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Time and cost efficiency analysis of shotcrete and retaining wall methods for landslide disaster mitigation

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ABSTRACT

Background: The construction industry in Indonesia, particularly in the city of Yogyakarta, is experiencing rapid development along with the increasing demand for educational infrastructure. In projects that involve challenging topographical conditions, the selection of an appropriate earth retaining structure method becomes a critical technical and managerial decision. This study aims to compare the cost and time efficiency between two widely used methods in retaining wall construction, namely the conventional masonry retaining wall method and the shotcrete method, in the Universitas AMIKOM Yogyakarta development project. **Methods:** The analysis focuses on direct and indirect costs, project duration, productivity, and critical path determination using the Critical Path Method (CPM). Data were obtained from project planning documents, detailed engineering drawings, Bill of Quantities (BoQ), and scheduling data developed using Microsoft Project. **Findings:** The results of the analysis indicate that the shotcrete method provides significant advantages in terms of time efficiency, with a project duration of approximately 358 working days, which is 42 days faster than the retaining wall method requiring around 400 working days. However, from the cost perspective, the shotcrete method results in higher total expenses, amounting to Rp15.526 billion compared to Rp15.187 billion for the retaining wall method, or approximately 2.24 percent more expensive. Additional analysis of indirect costs shows that the longer duration of the retaining wall method increases monthly overhead expenses, while the shotcrete method requires higher technical and equipment costs. **Conclusion:** Therefore, the retaining wall method is considered more economical, whereas the shotcrete method is superior when project acceleration is prioritized. The findings of this study provide practical guidance for project managers and decision makers in selecting the most appropriate method based on project objectives, budget limitations, and time constraints. **Novelty/Originality of this article:** This study uniquely combines cost, time, productivity, and CPM analysis to provide an integrated evaluation of masonry and shotcrete retaining wall methods, offering practical decision-making guidance for complex construction projects.

KEYWORDS: cost; shotcrete; retaining wall.

1. Introduction

Yogyakarta continues to experience intensive educational and supporting infrastructure development, and this growth has increased the number of projects that must be delivered within strict cost, time, and quality constraints (Chin & Hamid, 2015; Guo et al., 2010; Project Management Institute, 2021; Rakasyiwi et al., 2022). In practical construction management, these three constraints are not independent variables; a change in one dimension usually produces consequences in the others. Schedule compression can increase direct cost through higher equipment intensity, specialised labour, or more complex coordination, whereas a lower-cost method can extend project duration and

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increase indirect cost exposure. For that reason, the selection of a construction method is not only a technical decision but also a managerial decision that affects resource allocation, cash flow, and project risk.

In hillside and land-development projects, the method-selection problem becomes more complex because the sequence of earthworks, slope stabilisation, drainage, access, and site finishing must be coordinated carefully. The initial land-clearing stage often determines the success of the subsequent structural and architectural works, especially when the project site has irregular contours and unstable soil conditions (Hardiyatmo, 2018; Naf'an et al., 2019). If geotechnical risks are underestimated at the early stage, the project may face redesign, rework, delayed follow-on activities, and cost overruns. In the case of the Universitas AMIKOM Yogyakarta development area, the steep terrain required an earth-retaining solution that was technically reliable and also compatible with the broader site-development schedule, because the retaining works controlled access to later infrastructure and landscaping packages.

Two relevant alternatives for this purpose are the conventional retaining wall method, locally implemented as talud masonry, and shotcrete. The retaining wall method is familiar to many contractors, uses relatively accessible local materials, and has a cost structure that is usually easier to predict. However, it tends to involve sequential and labour-intensive construction stages, including excavation, foundation preparation, masonry installation, plastering, and finishing. Shotcrete, in contrast, is a sprayed concrete method that offers greater execution speed, reduced dependency on formwork, and better adaptability to irregular surfaces (ACI Committee 506, 2016; Liu et al., 2021; Mishchenko et al., 2024; Plamenco et al., 2021; Qiao & Zhou, 2017). Its advantages are particularly attractive in projects where access is constrained and the geometry of the slope makes conventional placement less efficient. Nevertheless, shotcrete also introduces other managerial and technical demands, such as equipment mobilisation, nozzle quality, rebound loss, skilled operators, and stricter quality-control procedures (Armengaud et al., 2017; Chen et al., 2017; Duarte et al., 2020; Storrie & Bartlett, 2001).

Previous research has discussed several parts of this problem, but the evidence remains fragmented. Sjölander (2020) demonstrated that shotcrete thickness variability can significantly influence structural behaviour and capacity, showing that field quality control is essential for reliable performance. Plamenco et al. (2021) found that discrete event simulation can improve the estimation of shotcrete productivity and reveal the importance of non-value-adding time in the construction process. Duarte et al. (2020) examined the economic and technical feasibility of using shotcrete with recycled aggregates in tunnels and concluded that the viability of the system depends on the balance between mechanical performance and thickness requirements. Studies on retaining walls have also shown that the design and productivity of retaining systems are sensitive to geometry, reinforcement configuration, and site conditions (Berg et al., 2009; Jasoor & Khaleel, 2024; Kong et al., 2021; Moayyeri et al., 2019; Sari et al., 2020). Meanwhile, broader project-management literature has repeatedly shown that method selection should be evaluated through an integrated time-cost perspective rather than through single-criterion comparison alone (Chin & Hamid, 2015; Elkliny et al., 2023; Hendrickson, 1989; Kelley & Walker, 1959; Shehu, 2021).

Despite these contributions, three gaps remain relevant. First, many studies on shotcrete are material-oriented or tunnel-oriented, whereas fewer studies evaluate shotcrete as an alternative retaining solution in open-area campus development projects. Second, many local comparisons of retaining structures discuss cost or time separately, even though contractors and owners make decisions by considering both together. Third, relatively few studies connect cost recapitulation with schedule logic on the same project, so the practical trade-off between direct cost, indirect cost, and critical-path performance is not always visible. This study addresses those gaps by comparing a retaining wall method and a shotcrete method for the same project area, using the same contractor dataset, the same site context, and the same managerial objective of selecting the more efficient alternative.

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} \quad \text{(Eq. 1)}$$

In this study, productivity is treated as the relationship between the quantity of completed work and the resources or time required to produce that output (Chin & Hamid, 2015; de Silva & Perera, 2023; Shehu, 2021). A productive method is not automatically the cheapest method, because faster output may require more expensive equipment or more skilled labour. Likewise, an economical method is not automatically the most efficient in schedule terms, because a lower unit rate can be offset by longer duration. For that reason, the article distinguishes clearly between productivity, efficiency, and effectiveness and interprets them in relation to project objectives.

