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Stability Analysis of Low-Cost Gabion Revetments for Adoption in Developing Countries: Insights from Field Investigations and Laboratory Experiments

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Abstract: Gabions are wire baskets filled with rocks and play a critical role in various civil engineering applications. These include roadside stabilization, riverbank protection, erosion control in gullies, dams, reservoirs, and foundational support for structures. However, despite their importance, scientific research on gabion technology, particularly in developing countries like Nepal, remains limited. Key challenges include the durability and stability of gabion structures under adverse conditions. To address these gaps, the authors conducted laboratory experiments and field investigations along the Khar Khola River in Gorkha, Nepal. The laboratory experiments compared the performance of Japanese-style gabions and hybrid structures combining Japanese and Nepalese elements, both with and without geotextiles. Meanwhile, field investigations focused on evaluating gabion stability by measuring horizontal deformation. The findings revealed that constructed gabion revetments demonstrated negligible deformation across different designs, signifying high structural stability. However, ensuring long-term effectiveness requires careful installation of base foundations and launching aprons, especially after flooding events, which can destabilize soft foundations and cause bed scouring. The hybrid gabion, blending Japanese and Nepali techniques, emerged as a particularly effective alternative. This design demonstrated improved resilience and stability, retaining its structural integrity even after two years of exposure to flooding and environmental stressors, making it an adaptable and cost-efficient solution for developing regions.

Key words: Gabion revetment, adoption, experiment, stability, cost effective.

1. Introduction

Gabion structures are wire cases or baskets that resemble cubes filled with rocks. These cubes are stacked on top of one another and connected in rows. The wire cases are typically made from heavy-duty wire that is galvanized and PVC (polyvinyl chloride)-coated. Gabions primarily stabilize slopes, reduce water current as levees in rivers, and stabilize roadside walls [1]. The porous nature of gabion revetments allows them to deform resiliently against external forces, and they are eco-friendly. The use of gabions dates back to ancient Egypt around 7,000 years ago [2]. Since then, gabions have evolved and become one of the most common tools in civil engineering. In Nepal, gabions are used for various purposes, such as roadside construction, river flood management, and landslide control. British engineers first used gabions in Nepal during the construction of the Dharan Pakhribash road in the nineteenth century [3]. In Japan, gabions were used as early as the 16th century for riverbank protection by filling stones in bamboo baskets. Japan has a long history of using gabions, and the construction method is employed to create natural rivers, harmonize with local lifestyles and cultures, and preserve diverse river environments [4]. Nowadays, gabion wire mesh is used in gabion construction worldwide, with a shift towards

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using iron for its productivity advantages. Galvanized iron wire gabions have been manufactured since 1905, based on the “Galvanized Iron Wire and Structural Standards for Gabions” [5]. The modern form of gabions, which uses wire mesh, was developed in California’s Napa Valley for building purposes [6]. This technology has since become the most used for roadside retaining structures and riverbank protection worldwide. However, in Nepal, there are currently no standardized design and construction guidelines for gabion installations for riverbank protection. Present issues with gabion systems in Nepal include their short lifespan, susceptibility to damage shortly after installation, and instability [7]. Additionally, current gabion design practices in developing countries, including Nepal, often fail to consider soil geotechnical characteristics and hydrological parameters, leading to poor construction quality and unstable gabion structures. On the other hand, in developed countries like Japan gabion technology excels with superior engineering, meticulous construction, advanced materials, and enhanced stability and resilience, ensuring greater durability and effectiveness. To maintain construction quality, Japan has developed separate technical standards. In Japan, gabion standards were enacted by the Ministry of Construction in 1951 and 1952, with the Japanese Industrial Standard (JIS A 5513) for galvanized iron wire gabions established in 1951 [8]. Despite the widespread use of gabions in Nepal and other developing countries, there are relatively few studies on their applications, particularly for riverbank protection and flood control [9]. Most research has focused on the stability of gabion retaining walls, especially for roadside protection and landslide control [10]. These studies underscore the advantages of gabion and other flexible structures over rigid retaining structures, primarily due to their ability to withstand deformation without collapsing [11]. This study aims to analyze suitable gabion practices within the context of developing countries.

This study evaluates the comparative stability and effectiveness of gabion technologies derived from Japanese, Nepali, and hybrid practices that are adoptable in developing countries. Through on-site investigations and controlled laboratory experiments, the research highlights critical parameters influencing gabion stability, particularly after flood events. Key considerations include proper base foundation installation, adherence to standard gabion designs, and the use of protective elements such as launching aprons and geotextiles. These components play a vital role in mitigating risks associated with soft foundations and bed scouring, which are prevalent during and after flooding. Field investigations along the Khar Khola River in Gorkha, Nepal, and laboratory tests provided data on the performance of various gabion designs, including slope-type, Japanese-type, and mixed Japanese-Nepalese gabions, with and without geotextile reinforcement. The field studies measured deformation under real environmental pressures, while the laboratory tests assessed structural integrity and resilience. The results revealed negligible deformation across all gabion types, demonstrating their high stability and robustness against external forces. These findings affirm the potential of hybrid gabion technologies to enhance the durability and resilience of flood control structures, especially when incorporating improved foundation and geotextile applications. This integrated approach offers promising advancements for flood risk management in developing countries.

2. Gabion Construction Practices in Developed Countries and Developing Countries

Gabion practices in developed countries like Japan and developing countries like Nepal differ significantly due to variations in local resources, technical expertise, and construction standards. In Japan, gabion technology prioritizes precision engineering, stringent quality control, and disaster resilience. These structures are built according to the Japanese Industrial Standard (JIS) A 5513, using high-quality, galvanized, or coated wire mesh combined with uniformly sized stone filling [12].

This approach ensures exceptional stability, longevity, and the capacity to withstand seismic activities, heavy rainfall, and flooding. Advanced geotechnical techniques and meticulous construction practices make Japanese gabions highly reliable for riverbank protection, slope stabilization, and coastal defenses [13]. In contrast, traditional methods and local resource availability heavily influence Nepal's gabion practices. While the Department of Roads has established norms for roadside gabion walls, there are no specific standards for riverbank protection [14]. Locally sourced materials, often inconsistent in size and quality, weaken the overall strength and durability of Nepali gabions. Additionally, the wire mesh used is thinner and less corrosion-resistant than Japan’s materials. A lack of engineering oversight during construction further contributes to variability in quality. Despite these challenges, Nepal is gradually adopting advanced techniques, including the use of geotextiles, to improve stability and resilience. Table 1 highlights these differences, emphasizing that developed countries rely on high-quality materials, sophisticated engineering principles, and regular maintenance to extend gabion lifespans [15]. In contrast, Nepal’s cost-effective methods utilize local resources and traditional knowledge but often lack maintenance plans, leading to premature failures. Blending local practices with advanced engineering techniques through hybrid approaches holds promise for improving Nepal’s gabion performance, provided there is sustained investment in training and infrastructure development [16].

3. Methodology

3.1 Study Area

This study focuses on Palungtar Municipality-9 in the Gorkha district, Nepal, where approximately 965 people and 215 households are directly affected by floods [17]. Additionally, around 350 students face direct impacts from the monsoon floods in the area. The authors selected the Khar Khola, a small river in the region, to investigate the stability and effectiveness of gabions. The chosen site is particularly vulnerable, being located at a curvature point of the river where flooding causes significant damage annually. This area experiences severe riverbank erosion and flooding, which overtop the banks during the monsoon season, impacting nearby lands and damaging crops. The site’s selection was based on its high vulnerability and urgent need for protection. Each year, floods in the Khar Khola cause bank overtopping and flooding, leading to loss of agricultural land through bank cutting and debris deposition.

