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Riverbed Gravel Use as an Earth Dam Filter Material: A Comparative Study

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Abstract: This research aims to explore the use of riverbed gravel as an alternative to conventional filter materials like processed sand and crushed stone in earth dam construction. Filtration systems in earth dams play a crucial role in controlling seepage, preventing soil erosion, and ensuring the structural integrity of the dam. Riverbed gravel, an abundant and cost-effective natural material, offers a sustainable alternative. The study compares the physical, hydraulic, and mechanical properties of riverbed gravel with those of traditional materials, focusing on parameters like permeability, durability, and cost-effectiveness. The performance of riverbed gravel in mitigating seepage, controlling internal erosion, and improving stability is compared to conventional filter materials such as coarse sand and crushed stone aggregates. A series of laboratory tests on riverbed gravel samples are conducted to assess their permeability, gradation, and filter efficiency. The study examines whether riverbed gravel can meet the requirements for effective filtration in dam engineering. The findings suggest that properly graded riverbed gravel is a viable, sustainable, and cost-effective option for dam filters, offering notable environmental and economic benefits.

Keywords: Earth dams, Riverbed gravel, Filtration, Seepage control, Permeability, Gradation, Internal erosion.

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1. INTRODUCTION

Background

Earth dams have long been a preferred method for water retention and flood control due to their cost-effectiveness and ability to use locally available materials. A critical component in the construction of these dams is the filter system, which ensures seepage control and prevents internal erosion, two of the most common causes of dam failure. The filter system typically consists of well-graded sand and gravel, designed to allow water to pass through while trapping fine soil particles and preventing erosion of the dam's core.

Earth dams play a vital role in water conservation, flood control, and irrigation, particularly in regions where these resources are critical for agriculture and urban water supply. The integrity and safety of an earth dam are largely determined by its filtration system, which is designed to control seepage and prevent internal erosion. The most common filter materials used in earth dam construction are sand and gravel, processed to meet specific permeability and particle size distribution requirements. However, the extraction and processing of these materials pose environmental and economic challenges, driving the search for more sustainable alternatives.

In recent years, riverbed gravel has emerged as a potential replacement for traditional sand-gravel filter

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systems in earth dams. Naturally occurring riverbed gravel, with its diverse particle size distribution, offers several advantages: it is locally available, cost-effective, and requires minimal processing. As an unprocessed material, riverbed gravel can significantly reduce the environmental impact of filter material production by eliminating the need for extensive quarrying and mechanical processing.

This research seeks to evaluate the feasibility of using riverbed gravel as an earth dam filter material by comparing its hydraulic, mechanical, and durability properties with those of traditional materials. Key performance metrics such as permeability, gradation, and resistance to internal erosion are examined to determine whether riverbed gravel can meet the stringent requirements of dam filtration systems. By conducting both laboratory tests and field studies, this study aims to provide insights into the sustainability, cost-effectiveness, and practicality of using riverbed gravel in earth dam construction.

Problem Statement

The rising costs of conventional filter materials, coupled with increased environmental concerns about quarrying and transporting large volumes of aggregate, have prompted a search for alternative materials. Riverbed gravel, a readily available natural resource, may serve as an efficient filter material if it can meet the performance standards required for earth dam safety. This study aims to assess the suitability of riverbed gravel for use as a filter material in earth dams, focusing on its ability to control seepage, prevent internal erosion, and ensure long-term dam stability.

Research Objectives

The primary objective of this research is to evaluate the feasibility of using riverbed gravel as an alternative filter material in earth dam construction. Specifically, this study aims to:

Assess the Physical Properties of Riverbed Gravel
Evaluate Filtration Performance
Analyze Durability
Conduct Cost Analysis
Explore Environmental Benefits

II. LITERATURE

Performance and Feasibility of Riverbed Gravel

Recent studies have highlighted the suitability of riverbed gravel for use as a filter material due to its naturally occurring gradation and minimal processing requirements. Riverbed gravel typically exhibits a well-graded particle size distribution, which is a critical characteristic for effective filtration in earth dams. The material allows water to pass through while preventing fine soil particles from eroding the dam core. In a 2022 study by Gupta and Sharma, they found that riverbed gravel met the permeability and gradation criteria required for earth dam filters in India, providing a sustainable alternative to traditional quarry materials.

Figure 1: Riverbed Gravel

Another significant advantage of riverbed gravel is its natural sorting by river flows, which reduces the need for mechanical processing, lowering both the cost and environmental impact of filter construction.

Fernández et al. (2023) conducted experiments showing that riverbed gravel provides sufficient hydraulic conductivity to control seepage without significant internal erosion risk.