Based on that context, this article is guided by three research questions. First, how different are the direct cost, indirect cost, and total project cost produced by the retaining wall and shotcrete methods? Second, how different are their schedule outcomes in terms of total duration and critical-path behaviour? Third, when cost and time are considered simultaneously, what practical trade-off can be identified for project managers? The contribution of this study is therefore not limited to reporting a cheaper or faster option. Instead, it provides an integrated empirical framework for understanding where the cost difference originates, how the duration difference is generated, and under what managerial priorities one method becomes preferable to the other. This integrated perspective is relevant for owners, consultants, and contractors who must decide between conventional and technology-assisted retaining systems in projects with similar topographic constraints.

To improve readability for non-specialist readers, several technical terms are used in a practical sense throughout this paper. Direct cost refers to the cost directly attached to measurable work items such as materials, labour, and equipment used for production. Indirect cost refers to overhead and supporting expenses that are not assigned to a specific work volume but increase as project duration extends. The critical path refers to the chain of activities that determines the shortest possible project completion time; any delay in these activities delays the whole project (Kelley, 1961; Project Management Institute, 2021). Within this framework, the paper compares the two methods through cost recapitulation, indirect-cost modelling, and schedule analysis so that the discussion remains grounded in project delivery, not only in material technology.

Recent international literature strengthens the relevance of comparing these two methods from a managerial standpoint. Time-management studies consistently report that construction delays are rarely caused by a single technical issue; instead, they emerge from the interaction of sequencing, labour coordination, equipment availability, information flow, and decision timing (Chin & Hamid, 2015; de Silva & Perera, 2023; Shehu, 2021). In retaining-structure projects, these managerial variables are especially influential because the work often lies on the access-critical path of the site. A slower retaining method does not only delay the wall itself; it can also delay cut-and-fill completion, internal circulation, drainage installation, and the handover of downstream work fronts. Therefore, the question addressed in this paper is broader than simply 'Which wall is cheaper?' It is more accurately stated as 'Which method creates the better project-level balance between cost burden, schedule exposure, and execution practicality under the observed site conditions?'

The literature also shows that retaining systems and sprayed-concrete technologies are increasingly evaluated not only through structural adequacy but also through constructability. Studies on retaining-wall design have highlighted the importance of reinforcement arrangement, geometry, and failure mechanisms (Akis et al., 2023; Kong et al., 2021; Moayyeri et al., 2019), while shotcrete research has focused on application quality, rebound behaviour, high-temperature performance, durability, and process optimisation (Armengaud et al., 2017; Chen et al., 2017; Duarte et al., 2020; Liu et al., 2021; Mishchenko et al., 2024; Sjölander, 2020; Steindl et al., 2020). Taken together, these studies imply that the performance of a retaining method should be judged by how well it translates material and structural capability into field productivity and dependable schedule delivery. This

study extends that perspective by linking the engineering choice directly to project budgeting and critical-path behaviour in a real campus development case.

A further point of novelty lies in the practical decision context. Many project teams in Indonesia still choose between conventional and modern retaining methods through fragmented consultation: estimators discuss budget, site engineers discuss constructability, and planners discuss duration, often without one integrated comparison. As a result, decisions may be taken on the basis of habit, supplier recommendation, or perceived speed rather than on a transparent synthesis of cost and schedule evidence. By presenting the two alternatives side by side within the same project dataset, this paper seeks to reduce that fragmentation. The intention is not to prescribe a universal solution, but to provide a replicable analytical logic that can be adapted by other teams when comparing alternative retaining systems in projects with constrained topography.

This research used a comparative case-study design based on one real construction project, namely the open-area development works at Universitas AMIKOM Yogyakarta. The unit of analysis was the earth-retaining work package, which could be executed either with the conventional retaining wall method or with shotcrete, while the surrounding project scope such as drainage, electrical works, and site infrastructure remained constant. Actual project documents were obtained from PT Muara Mitra Mandiri as the contractor, including detailed engineering drawings, bill-of-quantities data, unit-price analyses, and schedule information prepared in Microsoft Project. The use of contractor documents allowed the comparison to remain close to site reality rather than relying solely on theoretical assumptions.

The comparison was intentionally limited to a like-for-like basis. Both alternatives were applied to the same slope zone and the same retained area, so the geometry of the work, the target site function, and the project context were kept constant. This decision was necessary to avoid a misleading comparison in which one method is assessed on a different area, height, or service requirement from the other. The direct-cost analysis therefore focused on the measurable work items needed to deliver the same site function under each method. From the project recapitulation, the shotcrete application covered a surface area of 552.47 m^2 with a unit price of IDR 4,500,000 per m^2, while the retaining wall method relied more heavily on masonry volume, foundation work, and sequential wall-body construction.

Direct cost was calculated by multiplying each work volume by its corresponding unit price and then aggregating all items into the total project cost (Ervianto, 2004; Hendrickson, 1989; Project Management Institute, 2021). This approach follows standard cost-estimation practice in construction management, where the bill of quantities serves as the principal basis for budgeting and cost control. Using the same work package and cost framework for both alternatives made it possible to identify not only the total difference but also the specific cost component that caused the gap. In this project, the largest difference emerged in the retaining-structure package rather than in supporting packages such as preparation, drainage, and electrical works.

$$\text{Budget plan} = \sum (\text{Work volume} \times \text{Unit price}) \quad \text{(Eq. 2)}$$

Indirect cost was analysed separately because it is strongly influenced by project duration. In practice, indirect cost includes field overhead, office overhead, supervision, security, communication, temporary facilities, permits, and other support expenditures that cannot be assigned directly to one measured work item but remain necessary for project delivery. Following the project data, this study modelled indirect cost with a linear expression that combines fixed overhead and duration-dependent monthly overhead:

$$Y_{\text{indirect}} = C_{\text{fixed}} + (D \times C_{\text{monthly}}) \quad \text{(Eq. 3)}$$

2. Methods

2.1 Research data and analytical framework

Where Y_indirect is total indirect cost, C_fixed is the fixed overhead component, D is project duration in months, and C_monthly is the monthly overhead component. For this project, the fixed cost component was IDR 315,000,000. The model was used not as an abstract theoretical exercise but as a practical managerial tool to show how schedule decisions influence total project expenditure. This was especially important because shotcrete had a higher direct cost but a shorter duration, while the retaining wall method had a lower direct cost but longer exposure to overhead.