3.2 Site Geotechnical and Hydrological Condition

Soil samples from the study site revealed distinct characteristics across three layers. The top layer (0-30 cm) contained 9.4% fine particles, while the middle (30-100 cm) and bottom layers (100-200 cm) had only about 1%, indicating a predominance of gravel in deeper layers. The riverbank’s surface soil comprised more fine particles, while the middle and bottom layers were gravel-dominant, with the riverbed foundation

Table 1 Comparison of gabion practices between developed countries and developing countries.

Parameters	Developed countries	Developing countries
Planning and designing	Followed standard planning and design procedures	Emphasis on local practices
Considerations	Geological, seismic, hydrologic, and environmental conditions	Only hydrological condition
Materials used	High-quality construction materials used	Locally available materials
Construction	The standard rigorous construction process	Local construction practices
Lifespan	Up to 40 years	Up to 10 years
Cost of construction	High initial cost and low lifecycle cost	Low initial cost, high lifecycle cost
Maintenance	Proper maintenance plan	No maintenance plan

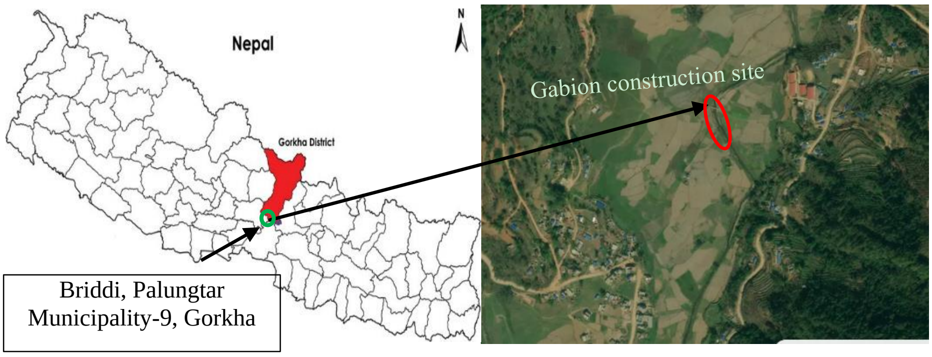


Fig. 1 Map of the study area.

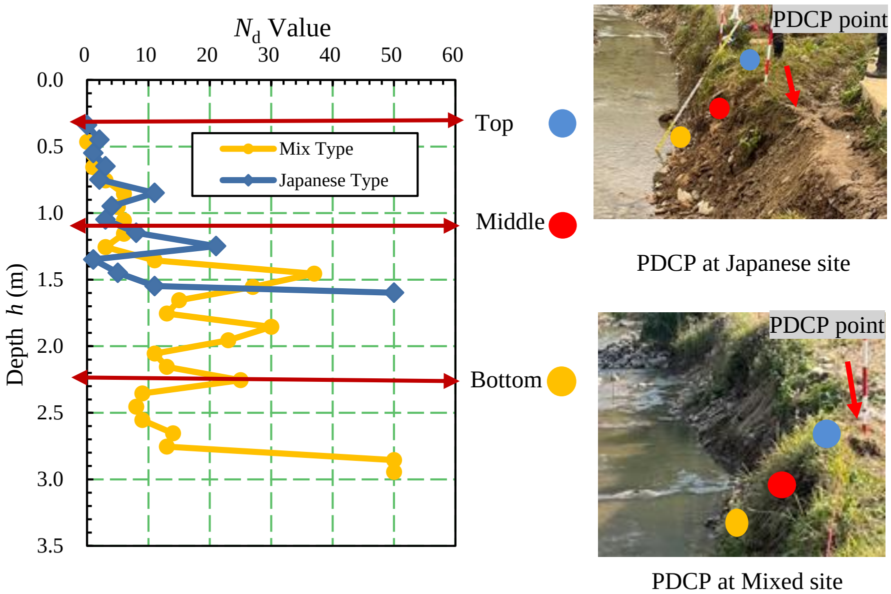


Fig. 2 PDCP (portable dynamic cone penetration) test result at site.

consisting of approximately 80% gravel. The PDCP test conducted at Japanese and mixed gabion sites confirmed similar topsoil properties. At one site, the test stopped at 1,600 mm due to large stones. As shown in Fig. 2, the top layer's N_d value was below 10, indicating softer, agricultural soil. Below 1.5 m, N_d values exceeded 20 at the mixed gabion location, reflecting harder soil with higher bearing capacity. At the Japanese site, hard rock was encountered below 1.5 m. Both locations exhibited stable gravel and hard soil below this depth, with N_d values over 20, confirming their suitability for gabion installation without requiring additional foundation treatment. While the top layer was softer, the deeper layers provided robust stability.

The Khar Khola River catchment area at the study site spans 28.87 km². In 2022, the region received 1,986 mm of rainfall, mainly from June to September. Table 2 shows that with an average rainfall intensity of 50 mm/h, the river discharge is 280.7 cubic meters. Flow through the river at different periods is calculated by using the following formula.

$$Q = 1/3.6 \times f \times r \times A \quad (1)$$

The river's average width (W) of 18 m allows for a high flood level of 2.0 m during this medium-intensity rainfall. This high flood level was calculated using Manning's Eq. (1) [18]. This information is crucial for evaluating the river's capacity to manage different rainfall intensities and for developing effective flood management strategies.

Table 2 Flow of Khar Khola River in different rainfall intensity.

	f (m/s)	r (m)	A (m^2)	Q (m^3/s)
1	0.7	30	28.9	168.4
2	0.7	50	28.9	280.7
3	0.7	100	28.9	561.4

where, Q = water flow velocity of river (m^3/s), A = area of river channel (m^2), R = hydraulic radius A/P (m), W = width of the channel (m).

3.3 Improved Gabion Design for Developing Countries

The authors have developed and constructed an improved gabion design for riverbank protection and flood control in Nepal, a developing country, drawing on Japanese design and construction practices. Current gabion practices in Nepal often fall short of required engineering standards, with less emphasis on quality control and adherence to construction standards, relying heavily on local practices and expertise. This often results in short-lived gabion structures. The construction of gabions has been completed in February 2023. The following two types of gabion designs were constructed at the site for further investigation.

Japanese type design features 500 mm height stacks with a 250 mm lapping width between consecutive stacks (shown in Fig. 3). Japanese and Nepalese mixed-type design features 1,000 mm height stacks with a 500 mm lapping width between consecutive stacks (shown in Fig. 4). These designs aim to improve the resilience and effectiveness of gabion structures for riverbank protection in Nepal [18]. The properties of the fill material influence the deformation of a gabion retaining wall, the wire mesh's confinement effect, and the gabion box's height, as illustrated in Figs. 3 and 4. Specifically, the tensile resistance of the wire mesh on the rear side restrains deformation on the front face when bending occurs in the flexible gabion structure.

3.4 Field Investigation

The authors measured the horizontal deformation of both gabion structures from May 2023 to August 2024. Figs. 5-7 illustrate that horizontal deformation was assessed by measuring the horizontal distance using staffs and ranging rods. Horizontal distances were measured from the front staff to three distinct points labeled a, b, and c, as depicted in Figs. 6 and 7. The average deformation was then calculated using the measurements from these three points.

As shown in Fig. 8, deformation measurements were taken at 0 m, 7.5 m, and 15 m sections of the Japanese gabion. For the mixed-type gabion, measurements were taken at 0 m, 25 m, and 46 m sections, as shown in Fig. 9. This methodology allowed for a comprehensive analysis of the stability and deformation patterns

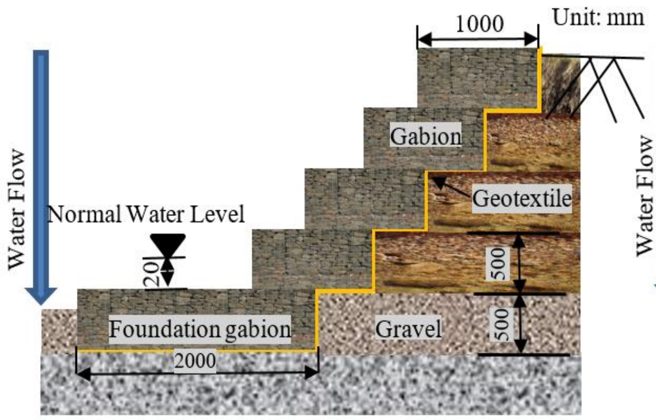


Fig. 3 Japanese type gabion design.