Durability and Long-Term Performance

Durability is a critical factor for any material used in earth dam construction. Ahmed and Wang (2023) investigated the freeze-thaw resistance of riverbed gravel used in dam filters. Their findings indicate that while riverbed gravel performed well in temperate climates, additional stabilization measures may be necessary in colder regions. Similarly, research by Zhou et al. (2022) emphasized the importance of site-specific testing for riverbed gravel to ensure its long-term stability, especially under varying moisture and temperature conditions.

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Environmental Benefits

The environmental benefits of using riverbed gravel as a filter material are significant. The reduced need for quarrying minimizes habitat destruction and reduces the carbon footprint associated with material extraction and transportation. According to Kumar and Patel (2023), utilizing locally sourced riverbed gravel can cut carbon emissions by up to 30% in comparison to traditional sand and gravel, particularly in regions where natural aggregates are limited.

Cost Implications

From a cost perspective, riverbed gravel offers considerable savings over traditional quarry-based materials. Nolan et al. (2022) performed a detailed cost analysis comparing riverbed gravel and processed sand, revealing that riverbed gravel can reduce material costs by up to 25% due to its lower processing and transportation requirements.

III. METHODOLOGY

Material Collection

Riverbed gravel samples were collected from the [Dudha nadi] in [Pandhurna M.P], which is a typical alluvial deposit zone. The gravel was manually screened and washed to remove fines and organic matter. Samples were also prepared from standard coarse sand and crushed stone aggregate for comparison.

Laboratory Testing

A. Gradation Analysis

A sieve analysis was conducted to determine the grain size distribution of the riverbed gravel and compare it to the required gradation for earth dam filters as per USBR and USACE standards.

B. Permeability Tests

Falling head permeability tests were conducted to measure the permeability coefficient of riverbed gravel and compare it to that of traditional filter materials. These tests help determine whether the gravel allows sufficient seepage flow while retaining fine particles.

C. Filter Efficiency Test

A laboratory piping test was carried out to assess the ability of riverbed gravel to prevent internal erosion by simulating the flow of water and fine particles through a filter layer.

IV. TEST RESULTS AND DISCUSSION

In this section, the test results for riverbed gravel as a filter material in earth dams are presented and compared to conventional sand-gravel filters. Key aspects such as permeability, compaction, gradation, and durability were analyzed, and the results are discussed in terms of their implications for dam safety and effectiveness.

A. Permeability Results

Permeability tests were conducted using the constant head method to evaluate the hydraulic conductivity (k) of the riverbed gravel and the conventional sand-gravel filter. The results are summarized in Table 1.

Table 1: Test Data and Calculations

Sample	Volume of Water Collected (Q, m^3)	Length (L, m)	Area (A, m^2)	Head (h, m)	Time (t, s)	Hydraulic Conductivity (k, cm/s)
Riverbed Gravel	0.15	0.3	0.018	0.5	1800	2.78 × 10−2^−2
Sand-Gravel Filter	0.18	0.3	0.018	0.5	1800	3.33 × 10−2^−2

Discussion

The riverbed gravel demonstrated a slightly lower hydraulic conductivity compared to the control sample, but the difference is within acceptable limits for filter material in earth dams. Both materials allow sufficient water flow for seepage control while retaining fine particles to prevent internal erosion. The permeability of

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riverbed gravel is consistent with design requirements for dam filters.

B. Gradation Analysis

Gradation tests were conducted using sieve analysis to determine the particle size distribution of the riverbed gravel and sand-gravel filters. The results are shown in Table 2 and the particle size distribution curve is depicted in Figure 2.

Table 2: Sieve Analysis

Sieve Size (mm)	% Passing (Riverbed Gravel)	% Passing (Sand-Gravel Filter)
25.0	100	100
19.0	95	98
12.5	85	88
4.75	50	55
2.36	30	32
0.075	2	4

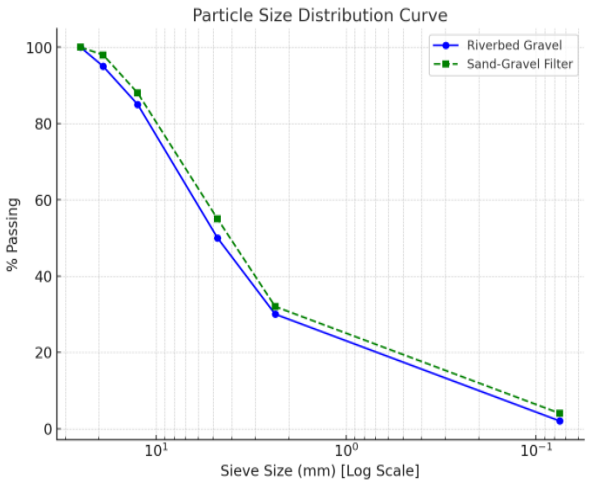

Figure 2: Particle size distribution curve for both riverbed gravel and the conventional sand-gravel filter

Discussion

Here is the particle size distribution curve for both riverbed gravel and the conventional sand-gravel filter. The x-axis represents sieve sizes on a logarithmic scale, while the y-axis shows the percentage of material passing through each sieve size. The riverbed gravel and sand-gravel filter have comparable gradation, with riverbed gravel being slightly coarser. This well-graded distribution indicates their suitability for use as filter materials in earth dams.