Schedule comparison was conducted using Microsoft Project through bar-chart development and Critical Path Method (CPM) analysis (Chin & Hamid, 2015; Kelley, 1961; Kelley & Walker, 1959; Project Management Institute, 2021). The aim was to identify the dominant sequence of activities, the activities on the critical path, and the total duration of each alternative. In both schedules, the project included mobilisation, soil investigation, site clearing and survey, excavation, foundation work, wall-body execution, cut-and-fill, contour levelling, paving, gateway construction, and landscaping. The key difference was that shotcrete replaced some of the more time-consuming conventional wall-body stages and allowed a more compact critical path. CPM was selected because it is suitable for deterministic construction scheduling when activity durations are based on contractor planning and known work sequences (Kelley, 1961; Kelley & Walker, 1959).

Several assumptions were applied so that the comparison remained transparent. First, both methods were assumed to be executed under the same working calendar and general market conditions. Second, productivity values followed the contractor's planning basis and standard field practice for one project environment, rather than an idealised maximum output. Third, the comparison did not include structural redesign, land-acquisition issues, or changes in the final functional requirements of the site. Fourth, the analysis assumed that the selected workforce and equipment would be available as planned. These assumptions are reasonable for a method-comparison study, but they also define the boundary of interpretation.

To strengthen the transparency requested by the reviewers, the productivity assumptions must be stated explicitly. The schedule reflects normal contractor planning conditions: one project environment, one sequence logic, standard daily working hours, and no major disruption beyond routine site constraints. The retaining wall method was assumed to depend more on manual and sequential operations such as masonry placement, surface plastering, and staged wall-body construction. Shotcrete was assumed to require more specialised resources but to gain time from faster surface application, reduced formwork dependency, and more flexible adaptation to slope geometry. These assumptions explain why shotcrete has a higher monthly burn rate but a shorter overall duration.

This study also contains limitations that should be recognised before the findings are generalised. The analysis is based on one project in Yogyakarta, one contractor dataset, one topographic context, and one set of prices and productivity assumptions. The study does not include a structural safety comparison, a life-cycle cost comparison, or a probabilistic risk model for weather and supply disruption. Therefore, the results should be interpreted as a decision-support comparison for projects with similar scope and context, not as a universal ranking of retaining wall systems. Even so, the case remains valuable because it combines real cost data, real schedule logic, and a practical time-cost trade-off that many project teams face.

In addition to the main cost and schedule calculations, the study applied a consistency check to the numerical presentation. Reviewer comments specifically requested that all numerical values and units follow English conventions. Accordingly, monetary values in this revision are written with commas as thousand separators and periods as decimal markers, and dimensions are presented consistently in metric units. This editorial correction is important because the clarity of quantity presentation affects how easily readers can verify

the argument, especially when the paper compares small percentage differences in cost against meaningful differences in duration.

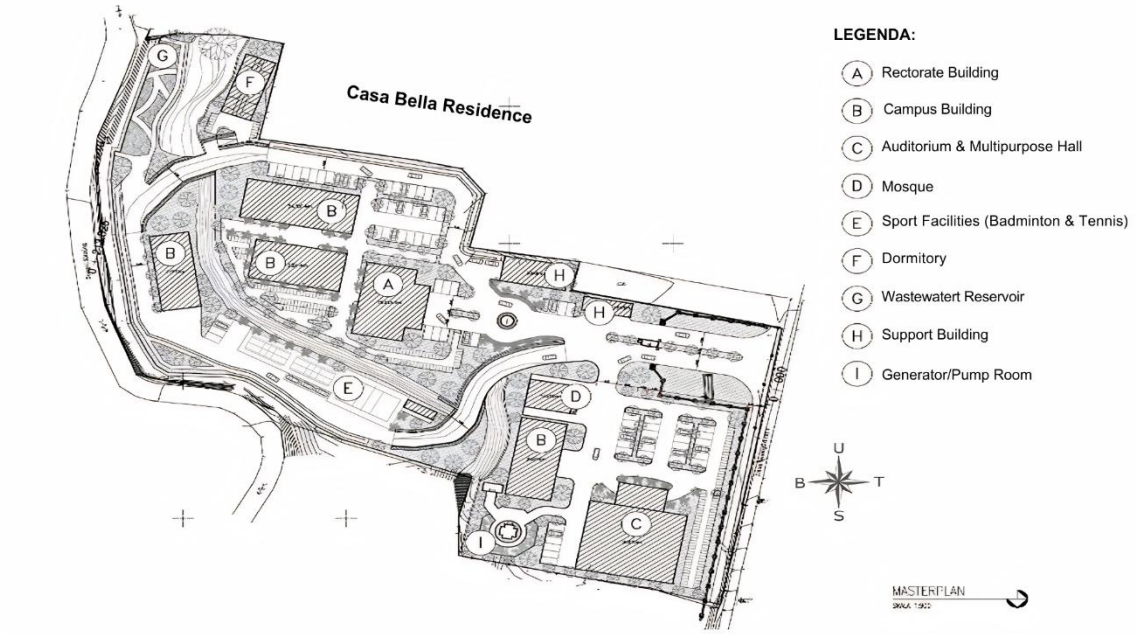


Fig. 1. Masterplan of Universitas AMIKOM Yogyakarta

Figure 1 presents the overall masterplan of the Universitas AMIKOM Yogyakarta development area. It shows the relative position of the main campus buildings, circulation routes, and supporting facilities, and it provides the spatial context for locating the retaining-work zone analysed in this study. The use of a case-study approach does not reduce scientific value; rather, it allows this study to examine the actual interdependence of cost items and schedule logic under one coherent project environment. In experimental terms, many variables that commonly distort cross-project comparisons were held relatively constant: project owner, site context, general scope, contractor basis, and retained area. This improves internal comparability. The trade-off, however, is that external validity depends on how similar future projects are to the observed case. The method is therefore most appropriate for analytical generalisation, meaning that the reasoning process may be transferable even when the exact figures are not.