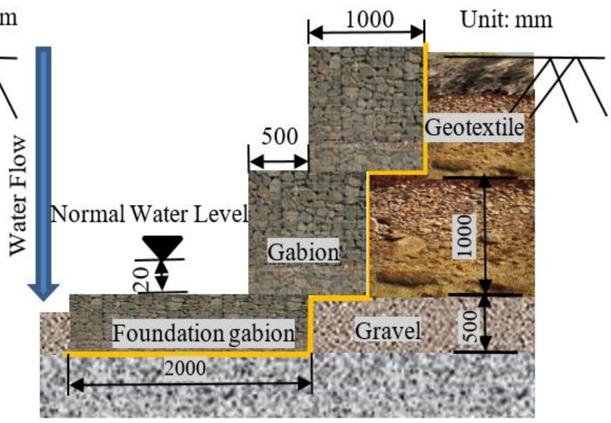


Fig. 4 Mixed type gabion design.

Fig. 5 Deformation measurement at site.

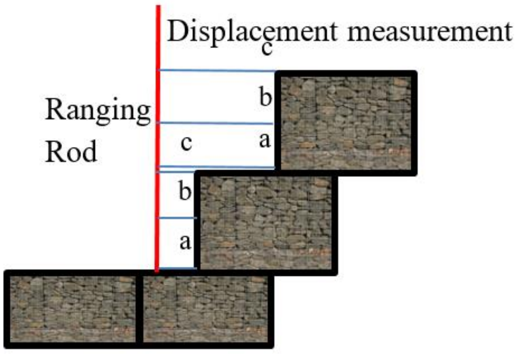


Fig. 6 Deformation measurement points for mixed type gabion.

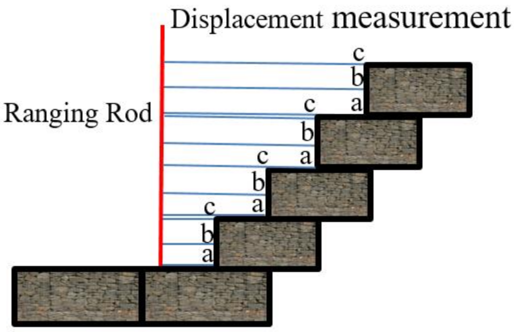


Fig. 7 Deformation measurement points for Japanese type gabion.

of the gabion structures over one year. By tracking these measurements, the study provided valuable insights into the performance and structural integrity of the gabion installations. The analysis highlighted the critical factors affecting deformation and helped understand the long-term behavior of gabion walls under varying conditions. The data are essential for optimizing the design and maintenance of gabion structures to ensure their durability and effectiveness in different environments.

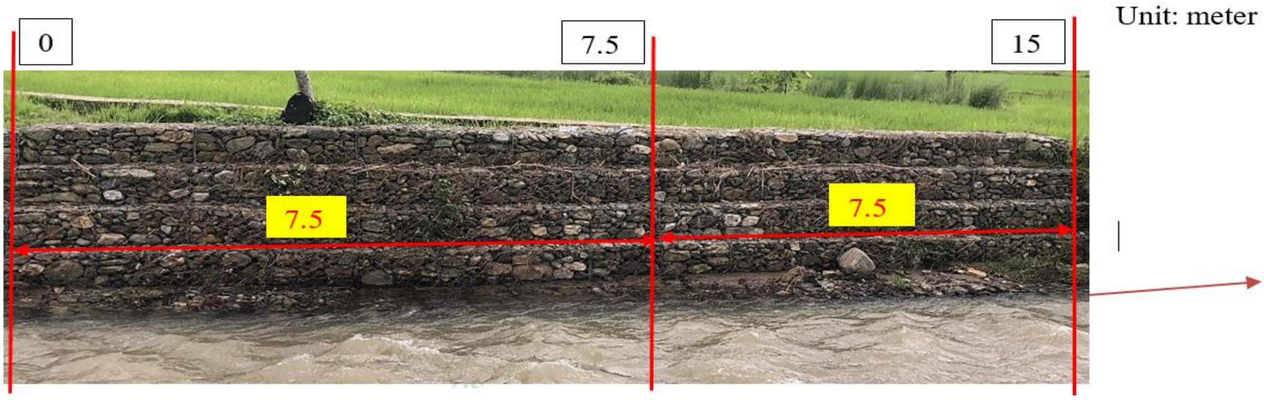


Fig. 8 Measurement locations of Japanese type gabion in the site.

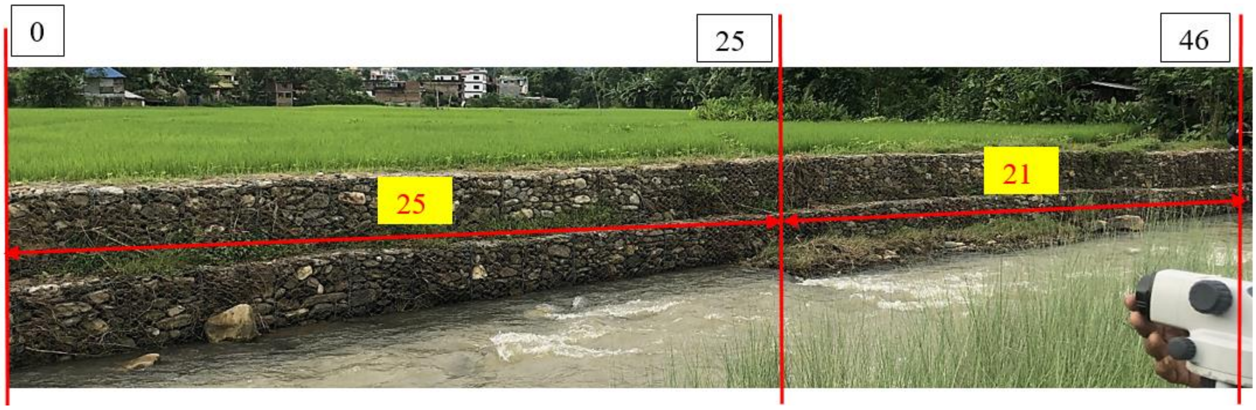


Fig. 9 Measurement locations of Japanese & Nepalese mixed type gabion in the site.

3.5 Laboratory Experiment

Laboratory experiments conducted at Kochi University's Geotechnical Engineering Laboratory investigated the effects of water level fluctuations on Japanese-type and mixed-type gabions, which integrate features from Japanese and Nepali designs. The study aimed to evaluate the stability and performance of gabion revetments under varying hydrological conditions, focusing on designs with and without geotextiles. The experiments also assessed the impact of water currents on straight-type gabions without foundational support or launching aprons. The experimental setup, detailed in Fig. 10 and based on considerations outlined in Table 3, simulated conditions observed at the Gorkha, Nepal construction site. Materials, as shown in Fig. 11, were arranged according to configurations illustrated in Figs. 10 and 12 During the tests, water was incrementally supplied to the front of the setup until it rose 10 cm above the gabion box's top. This elevated level was maintained for several hours before being lowered to half the height of the first gabion box. This cycle was repeated three times, with the experiment performed twice to evaluate the impact of different structural designs and geotextile use.

The study demonstrated how fluctuating water levels influence gabion stability and durability. Findings provide valuable insights for optimizing gabion designs to enhance resilience in real-world scenarios, especially in developing nations like Nepal with dynamic hydrological challenges.