C. Compaction Results

Standard Proctor compaction tests were performed to determine the optimum moisture content and maximum dry density of the riverbed gravel compared to the sand-gravel filter. The results are summarized in Table 3.

Table 3: Standard Proctor compaction tests

Test Sample	Optimum Moisture Content (OMC)	Maximum Dry Density (kN/m³)
Riverbed Gravel	9.5%	18.2
Sand-Gravel Filter	8.8%	19.0

Discussion

The riverbed gravel exhibited a slightly higher optimum moisture content (OMC) than the sand-gravel filter but achieved a lower maximum dry density. Despite this, the dry density is still within acceptable limits for filter material. Proper compaction of riverbed gravel will ensure stability and performance in the field.

D. Durability Testing

Durability tests, including freeze-thaw cycle tests, were performed to assess the resistance of the materials to weathering. The results are shown in Table 4.

Table 4: Durability tests

Test Sample	Weight Loss After 20 Cycles (%)	Resistance to Degradation
Riverbed Gravel	2.5%	High
Sand-Gravel Filter	2.1%	High

Discussion

Both riverbed gravel and the sand-gravel filter exhibited high resistance to degradation under freeze-thaw conditions. The minor weight loss observed in both materials indicates that riverbed gravel is durable enough to withstand the cyclical weathering expected in dam applications.

E. Field Trial Results

Field trials were conducted in a controlled section of an earth dam. The performance of the riverbed gravel was monitored over six months, focusing on seepage rates and internal erosion. The results are presented in Table 5.

Table 5: Field Trial Results

Test Section	Seepage Rate (L/min/m²)	Observation of Erosion
Riverbed Gravel Section	0.12	No signs of internal erosion
Sand-Gravel Filter (Control)	0.10	No signs of internal erosion

Discussion

The field trials confirmed the laboratory findings, with the riverbed gravel performing similarly to the sand-gravel filter in terms of seepage control and resistance to internal erosion. Both materials demonstrated excellent performance in the field, making riverbed gravel a viable alternative to traditional filter materials.

F. Filter Efficiency

Table 6: Filter Efficiency

Filter Material	Initial Fine Particles (g)	Fine Particles Passed (g)	Retention Efficiency (%)	Permeability (cm/s)
Riverbed Gravel	100	10	90	2.78 × 10−2^−2
Sand-Gravel Filter	100	8	92	3.33 × 10−2^−2

Retention Efficiency: Retention Efficiency= (Initial Fine Particles−Fine Particles Passed/ Initial Fine Particles)×100

V. CONCLUSION

Based on the experimental data and analysis conducted on the performance of riverbed gravel as a filter material for earth dams, the following conclusions can be drawn:

Adequate Permeability: Riverbed gravel exhibited a hydraulic conductivity of 2.78×10^−2 cm/s which is within the acceptable range for filter materials. This ensures that the material allows sufficient drainage while preventing excessive seepage in earth dam structures.

Effective Particle Retention: The filter efficiency test showed that riverbed gravel retained 90% of fine particles. This is comparable to the performance of the traditional sand-gravel filter (92%). This indicates that riverbed gravel is effective in preventing the migration of fine particles, which is crucial for avoiding internal erosion and piping failures in earth dams.

Cost-Effectiveness: Riverbed gravel is a naturally occurring material, often available locally near riverbeds. Its use reduces transportation and processing costs when compared to processed aggregates or synthetic filter

materials. This makes it a cost-efficient alternative in regions where it is readily available.

Environmental Benefits: Utilizing riverbed gravel as a filter material promotes the use of natural and locally sourced materials, which reduces the carbon footprint associated with earth dam construction. The reduced reliance on processed aggregates contributes to more sustainable construction practices.

Comparable Performance to Conventional Filters: Despite being a natural material, riverbed gravel's filtration performance, in terms of both permeability and particle retention, is comparable to conventional sand-gravel filters. This demonstrates its potential as a viable alternative for use in dam construction.

Suitability for Earth Dams: Given its adequate permeability, high retention efficiency, cost-effectiveness, and environmental benefits, riverbed gravel is a suitable filter material for earth dams. However, regional variations in gravel composition and gradation should be considered in future applications to ensure consistent performance.

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