2.2 Research procedure and assumptions

The research procedure followed four linked stages. First, the project drawings, bill of quantities, and scheduling data were checked to ensure that the two alternatives referred to the same site function and comparable retained area. Second, direct-cost calculations were prepared in Excel by recapitulating work volumes and unit prices for each method. Third, schedule logic was developed and reviewed in Microsoft Project to identify total duration, sequencing, relationships among activities, and the critical path. Fourth, the direct cost, indirect cost, and schedule results were interpreted together to generate a practical time-cost trade-off. This analytical sequence ensured that the final comparison did not stop at descriptive cost recapitulation but also explained why the observed differences emerged.

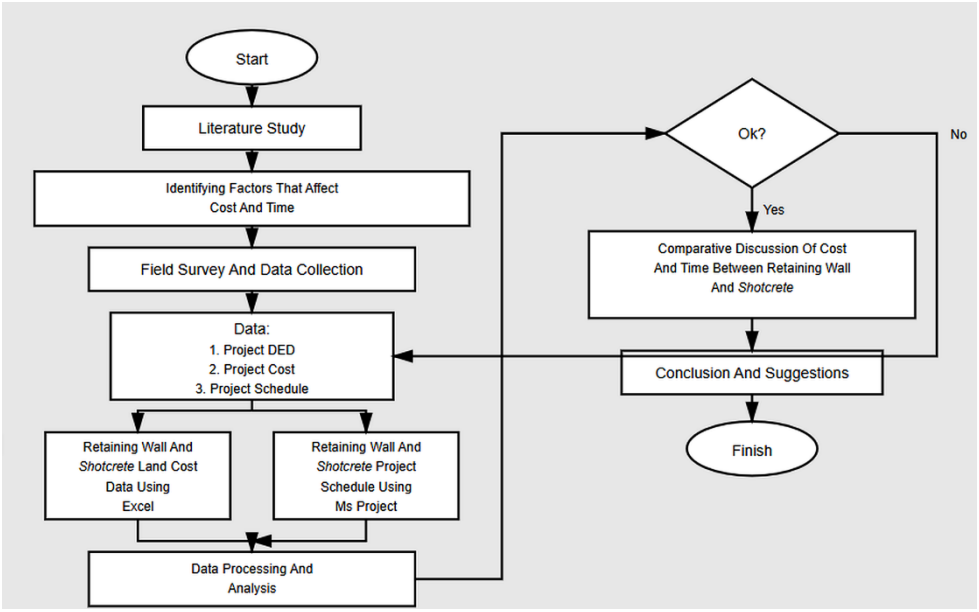


Fig. 2. Flowchart of the research procedure

Figure 2 summarises the analytical workflow used in this study, starting from literature review and field data collection and continuing to cost recapitulation, schedule modelling, and integrated time-cost interpretation. The diagram clarifies that the comparison between the retaining wall and shotcrete alternatives was conducted through linked stages rather than through a single isolated cost calculation.

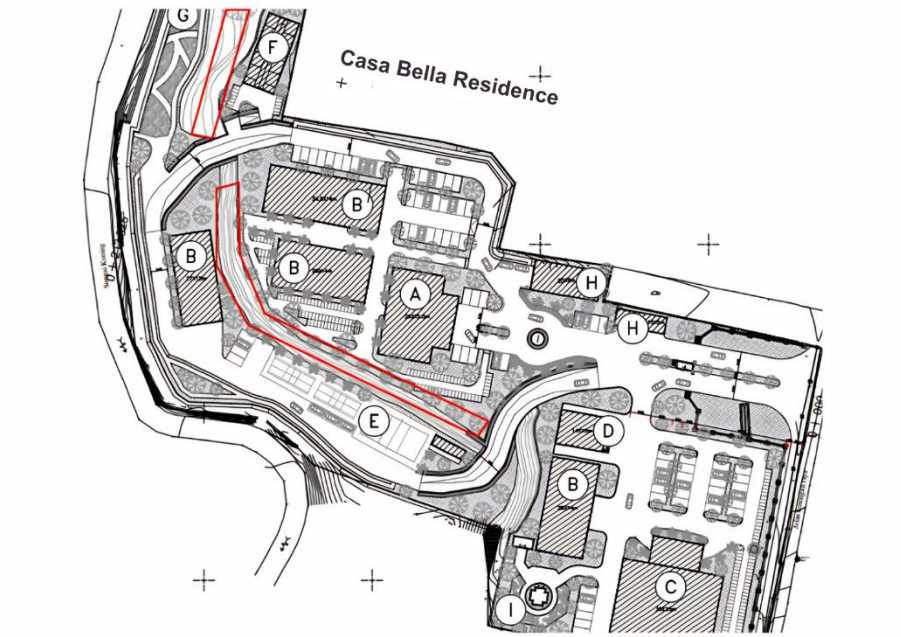


Fig. 3. Area selected for shotcrete or retaining wall application

Figure 3 highlights the specific corridor and slope segments used as the like-for-like comparison area for both alternatives. The marked zone indicates that the retaining wall and shotcrete methods were evaluated on the same functional area and under the same project context so that the cost and duration comparison remained directly comparable.

3. Result and Discussion

3.1 Project cost estimate

Table 1 present the direct-cost recapitulation for both alternatives. The retaining wall method produced a total direct cost of IDR 14,500,665,354.25, whereas shotcrete produced IDR 14,851,400,734.25. In absolute terms, the shotcrete option was IDR 350,735,380.00 more expensive, equivalent to a 2.42% premium. This difference is not uniform across all work items. Most supporting packages, including preparation, stormwater drainage, electrical works, and greenery, remained essentially identical. The decisive gap came from the retaining-system component itself, which means the direct-cost comparison is driven mainly by the technology and execution method of the slope-support work rather than by unrelated site-development packages.