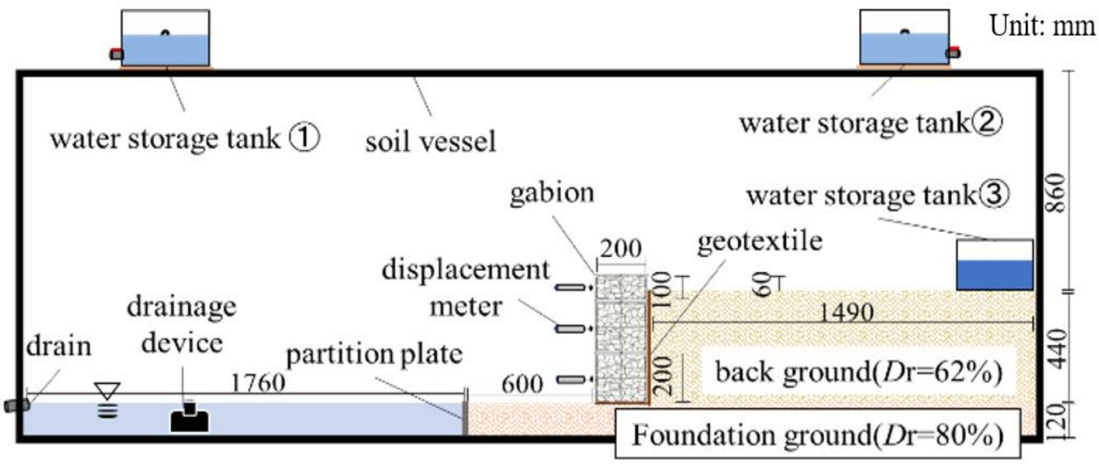
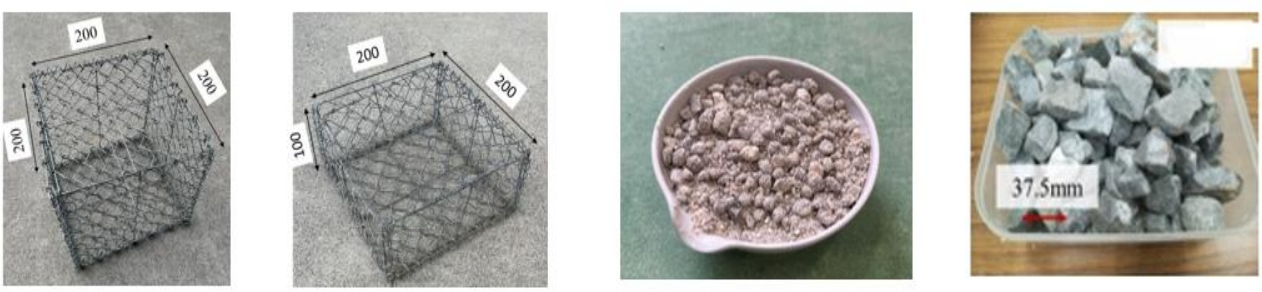
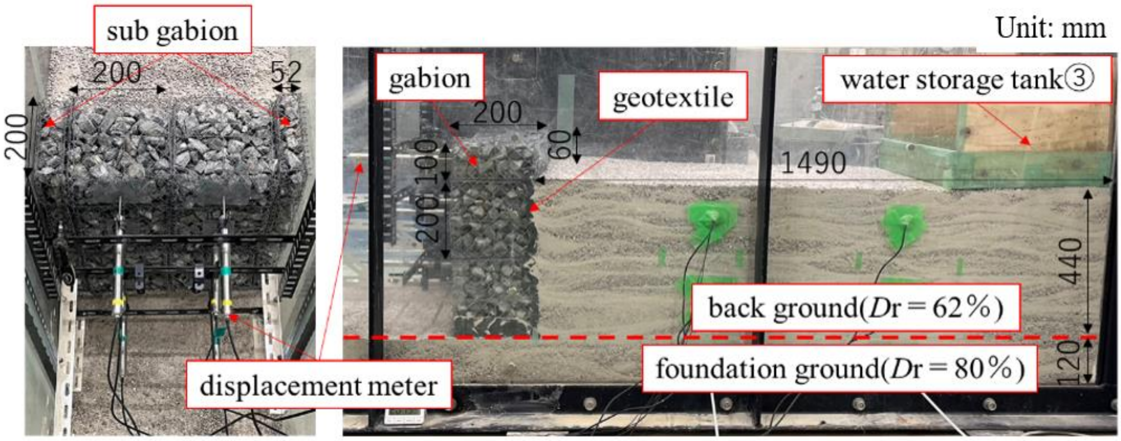


Fig. 10 Typical experimental plan.



(a) Cubic wire (b) Rectangular (c) Backfill soil (d) Filling stone

Fig. 11 Materials used for the experiment.



(a) Plan view (b) Side view

Fig. 12 Picture of laboratory experiment.

Table 3 Consideration for experiment.

	Experiment	Field
Size	1/5	Actual size
River flow	No flowing water	Flowing water
Ground condition	At the start: dry	Varies
Rain	No rain	Raining
Vegetation	No vegetation	Vegetation
Overflow water	Pure water	Muddy and turbulence water

4. Result and Discussion

4.1 Field Investigation

The authors investigated the stability of gabions by examining their deformation over time. We compared the surface deformation of two types of gabions, from May 2023 to August 2024, especially two cycles of deformation before and after the rainy seasons. Figs. 13 and 14 illustrate the horizontal deformation results from May 2023, immediately after construction, to August 2024 for Japanese-type gabions. Negligible deformations were observed in the gabions after one year of construction. The maximum deformation for the Japanese-type gabion in May 2023 was 5 mm, which increased to 17 mm after two cycles of construction. The slight increase in deformation is due to higher earth pressure during the rainy season. Rain increases the weight of the earth behind the gabion, pushing the front side forward. The horizontal force from behind the gabion exceeds its self-weight. With each gabion stack only 50 cm high, the back pressure is not substantial enough to cause significant displacement. However, it was observed that the third layer experienced more front-side deformation compared to other layers, indicating that localized pressure and saturation effects contribute more significantly to the displacement in this layer than in others. Similarly, the authors analyzed the deformation measurements for mixed types in different sections. Figs. 15, 16a, and 16b describe the results of horizontal deformation at different locations in the mixed-type gabion. The maximum deformation observed was up to 37 mm. The deformation after one year of construction was found to be 10 mm in most of the sections, indicating that the deformation is negligible. Comparing the measurements from both types after one year of construction, the deformation of the mixed-type gabion was slightly higher than that of the Japanese-type gabion. The post-rainy season measurements indicate that Japanese-type gabions exhibited a normal deformation of 5 mm, whereas the mixed type showed 10 mm. The increased deformation in mixed-type gabions is primarily due to their 100 cm layer height, which amplifies the back-wall's weight during rainfall. This added weight intensifies backside forces, pushing the gabions forward due to the higher lateral pressure from the saturated backfill. In contrast, Japanese-type gabions, with fewer tiers, experience reduced vertical loads on their lower tiers, resulting in less overall deformation. Figs. 13-16 illustrate that deformation in both gabion types is most pronounced at the lower retaining wall sections. As the number of tiers increases, the lower gabions deform under the vertical load from the upper tiers. Deformation is influenced by the gabion frame quality, the stone packing density, and porosity. The stone density used is 1.74 kg/m ^{3} for both gabion types. At lower layers, horizontal deformation is primarily driven by the lateral pressure of the backfill material. This earth pressure rises with the backfill height, leading to significant deformation at the base layers of the retaining wall.

