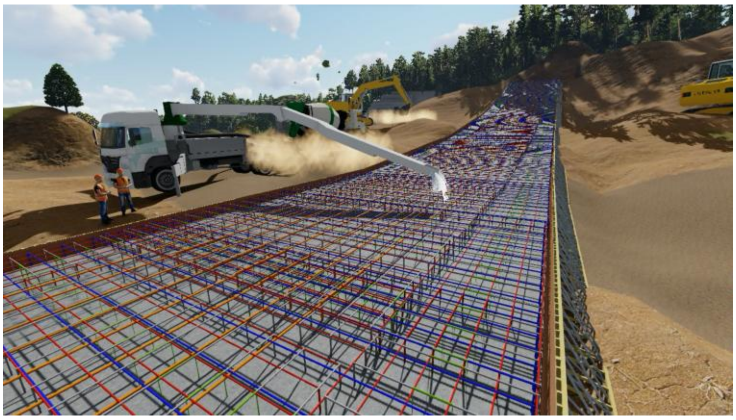

Figure 9. Rebar Work

Figure 10. Concrete Work

Effective management of heavy equipment played a critical role in improving construction productivity and cost efficiency. As presented in Table 2, the deployment of excavators, dump trucks, bulldozers, graders, water tank trucks, and rollers was organized to support continuous material flow between excavation areas, stockpiles, and embankment zones. Equipment selection and balancing were designed to minimize idle time and prevent bottlenecks during hauling, spreading, and compaction operations. As a result, approximately 304,653 m^3 of embankment work was completed within 53 working days during critical construction stages. This performance demonstrates that optimized equipment management directly contributes to reduced construction duration and improved resource efficiency.

The integration of zoning strategy with systematic construction sequencing further enhanced schedule reliability. Embankment works were executed in parallel across zones, while temporary drainage systems, dewatering pumps, and surface protection measures were implemented to control seepage and rainfall effects. These measures reduced weather related disruptions, ensured stable working conditions, and prevented delays associated with water infiltration and material instability. The results highlight that construction efficiency depends not only on material and equipment availability but also on effective sequencing and environmental control.

Overall, the findings confirm the research hypothesis that a structured construction strategy integrating zoning design, quality control, construction sequencing, and equipment management significantly improves time and cost efficiency in main dam construction. Construction efficiency in large-scale dam projects is therefore achieved through the synchronization of technical design, operational planning, and resource management rather than through isolated optimization of individual work components.

CONCLUSION

This study demonstrates that the implementation of a zoned construction system combined with systematic execution methods significantly improves time efficiency, cost control, and resource utilization while maintaining high construction quality in earthfill dam projects. The division of the Main Dam of the Bagong Dam Project into six functional zones—Core Clay, Fine Filter, Coarse Filter (Transition), Random Fill, Rock Fill, and Rip-Rap—proved effective in achieving structural stability and hydraulic integrity through controlled material placement and balanced load distribution.

The findings indicate that zoning enables parallel and well-coordinated construction activities, reducing material rehandling, rework, and schedule delays. The integration of layered compaction, foundation grouting, and dewatering systems successfully mitigated challenges associated with seepage and rainfall, which are common constraints in dam construction under tropical climate conditions. In addition, optimized heavy equipment management minimized idle time and operational bottlenecks, allowing approximately 304,653 m^3 of embankment work to be completed within 53 working days. Consistent application of quality control procedures, including trial embankments and field compaction testing, ensured that all embankment layers achieved more than 95% of maximum dry density, supporting predictable and reliable construction performance.

From a practical perspective, the construction strategy applied in the Bagong Dam Project offers a transferable framework for earthfill dam projects in Indonesia and other regions with similar geological, climatic, and logistical conditions. The zoning-based approach provides clear guidance for planning construction sequences, allocating resources, and managing quality control in large-scale embankment works, particularly in environments characterized by high rainfall, variable foundation conditions, and limited construction access.

Despite these contributions, this study is based on a single case project, which may limit the generalization of the findings to other dam types or site conditions. Future research is recommended to apply and validate the proposed construction strategy across multiple dam projects, incorporate detailed cost-benefit and life-cycle performance analyses, and explore the integration of digital construction tools such as Building Information Modeling (BIM) to further enhance planning accuracy, productivity, and risk management.

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