Table 1. Cost estimate recapitulation of retaining wall and shotcrete

No.	Retaining wall		Shotcrete	
	Description of work	Total cost (IDR)	Description of work	Total cost (IDR)
A	Preparatory Works	IDR 30,000,000.00	Preparatory Works	IDR 30,000,000.00
B	Earthworks	IDR 171,716,200.00	Earthworks	IDR 171,716,200.00
C	Retaining Wall and Perimeter Fence Works	IDR 4,921,310,838.25	Shotcrete and Perimeter Fence Works	IDR 5,272,086,248.25
D	Infrastructure and Land Development Works	IDR 7,781,187,705.00	Infrastructure and Land Development Works	IDR 7,781,147,675.00
E	Stormwater Drainage Works	IDR 908,900,611.00	Stormwater Drainage Works	IDR 908,900,611.00
F	Electrical Works	IDR 636,300,000.00	Electrical Works	IDR 636,300,000.00
G	Planting (Greenery) Works	IDR 51,250,000.00	Planting (Greenery) Works	IDR 51,250,000.00
	Total project cost	IDR 14,500,665,354.25	Total project cost	IDR 14,851,400,734.25

The structure-package analysis clarifies the source of this premium. The retaining wall alternative used more conventional stone masonry and foundation work, which benefited from locally familiar materials and simpler construction logistics. The shotcrete alternative required a higher unit price, specialised spraying equipment, and a more technically demanding placement process. In addition, rebound loss, nozzle control, surface preparation, and quality monitoring are embedded in shotcrete execution and can increase both production cost and quality-control cost (Armengaud et al., 2017; Chen et al., 2017; Duarte et al., 2020; Mishchenko et al., 2024; Storrie & Bartlett, 2001). Consequently, even when shotcrete reduces project duration, its cost structure remains more concentrated in equipment, technical execution, and workmanship control.

From a managerial perspective, the direct-cost result suggests that the retaining wall method is advantageous when the owner's primary objective is budget minimisation and when schedule flexibility is still available. This interpretation aligns with the broader time-cost literature, which emphasises that accelerated or technology-assisted execution often requires additional direct expenditure (Chin & Hamid, 2015; Elkliny et al., 2023; Shehu, 2021). However, the direct-cost view alone is incomplete. A method with a lower direct cost can still become less attractive when it prolongs the project and increases exposure to

overhead, supervision, and project risk. Therefore, the direct-cost results must be interpreted together with the indirect-cost and schedule results.

A closer reading of the cost recapitulation shows that the difference between the two methods is concentrated rather than dispersed. This is analytically important because it means the cost premium of shotcrete is not caused by general inefficiency in the whole project, but by the characteristics of one dominant work package. If the wall-structure package were excluded, the two project budgets would be nearly identical. For practitioners, this suggests that value engineering efforts should focus on the retaining package itself, such as reviewing surface preparation standards, equipment productivity, or partial application zones, rather than attempting broad reductions in unrelated support packages. The result also indicates that a managerial decision on retaining method can have a visible project-level impact even when all other packages remain unchanged.

The duration results can also be interpreted from a production-flow perspective. Long sequential work chains reduce the flexibility of the project because downstream activities must wait for completion of upstream tasks with little opportunity for overlap. In the retaining wall method, wall-body construction is staged and cumulative, which means that delays propagate easily through the sequence. Shotcrete changes this flow pattern by shortening individual wall activities and reducing some intermediate steps. The value of this change lies not only in the final 42-day saving, but also in the greater schedule responsiveness it creates during project control. A shorter and less segmented critical path is generally easier to monitor and recover when small disturbances occur.

Although this paper does not perform a probabilistic simulation, the case supports an important planning insight: the method with the lower total duration can reduce the window during which unexpected events may occur. This does not mean that the faster method is always safer, because technical failure within a specialised method can be costly. It does mean, however, that schedule exposure itself should be treated as a risk variable. In practical terms, the retaining wall method carries more calendar exposure, while shotcrete carries more execution-intensity exposure. This distinction helps explain why the final choice may differ from one project to another even when the nominal cost difference looks modest.

3.2 Indirect cost analysis of retaining wall and shotcrete

Indirect cost analysis shows a more nuanced pattern than the direct-cost comparison. The retaining wall method lasted for 13 months and generated total indirect cost of IDR 686,900,000, while shotcrete lasted for 12 months and generated IDR 676,685,500. The difference was only IDR 10,214,500, or around 1.49%, but the direction of the difference is important. The shorter shotcrete schedule reduced total exposure to field overhead and office overhead, which offset part of the higher direct construction cost. In other words, the faster method partially compensated for its more expensive execution by reducing the project's time-dependent support burden.

The monthly recapitulation further explains how this mechanism works. The retaining wall method required about IDR 52.84 million of indirect cost per month, while shotcrete required about IDR 56.39 million per month. Therefore, shotcrete had a higher monthly burn rate, but the shorter schedule prevented this higher monthly value from producing a higher cumulative total. This distinction matters in project finance. A project owner choosing shotcrete must be prepared for more concentrated monthly expenditure, whereas a project owner choosing the retaining wall method faces lower monthly pressure but a longer period of overhead commitment. In cash-flow terms, shotcrete compresses cost into a shorter period, while the retaining wall method spreads cost over a longer period.

The linear model of indirect cost, $Y_{indirect} = C_{fixed} + (D \times C_{monthly})$, proved useful because it made the schedule–overhead relationship explicit. With C_{fixed} = IDR 315,000,000 as the fixed component, the difference between the two methods can be interpreted as the effect of one additional month of project exposure. This finding is important for practitioners because method-selection discussions often focus only on unit

price and ignore the fact that overhead accumulates simply because the project remains active longer. The model does not replace detailed budgeting, but it provides a transparent first-level prediction tool for comparing alternative methods before a final decision is made.

Table 2. Indirect cost analysis recapitulation of both methods (per month)

Month	Retaining wall	Shotcrete (IDR)	Cumulative retaining wall (IDR)	Cumulative shotcrete (IDR)
1	52,838,462	56,390,458	52,838,462	56,390,458
2	52,838,462	56,390,458	105,676,923	112,780,917
3	52,838,462	56,390,458	158,515,385	169,171,375
4	52,838,462	56,390,458	211,353,846	225,561,833
5	52,838,462	56,390,458	264,192,308	281,952,292
6	52,838,462	56,390,458	317,030,769	338,342,750
7	52,838,462	56,390,458	369,869,231	394,733,208
8	52,838,462	56,390,458	422,707,692	451,123,667
9	52,838,462	56,390,458	475,546,154	507,514,125
10	52,838,462	56,390,458	528,384,615	563,904,583
11	52,838,462	56,390,458	581,223,077	620,295,042
12	52,838,462	56,390,458	634,061,538	676,685,500
13	52,838,462	-	686,900,000	676,685,500

At the same time, the indirect-cost result should not be overgeneralised. Shotcrete required higher expenditure in testing, commissioning, and post-construction technical attention, reflecting the more specialised nature of the method. This means that the shorter schedule does not automatically make shotcrete cheaper in all projects. If specialised equipment is scarce, operator skill is limited, or quality-control requirements become more stringent, its overhead advantage may shrink or disappear. Conversely, if a project faces high rainy-season risk, access constraints, or strong penalties for late completion, the value of schedule acceleration may become more important than the small premium in total cost. Therefore, the result should be interpreted as a context-based trade-off rather than a universal rule.