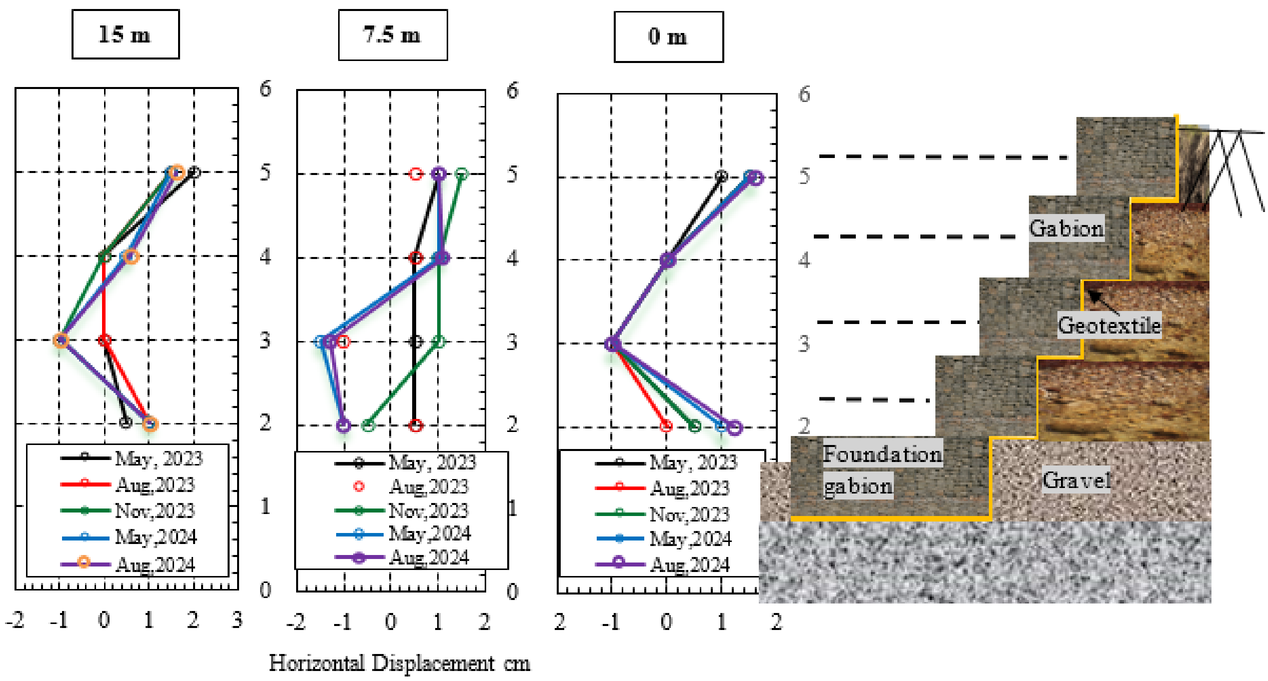


Fig. 13 Deformation of Japanese-type gabion.

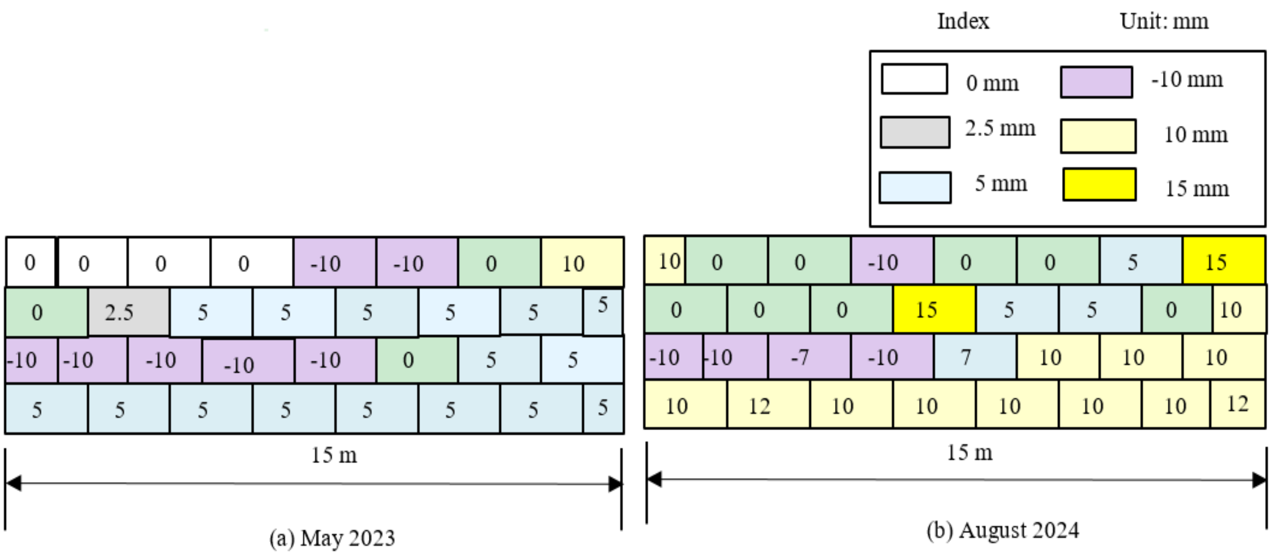


Fig. 14 Deformation measurement of Japanese type.

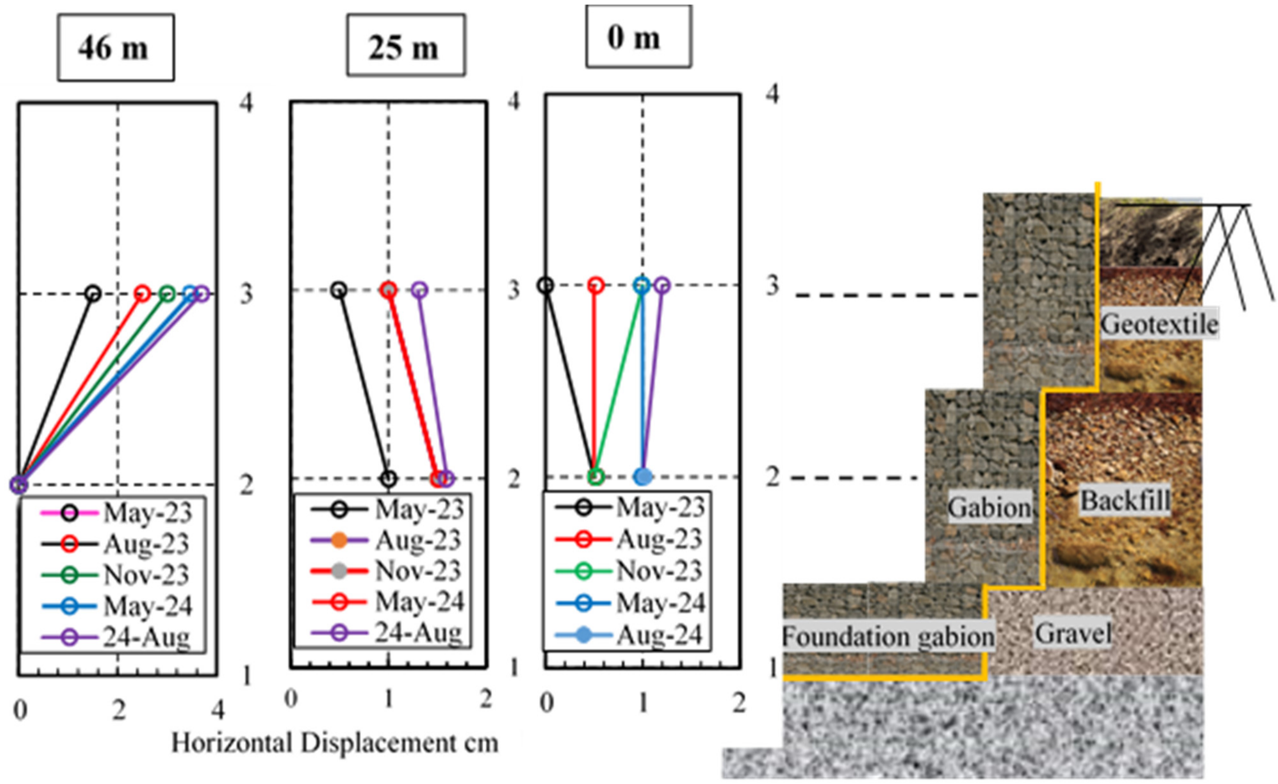
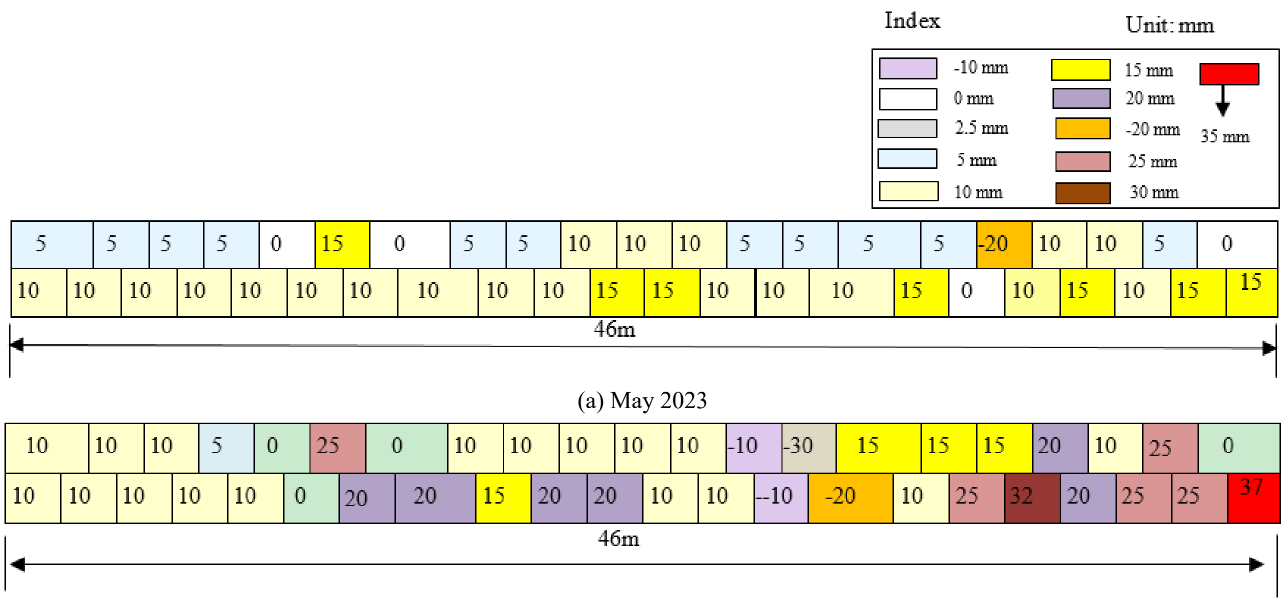


Fig. 15 Deformation of Nepalese & Japanese mixed type gabion.



(a) May 2023

(b) August 2024

Fig. 16 Deformation measurement of Nepalese & Japanese mixed type gabion.

The study reveals that both gabion types exhibit deformation, with the mixed-type gabion showing slightly more deformation compared to the Japanese type at the same condition. However, this difference can be attributed to variations in construction materials, such as the size and shape of the stones used, the thickness of the gabion wire mesh, and construction techniques. The Japanese-type gabion, with its lower height per stack, bears less back-earth weight at the time of rain and is subjected to lower earth pressure, resulting in reduced deformation. The findings highlight the critical factors influencing deformation, including the height of the gabion frame, stone density, and lateral earth pressure. Understanding these factors is essential for optimizing gabion design to enhance stability and durability, especially in regions susceptible to heavy rainfall and significant earth pressure. These insights provide valuable guidance for engineers in designing more effective and resilient gabion structures. Monitoring deformation over a year offers crucial data on gabion performance, helping engineers design more resilient structures that withstand environmental stresses and maintain integrity through careful material and construction considerations.

4.2 Laboratory Experiment

Laboratory experiments have revealed distinct deformation patterns between Japanese-type and mixed-type gabions under fluctuating water levels. The Japanese-type gabion demonstrated a tendency to lean backward, largely attributed to the lower density of its top-layer backfill material. As illustrated in Fig. 17, the top layer of the Japanese gabion shifted backward by up to 0.6 mm, whereas the mixed-type gabion exhibited forward displacement of up to 0.4 mm. Interestingly, the bottom layers of the mixed-type gabion displayed greater displacement compared to its upper layers. Despite both types having identical revetment slopes, the Japanese-type gabion experienced more significant backside displacement due to its closer proximity to the less stable backside material, as shown in Figs. 18a and 18b. The initial displacement observed in both gabion types during the first water level change can be attributed to the saturation of the backfill soil. Water infiltration led to soil subsidence, causing the gabions to lean backward. However, once the backside material stabilized, subsequent water level changes resulted in minimal to no displacement. This indicates that the initial adjustment phase is critical for gabion stability.

In the mixed-type gabion, the rooting effect of the bottom layers provided enhanced anchoring, minimizing displacement. Conversely, the Japanese-type gabion showed a distinct pattern where its top layer leaned backward and its bottom layer moved slightly forward. These behaviors emphasize the influence of backfill material properties and structural design on gabion stability. The Japanese-type gabion's susceptibility to backward displacement highlights the necessity of denser or more compact backfill materials to mitigate initial instability. On the other hand, while the mixed-type gabion benefits from better-anchored bottom layers, its forward displacement in the lower segments suggests room for further optimization. These findings underscore the importance of understanding the interaction between gabion structures and backfill materials. Properly addressing these dynamics is essential for designing durable and stable gabion systems, particularly in regions with fluctuating water levels and complex hydrological conditions. By tailoring gabion designs to account for these factors, their performance and longevity can be significantly improved.

Laboratory tests were conducted to evaluate the performance of mixed-type gabions under conditions with and without geotextile. The findings revealed similar overall trends for both scenarios, yet distinct differences in displacement patterns emerged. As shown in Fig. 19, the inclusion of geotextile significantly reduced overall displacement. Without geotextile, the top layer exhibited backside displacement of up to 0.4 mm, while the bottom layer displayed forward displacement of up to 0.4 mm. In comparison, the use of geotextile limited front-side displacement, particularly in the bottom layers, to just 0.3 mm. This underscores the effectiveness of geotextile in enhancing stability and reducing deformation. The absence of geotextile contributed to the outflow of backside materials, as depicted in Figs. 20a and 20b. This destabilization of the gabion's backside occurred due to material loss through infiltration, weakening the structural integrity.

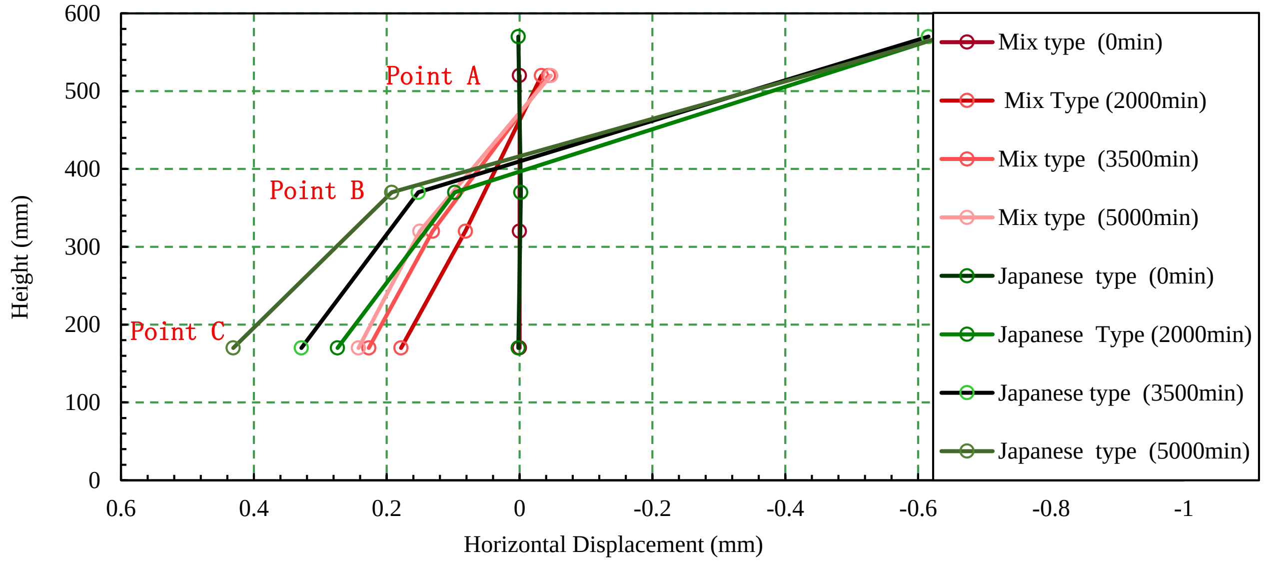


Fig. 17 Result for different structural design experiments.