3.3 Comparison of duration between both methods

The critical-path comparison also reveals where the acceleration occurred. Both methods shared early activities such as mobilisation, soil investigation, site clearing, topographic survey, foundation installation, cut and fill, contour levelling, paving, gateway construction, and landscaping. The main divergence occurred in excavation and wall-body execution. In the retaining wall method, excavation and staged wall construction required a longer sequential chain, including approximately 20 days of retaining-wall excavation, 30 days for the lower wall structure, and 30 days for the upper wall tier. In the shotcrete method, the equivalent wall-body operations were compressed into shorter sprayed-concrete stages of about 20 days per tier, and excavation was reduced to about 8 days on the corresponding critical path. At the main-work level, the thesis data show that the retaining-wall body and associated excavation required about 80 working days, while the comparable shotcrete sequence required about 48 working days. This explains why the schedule benefit of shotcrete is especially visible in the slope-stabilisation portion of the project rather than in later site-finishing works.

The practical reason for this acceleration is consistent with the literature on construction productivity and technology-assisted execution (Chin & Hamid, 2015; Elkliny et al., 2023; Plamenco et al., 2021; Qiao & Zhou, 2017; Shehu, 2021). Shotcrete adapts more easily to irregular slope geometry, reduces dependency on extensive formwork, and allows faster surface coverage once mobilisation and preparation are in place. The method also reduces some of the handling, placement, and finishing intensity associated with conventional masonry-based retaining structures. In management terms, shotcrete

improved scheduling efficiency by shortening the most restrictive sequence of activities. This reduced idle time on dependent activities and created a more compact project logic.

However, the faster schedule should not be interpreted as meaning that shotcrete is operationally simpler. The method demands better coordination among equipment, material delivery, surface preparation, nozzle operation, and quality control. If any of these inputs fail, the expected time gain can erode quickly. The retaining wall method is slower, but its process is more familiar and may be more resilient in settings with limited specialist resources. Therefore, the time advantage of shotcrete is real, but it is conditional on competent execution and adequate site support. When the cost and time results are interpreted together, a clear trade-off emerges. The retaining wall method is the lower-cost option, while shotcrete is the lower-duration option. At the total-project level, the retaining wall method reached IDR 15,187,565,354.25 with a duration of about 400 working days, whereas shotcrete reached IDR 15,528,086,234.25 with a duration of about 358 working days. Thus, the project obtained approximately 10.5% time saving at the expense of approximately 2.24% additional total cost. Put differently, every 1% of schedule saving was associated with roughly 0.23% additional total cost in this case study. This ratio is valuable because it translates the comparison into a form that project managers can use during decision making.

Table 3. Indirect cost analysis recapitulation of both methods

	Retaining wall method		Shotcrete method	
No.	Main activity	Duration (Days)	Main activity	Duration (Days)
1	Mobilization and equipment procurement	10	Mobilization and equipment procurement	10
2	Soil investigation work	14	Soil investigation work	14
3	Site clearing and topographic survey	12	Site clearing and topographic survey	12
4	Retaining wall excavation work	20	Retaining wall excavation work	8
5	Retaining wall foundation installation	25	Retaining wall foundation installation	25
6	Plastering and finishing of Retaining wall surface	20	Plastering and finishing of Retaining wall surface	20
7	Lower Retaining wall structure	30	Shotcrete (replacement for Retaining wall tier 1)	20
8	Retaining wall structure tier 2	30	Shotcrete (replacement for Retaining wall tier 2)	20
9	Cut and fill earthwork	35	Cut and fill earthwork	35
10	Land contour leveling	15	Land contour leveling	15
11	Paving block installation	25	Paving block installation	25
12	Construction of AMIKOM University gateway	30	Construction of AMIKOM University gateway	30
13	Final stage: landscaping and greening	15	Landscaping and greening	15

The result has several practical implications. First, if the project objective is to minimise initial expenditure and the completion date still has some flexibility, the retaining wall method is more rational. Second, if the project is facing a tight operational deadline, seasonal risk, or strong delay penalties, shotcrete may become more attractive because the value of finishing earlier can exceed the observed cost premium. Third, the selection should

consider the availability of skilled operators and specialised equipment. Shotcrete performs well only when the project can support the technical requirements of the method. In settings where these resources are uncertain, the apparent time advantage may not be fully realised. Risk and uncertainty must also be considered more explicitly, as requested by the reviewers. The retaining wall method is exposed to uncertainty related to longer duration, higher cumulative overhead, extended supervision, and stronger vulnerability to disruption over time. A longer schedule increases the chance that adverse weather, changes in material prices, labour turnover, or site access problems will affect the project. Shotcrete, by contrast, reduces the duration of exposure but carries method-specific risks such as rebound loss, uneven thickness, nozzle-quality variation, equipment breakdown, and dependence on experienced operators (Armengaud et al., 2017; Chen et al., 2017; Duarte et al., 2020; Mishchenko et al., 2024; Storrie & Bartlett, 2001). Therefore, the time-cost trade-off is inseparable from the risk profile of each option.

Another important implication concerns communication between engineers and decision makers. Conventional discussion of retaining methods often focuses heavily on technical suitability, whereas project owners also need a financially readable explanation of the consequences of method choice. By showing direct cost, indirect cost, duration, and critical path in one framework, this study makes the decision more transparent. The owner can see that shotcrete is not simply 'better' or 'worse'; it is faster but more expensive. Similarly, the retaining wall method is not simply 'cheaper'; it is cheaper partly because it accepts a longer and more overhead-sensitive schedule. This type of integrated explanation is useful for practical decision making in land-development projects with constrained topography. The findings also contribute to the local Indonesian context. Many campus, road-access, and slope-stabilisation projects in Indonesia are executed under fluctuating market conditions, diverse contractor capabilities, and seasonal constraints. In such settings, method selection often has to balance short-term affordability against implementation speed. The present case indicates that technology-assisted methods like shotcrete deserve serious consideration, especially when schedule is a strategic objective rather than a secondary consideration. At the same time, the case confirms that conventional methods remain competitive when local material supply and cost control are the main priorities.

The present comparison therefore supports a broader methodological lesson for construction management research. Method evaluation is more informative when cost, time, and implementation conditions are analysed as one system. A pure cost comparison can undervalue schedule exposure, and a pure duration comparison can hide the resource intensity required to achieve acceleration. By combining cost recapitulation, indirect-cost modelling, and critical-path logic, this paper demonstrates a format that can be replicated for other competing construction methods, including hybrid systems, alternative wall materials, or staged earth-retaining strategies. For readers concerned with implementation, the practical message is straightforward: the better method depends on the project objective that is treated as non-negotiable. If the non-negotiable objective is the lowest feasible budget, the retaining wall method performs better in this case. If the non-negotiable objective is faster completion with better schedule flexibility, shotcrete performs better.

In summary, the manuscript now responds to the major review points by presenting explicit research questions, fuller method assumptions, standard-form equations, critical discussion of uncertainty, a clearer stand-alone conclusion, and a substantially expanded English-language reference base that is more closely related to retaining structures, shotcrete application, and project time-cost analysis. Within the limits of one case study, the revised article therefore offers both empirical results and a reusable decision framework for future method-selection studies. Finally, this study has limitations that open space for future research. The analysis was carried out on one project and was based on deterministic schedule assumptions. Future studies should incorporate risk-based duration modelling, probabilistic cost analysis, sensitivity testing for material prices and equipment rates, and, if possible, life-cycle performance indicators such as maintenance need and durability. Hybrid solutions are also worth studying, for example combining conventional retaining

structures in accessible zones with shotcrete in irregular or difficult segments. Such extensions would make the decision framework even stronger for practitioners.

A useful way to interpret the result is through scenario thinking. In a budget-driven scenario, where the owner has no urgent opening date and no severe delay penalty, the retaining wall method is attractive because it preserves capital at the start of the project. In a deadline-driven scenario, where early completion creates value by allowing earlier use of the site, avoiding a rainy season, or protecting downstream milestones, the additional cost of shotcrete can be economically justified. In a risk-driven scenario, where the owner is highly concerned about prolonged site exposure, the shorter schedule of shotcrete can reduce uncertainty even if the initial cash requirement is higher. These scenarios show why no single method should be labelled universally optimal. The findings also suggest that managerial capability is part of the method itself. A conventional retaining wall may appear technically simple, but its success depends on disciplined sequencing, steady material supply, and long-term quality consistency over a longer duration. Shotcrete appears faster, but its performance depends on whether the team can maintain equipment reliability, nozzle quality, thickness control, and rapid coordination of preparation and spraying stages. Consequently, the real comparison is not only between two construction materials or two structural forms, but between two project delivery systems with different demands on planning, supervision, and field control.

4. Conclusions

This study demonstrates that the two alternatives serve different project priorities. The retaining wall method is the more economical option, while shotcrete is the more time-efficient option. In direct construction cost, the retaining wall method reached IDR 14,500,665,354.25 and shotcrete reached IDR 14,851,400,734.25. After indirect cost was added, the total project values became IDR 15,187,565,354.25 for the retaining wall and IDR 15,528,086,234.25 for shotcrete, confirming that shotcrete remained 2.24% more expensive overall. From the schedule perspective, the retaining wall method required approximately 400 working days, whereas shotcrete required approximately 358 working days. The 42-day acceleration came mainly from the shorter excavation and wall-body sequence on the critical path, particularly in the main slope-stabilisation works. This means that shotcrete offers a clear managerial advantage when the project needs faster site turnover, tighter deadline control, or reduced exposure to time-dependent overhead.

The main contribution of this article is the integrated comparison of direct cost, indirect cost, and CPM-based schedule logic for two retaining systems under the same project context. The results show that the choice between the methods should not be made by unit price alone. Instead, project teams should align the method with the dominant objective of the project: retaining wall for lower total expenditure, or shotcrete for faster completion. Future research should test the findings under different soil conditions, market-price scenarios, and contractor capabilities, and should also include formal risk assessment, sensitivity analysis, and hybrid retaining strategies. Such work would strengthen the external validity of the present case and improve decision support for similar topographic projects in Indonesia and elsewhere.

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Author Contribution

Conceptualization, M.A.R. and T.D.; methodology, M.A.R. and T.D.; software, M.A.R.; validation, M.A.R. and T.D.; formal analysis, M.A.R.; investigation, M.A.R.; resources, M.A.R. and T.D.; data curation, M.A.R.; writing—original draft preparation, M.A.R.; writing—review and editing, M.A.R. and T.D.; visualization, M.A.R.; supervision, T.D.; project administration,

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The study used publicly available spatial and demographic data without human or animal subjects.

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The author declares no conflict of interest.

Declaration of Generative AI Use
During the preparation of this work, the author used ChatGPT (OpenAI, GPT-5 model) to assist in improving the academic tone, English structure, and clarity of the manuscript. After using this tool, the author thoroughly reviewed and edited the content as needed and takes full responsibility for the final version of the publication.

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References
ACI Committee 506. (2016). *Guide to shotcrete (ACI 506R-16)*. American Concrete Institute. https://www.concrete.org

Akis, E., Cebeci, I., & Yildiz, A. (2023). Optimum cost prediction of reinforced concrete cantilever retaining walls. *Buildings, 13*(10), 2409. https://doi.org/10.3390/buildings13102409

Armengaud, J., Casanova, P., Buffo-Lacarrière, L., Aubert, J.-E., & Bertron, A. (2017). Characterization of fresh dry-mix shotcrete and correlation with rebound. *Construction and Building Materials, 131*, 224–232. https://doi.org/10.1016/j.conbuildmat.2016.11.090

Berg, R. R., Christopher, B. R., & Samtani, N. C. (2009). *Design and construction of mechanically stabilized earth walls and reinforced soil slopes* (FHWA-NHI-10-024). Federal Highway Administration. https://www.fhwa.dot.gov/engineering/geotech/pubs/nhi10024/

Chen, L., Chen, X., Wang, X., Wang, J., & Wang, H. (2017). Numerical simulation for optimizing the nozzle of moist-mix shotcrete machine. *Journal of Measurements in Engineering, 5*(4), 187–197. https://doi.org/10.21595/jme.2017.19212