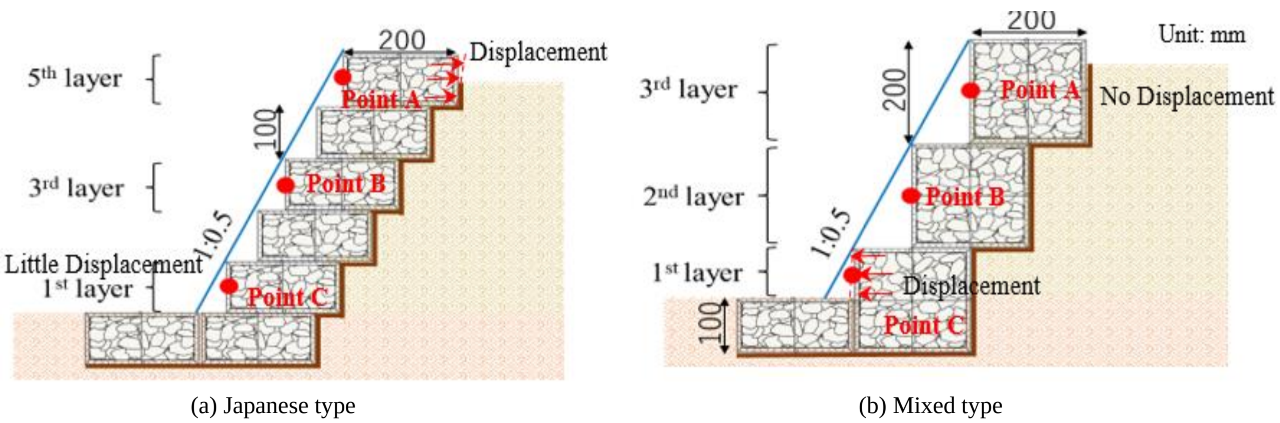


Fig. 18 Experiment with different structural design.

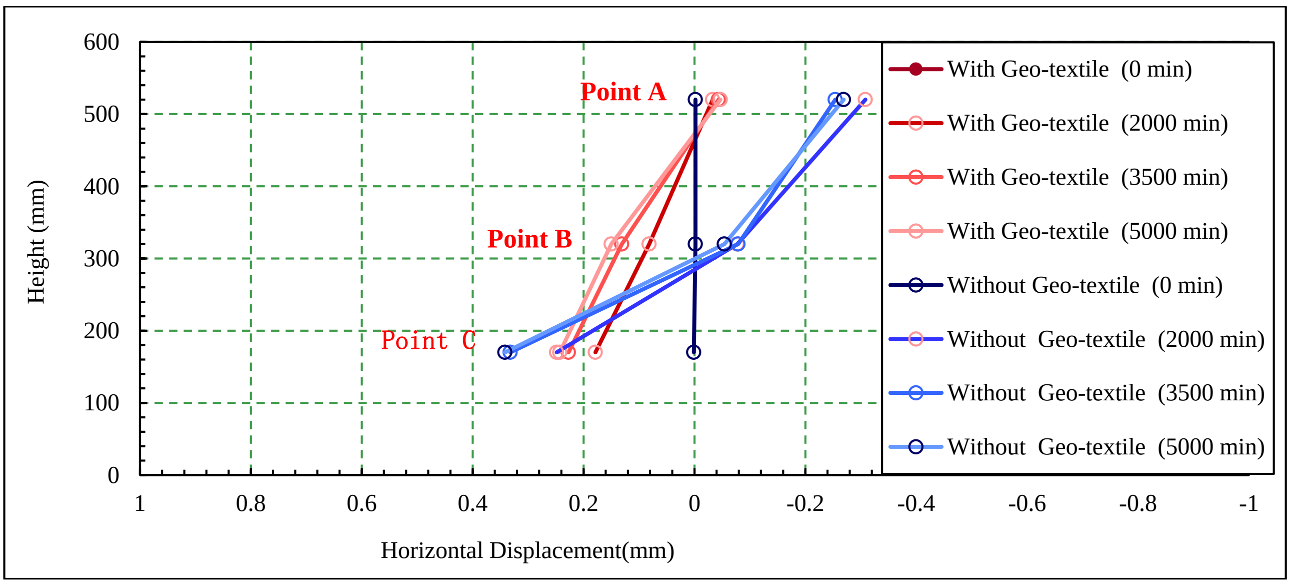
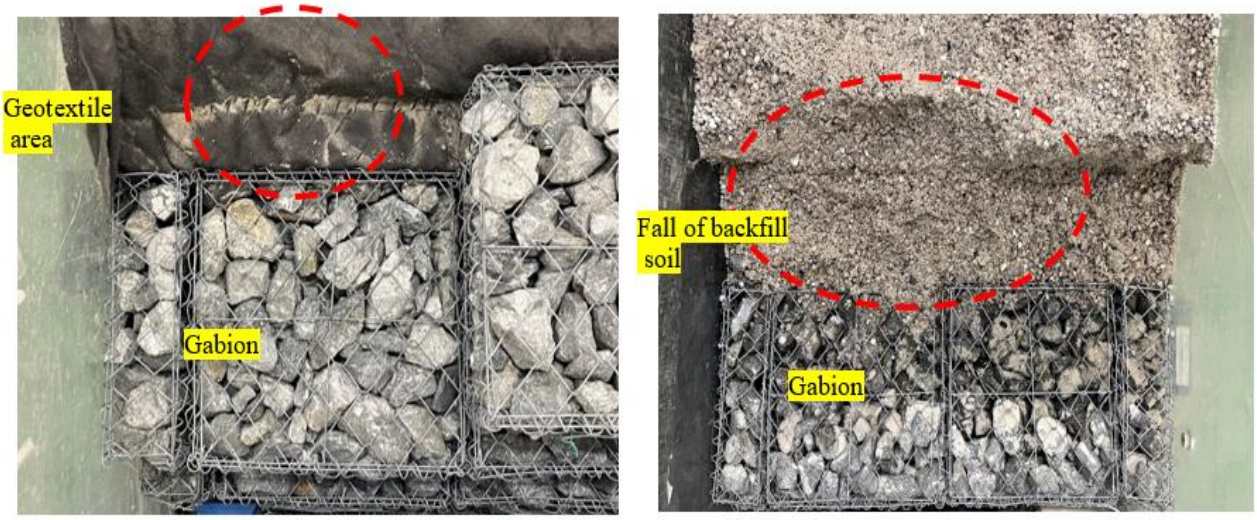


Fig. 19 Experiment with and without geotextile.



(a) With geotextile result (b) Without geo-textile result

Fig. 20 Pictures showing the effects of back soil with and without geotextile.