Chin, L. S., & Hamid, A. R. A. (2015). The practice of time management on construction projects. *Procedia Engineering, 125*, 32–39. https://doi.org/10.1016/j.proeng.2015.11.006

de Silva, K. S. U., & Perera, B. A. K. S. (2023). Spatial factors contributing to worker time management at construction sites. *A/Z ITU Journal of the Faculty of Architecture, 20*(2), 365–380. https://doi.org/10.58278/0.2023.17

Duarte, G., Gomes, R. C., de Brito, J., Bravo, M., & Nobre, J. (2020). Economic and technical viability of using shotcrete with coarse recycled concrete aggregates in deep tunnels. *Applied Sciences, 10*(8), 2697. https://doi.org/10.3390/app10082697

Elkliny, A. F., Ibrahim, M. E., Younes, A., & Gomaa, M. A. (2023). Time–cost–quality tradeoff considering resource-scheduling limits and multiskilling strategy. *Alexandria Engineering Journal, 76*, 523–541. https://doi.org/10.1016/j.aej.2023.06.054

Ervianto, W. I. (2004). *Teori-aplikasi manajemen proyek konstruksi*. Andi.

Guo, H. L., Li, H., & Skitmore, M. (2010). Life-cycle management of construction projects based on virtual prototyping technology. *Journal of Management in Engineering, 26*(1), 41–47. https://doi.org/10.1061/(ASCE)0742-597X(2010)26:1(41)

Hardiyatmo, H. C. (2018). *Penanganan tanah longsor dan erosi* (2nd ed.). Gadjah Mada University Press. https://ugmpress.ugm.ac.id/id/product/teknik-sipil/tanah-longsor-erosi-kejadian-dan-penanganan

Hendrickson, C. (1989). *Project management for construction: Fundamental concepts for owners, engineers, architects, and builders*. Prentice Hall. https://www.cmu.edu/cee/projects/PMbook/

Jasoor, W. M., & Khaleel, T. A. (2024). Prediction model for bridge retaining walls construction productivity rate utilizing the multiple linear regression technique. *AIP Conference Proceedings, 3106*, 020006. https://doi.org/10.1063/5.0236558

Kelley Jr, J. E. (1961). Critical-path planning and scheduling: Mathematical basis. *Operations research*, *9*(3), 296-320. https://doi.org/10.1287/opre.9.3.296

Kelley Jr, J. E., & Walker, M. R. (1959, December). Critical-path planning and scheduling. In *Papers presented at the December 1-3, 1959, eastern joint IRE-AIEE-ACM computer conference* (pp. 160-173). https://doi.org/10.1145/1460299.1460318

Kong, S. M., Oh, D. W., Lee, S. Y., Jung, H. S., & Lee, Y. J. (2021). Analysis of reinforced retaining wall failure based on reinforcement length. *International Journal of Geo-Engineering, 12*(1), 1–17. https://doi.org/10.1186/s40703-021-00143-6

Liu, G., Zhao, J., Zhang, Z., Wang, C., & Xu, Q. (2021). Mechanical properties and microstructure of shotcrete under high temperature. *Applied Sciences, 11*(19), 9043. https://doi.org/10.3390/app11199043

Mishchenko, V., Yushyn, O., Romanyuk, M., Chyrva, A., Kostyria, I., & Matushko, Y. (2024). Shotcreting with cement–sand mixtures under the influence of electrostatic treatment. *Buildings, 14*(10), 3325. https://doi.org/10.3390/buildings14103325

Moayyeri, N., Bahreininejad, A., & Hajfathalian, A. (2019). Cost-based optimum design of reinforced concrete retaining walls considering different bearing-capacity methods. *Mathematics, 7*(12), 1232. https://doi.org/10.3390/math7121232

Naf'an, A. K., Zubaidi, T., & Astuti, R. W. (2019). Analisis risiko keterlambatan proyek konstruksi akibat perubahan desain dan kondisi lapangan. *Jurnal Rekayasa Sipil dan Lingkungan, 4*(2), 99–108. https://rumahjurnal.unej.ac.id/journal/jurnal-rekayasa-sipil-dan-lingkungan/

Plamenco, D. A. D., Germar, F. J., & Caparros, P. M. (2021). Application of discrete event simulation in estimating productivity of shotcrete method in divider wall construction. *International Journal of Sustainable Construction Engineering and Technology, 12*(3), 35–42. https://doi.org/10.30880/ijscet.2021.12.03.004

Project Management Institute. (2021). *The standard for project management and a guide to the project management body of knowledge (PMBOK® Guide)* (7th ed.). https://www.pmi.org/standards/pmbok

Qiao, P., & Zhou, Z. (2017). *Best practices of using shotcrete for wall fascia and slope stabilization (Phase I Study)* (WA-RD 870.1). Washington State Department of Transportation. https://rosap.ntl.bts.gov/view/dot/32893

Rakasyiwi, G. R., Witjaksana, B., & Tjendani, H. T. (2022). The literature review of construction project scheduling methods and effectiveness for the last 5 years in

Indonesia. *International Journal on Advanced Technology, Engineering, and Information System, 1*(3), 43–50. https://doi.org/10.55047/ijateis.v1i3.446

Sari, U. C., Sholeh, M. N., & Hermanto, I. (2020). The stability analysis study of conventional retaining walls variation design in vertical slope. *Journal of Physics: Conference Series, 1444*(1), 012053. https://doi.org/10.1088/1742-6596/1444/1/012053

Shehu, S. (2021). A review of time management factors in construction project delivery. *Journal of Project Management Practice, 1*(2), 34–45. https://doi.org/10.22452/jpmp.vol1no2.3

Sjölander, A. (2020). Structural behaviour of shotcrete on irregular hard rock surfaces. In *Shotcrete: Elements of a system* (pp. 11–19). CRC Press. https://doi.org/10.1201/b10545-5

Steindl, F. R., Galan, I., Baldermann, A., Sakoparnig, M., Briendl, L., Juhart, J., Thumann, M., Dietzel, M., Röck, R., Kusterle, W., & Mittermayr, F. (2020). Sulfate durability and leaching behaviour of dry- and wet-mix shotcrete mixes. *Cement and Concrete Research, 137*, 106180. https://doi.org/10.1016/j.cemconres.2020.106180

Storrie, AD & Bartlett, P. (2001). Wet shotcrete trial. *Journal of the Southern African Institute of Mining and Metallurgy*, *101*(4), 189-202. https://hdl.handle.net/10520/AJA0038223X_2670

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