Geotextile, on the other hand, played a vital role in maintaining stability by preventing the intrusion of solid materials into the gabion box and protecting gabion wires from corrosion. Without geotextile, backfill soil drained toward the front, leading to a reduction in earth pressure on the top layers and causing the gabion to lean backward. This dynamic is clearly shown in Fig. 19b, where the gabion without geotextile is surrounded by backfill material, unlike the geotextile-protected gabion depicted in Fig. 19a, which remains free of infiltrated materials. These results highlight the critical function of geotextile in maintaining gabion stability. By filtering backfill materials and preventing soil erosion, geotextile not only enhances durability but also minimizes structural deformation. This finding underscores the importance of incorporating geotextile into gabion design, especially in conditions susceptible to material loss and displacement, ensuring long-term performance and resilience.

The authors conducted a laboratory experiment to investigate the impact of the front foundation layer on the stability of straight-type gabions. In the scenario without a front-side foundation, as illustrated in Fig. 21, the gabion wall displaced towards the front due to the scouring of the foundation layer. This scouring led to the tilting of the gabion in the front direction because of the earth pressure from the backside filling material, ultimately resulting in the collapse of the gabion wall. Fig. 21 clearly shows that the upper part of the backside soil was washed away and moved towards the front side, highlighting the importance of a robust front foundation layer for maintaining gabion stability.

This crucial experiment demonstrates the importance of providing a proper foundation for gabions to ensure their stability by reducing the adverse effects of scouring caused by river flow. Additionally, the application of a launching apron is essential to protect the front portion of the gabion from the direct impact of the river’s water flow. This apron helps prevent erosion and maintains the structural integrity of the gabion, highlighting the need for comprehensive foundation and protective measures in gabion construction for riverbank protection and flood control. The experiment underscores the significance of integrating robust foundation layers and protective aprons in gabion construction to safeguard against the detrimental impacts of scouring and water flow, thereby improving the overall reliability and longevity of gabion structures.

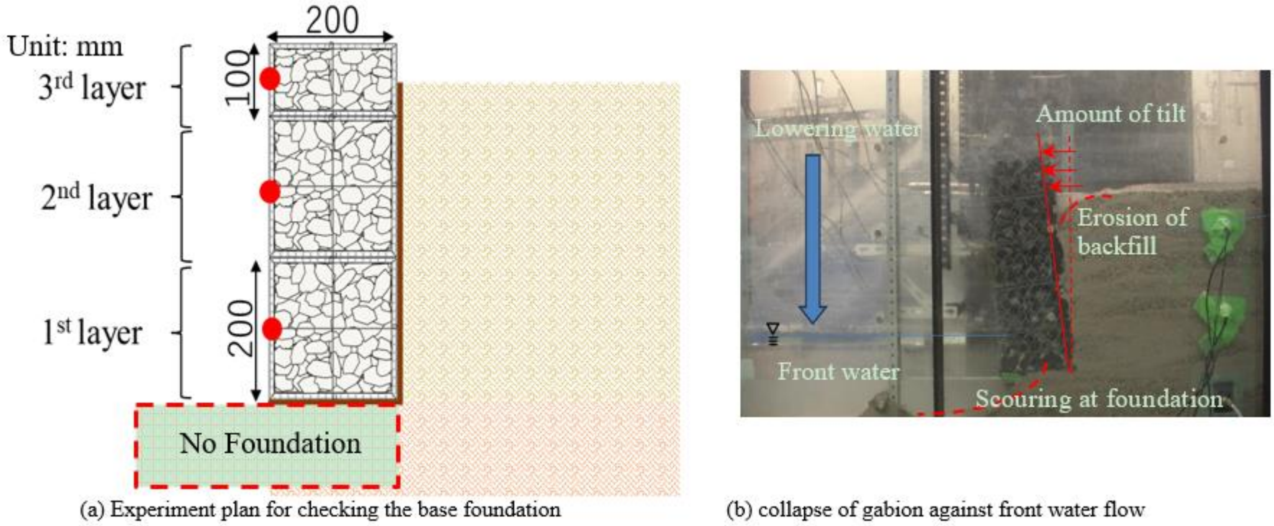


Fig. 21 Experiment front foundation effect.

Site deformation analysis and laboratory analysis revealed that mixed-type gabions were slightly deformed towards the front side due to the high weight of the filling materials, causing the gabion to push outwards. This was proved by laboratory experiments, which also showed that some gabion sections displaced towards the backside due to the backwater effect. The experiments demonstrated that mixed-type gabions are more stable than Japanese-type gabions under backwater pushing conditions.

The application of geotextile is crucial for constructing gabions, enhancing structural stability and longevity by serving multiple functions. Geotextiles act as a filtration layer, preventing fine soil particles from migrating into the gabion fill, thus maintaining the wall's integrity and preventing internal erosion.

Another important finding from the laboratory experiments is the necessity of a foundation layer and launching apron for the stability of the gabion. Without these elements, the gabion is prone to collapse. In the field, the application of foundation gabions and front gabions resulted in no significant deformation, demonstrating their effectiveness in stabilizing the structure. Gabion walls were stable enough to withstand the front water force from the river, emphasizing the importance of proper foundational support and protective measures in gabion construction for riverbank protection and flood control. Regarding the cost of construction, Nepali construction workers have extensive experience with gabions, particularly those resembling the mixed-type design. This familiarity allows them to construct these structures with minimal instruction. Conversely, Japanese-type gabions necessitate special training, which makes the mixed-type gabion technology more suitable for Nepali construction workers. One notable distinction between these two types is the cost of construction. The cost per cubic meter for mixed-type gabion construction is approximately 15% lower than that of Japanese-type gabions. While Japanese-type gabions offer superior stability and durability, mixed-type gabions are more cost-effective and simpler to construct. This makes them a practical choice for local workers. Therefore, although Japanese-type gabions are more stable and durable, mixed-type gabions are more adaptable and economical, presenting a feasible alternative for construction practices in Nepal.

5. Conclusion

This study evaluated the effectiveness of gabion structures in developing countries by integrating stability analyses through laboratory experiments and site investigations. Existing practices in these regions often reveal shortcomings, with gabion structures becoming unstable and non-functional shortly after construction. This underlines the urgent need for comprehensive research to enhance the stability and durability of gabion structures, particularly in environments where engineering standards are inconsistent. In contrast, developed countries emphasize engineering precision, quality control, and the utilization of durable materials, including advanced technologies such as geotextiles. These practices ensure the long-term functionality and reliability of gabions. However, in developing countries, reliance on locally available materials and traditional construction methods often leads to variability in quality and insufficient adherence to rigorous engineering principles.

Field studies conducted in this research highlight critical differences between mixed-type gabions and Japanese-type gabions. The mixed-type structures exhibited slightly more deformation than their Japanese counterparts, primarily due to differences in stack height and associated earth pressures. Japanese-type gabions, with their lower stack heights, experienced reduced back-earth weight and lateral earth pressure, thereby minimizing deformation. Key factors such as gabion frame height, stone density, and earth pressure were identified as influential in determining stability. Laboratory experiments further revealed that Japanese-type gabions experienced slight backward displacement at the top layers, while mixed-type gabions demonstrated no such movement. The inclusion of geotextiles proved essential in enhancing stability, as they effectively filter fine particles and prevent internal erosion. This study underscores the importance of several design considerations, including proper drainage, appropriate stone size and shape, and a robust launching apron, for achieving long-term gabion stability. Mixed-type gabions, incorporating geotextiles and well-designed foundations, emerged as cost-effective and practical solutions for flood control and riverbank protection in developing countries. Their ability to utilize local materials and labor, combined with minimal training requirements, makes them suitable for widespread adoption. This adaptability ensures enhanced resilience and effective protection against flood-related challenges.

The mixed-type gabions, informed by both laboratory and field data, offer a balanced and sustainable approach to addressing the limitations of existing practices in developing regions. Future research will focus on optimizing design parameters and developing standardized guidelines to ensure the broad applicability of gabion revetments in developing countries.

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