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Community-Based Coastal Abrasion Mitigation through Hybrid Engineering: Application of Bamboo Breakwater in Cemara Gading Beach

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ABSTRAK

Abrasi pantai merupakan ancaman serius bagi Pantai Cemara Gading, Desa Sukojati, di pesisir timur Kabupaten Banyuwangi. Program pengabdian kepada masyarakat ini bertujuan untuk memitigasi abrasi pantai melalui penerapan bamboo breakwater dengan pendekatan hybrid engineering yang mengintegrasikan langkah struktural dan prinsip ekologi. Kegiatan dilaksanakan melalui forum diskusi kelompok, perancangan teknis, pembangunan secara partisipatif, serta perencanaan pemeliharaan berbasis masyarakat. Bamboo breakwater dipasang sejajar dengan garis pantai sebagai perpanjangan struktur eksisting dengan panjang sekitar 10 m dan dilengkapi rangka bambu serta isian karung pasir untuk meningkatkan stabilitas. Hasil pengamatan awal menunjukkan penurunan intensitas hidrodinamika di daerah dekat pantai dan terjadinya pengendapan sedimen di belakang struktur, yang mengindikasikan peningkatan kemampuan retensi sedimen. Keterlibatan masyarakat memperkuat kapasitas lokal dalam praktik dasar teknik pantai. Meskipun pemantauan jangka panjang masih diperlukan, hasil kegiatan menunjukkan bahwa bamboo breakwater merupakan solusi yang praktis dan berkelanjutan untuk mitigasi abrasi pantai di wilayah pesisir yang rentan.

ABSTRACT

Coastal abrasion poses a significant threat to Cemara Gading Beach, Sukojati Village, along the eastern coast of Banyuwangi Regency. This community engagement program aimed to mitigate coastal abrasion through the implementation of a bamboo breakwater using a hybrid engineering approach that integrates structural measures with ecological principles. The program was carried out through focus group discussions, engineering design, participatory construction, and community-based maintenance. The bamboo breakwater, installed parallel to the shoreline as a continuation of the existing structure, extended approximately 10 m and incorporated bamboo frameworks with internal sandbag infill to enhance stability. Initial observations indicated reduced nearshore hydrodynamic intensity and sediment accumulation behind the structure, suggesting improved sediment retention. Community participation strengthened local capacity in basic coastal engineering practices. Although long-term monitoring is required, the results demonstrate that bamboo breakwaters offer a practical and sustainable solution for coastal abrasion mitigation in vulnerable coastal areas.

INTRODUCTION

The eastern coastal region of Banyuwangi Regency, particularly Sukojati Village in

Blimbingsari District, has been experiencing severe coastal abrasion driven by complex coastal hydrodynamic processes (Badan Nasional Penanggulangan Bencana (BNPB), 2021). The dominant contributing factors include wave-induced erosion, longshore and cross-shore currents, and sediment transport imbalance (Chaerul & Firdaus, 2023; Grases et al., 2020; Moskvichev et al., 2025). Interviews with the Chairperson of the Ikatan Pemuda Pemudi Dusun Sengon (IPPDS) and the Secretary of Sukojati Village further confirm that the area is classified as high risk for coastal abrasion. Field assessments indicate that the shoreline has retreated by approximately 60–100 m since 2009, posing serious threats to coastal ecosystems, infrastructure, residential areas, and tourism-related facilities (Rinaldi et al., 2023; Rostika et al., 2016). As a key coastal tourism asset and source of local economic activity, Cemara Gading Beach has been particularly affected by this progressive abrasion (Hailuddin et al., 2022; Safitri et al., 2024).

In response to these conditions, the village government has implemented several countermeasures, including mangrove rehabilitation in the backshore zone and the installation of conventional breakwater structures. However, the effectiveness of these measures remains limited, as the existing breakwaters have not sufficiently dissipated wave energy nor altered nearshore hydrodynamic conditions to promote sediment deposition(Chan et al., 2024; Fitri et al., 2019). Consequently, erosional processes continue to dominate, indicating the need for improvements in structural configuration, material selection, and integration with natural coastal systems (Rashidi et al., 2021). This situation highlights the importance of adopting a more adaptive and sustainable coastal protection strategy, such as hybrid engineering, which combines civil engineering structures with nature-based solutions. The existing condition of Cemara Gading Beach and the current breakwater structure are illustrated in Figures 1 and 2, respectively.

Cemara Gading Beach is currently managed by the Ikatan Pemuda Pemudi Dusun Sengon (IPPDS), a local youth organization formally designated by the village government. While IPPDS has contributed positively to the development of coastal ecotourism, current management practices remain primarily tourism-oriented and have not yet incorporated a comprehensive coastal disaster risk reduction strategy. This condition is particularly relevant given that Sukojati Village has adopted the Disaster-Resilient Village (Desa Tangguh Bencana/Destana) concept, which emphasizes community empowerment through education, training, and the strengthening of disaster mitigation infrastructure (Dewa et al., 2024; Yadnya et al., 2022).

Figure 1. The existing condition of Cemara Gading Beach

Figure 2. The existing breakwater structure

Within this framework, IPPDS has the potential to play a strategic role in implementing Destana principles at the coastal level. The application of a hybrid engineering approach through bamboo breakwater construction offers a practical solution that addresses both physical abrasion processes and community-based disaster preparedness (Roldán et al., 2024). Bamboo breakwaters function as low-crested, permeable structures capable of attenuating wave energy, modifying nearshore current patterns, and enhancing sediment trapping, while offering advantages in terms of lower construction costs (Alamsyah et al., 2025; Kristiningsih et al., 2018). Moreover, the integration of hybrid engineering into coastal ecotourism management supports shoreline stabilization, enhances visitor safety, and strengthens the resilience of coastal tourism destinations.

Hybrid engineering (HE) is an environmentally adaptive coastal protection approach that combines engineering structures with natural coastal processes. HE utilizes permeable bamboo structures that function as sediment traps rather than conventional wave barriers. During tidal cycles, sediments transported by waves are deposited behind the structure, gradually restoring the eroded shoreline. This system mimics the ecological function of mangrove roots in reducing hydrodynamic energy and enhancing sediment accumulation. In addition, the use of bamboo offers advantages such as lower construction costs, environmental compatibility, and ease of community-based implementation, making HE a sustainable alternative for coastal abrasion mitigation (Hafid, 2023; Hafid et al., 2021).

Accordingly, this community engagement program aims to implement a bamboo breakwater-based hybrid engineering approach as an environmentally adaptive coastal protection measure at Cemara Gading Beach. Beyond mitigating coastal abrasion, the program seeks to strengthen community awareness, institutional capacity, and collaboration among stakeholders, thereby supporting the realization of a disaster-resilient and sustainable coastal tourism area in Sukojati Village.

METHOD

To effectively achieve the objectives of the community engagement program, the activities were implemented through a systematic and structured methodology. The implementation framework was designed to ensure active participation of community partners, appropriate application of coastal engineering technology, and long-term program sustainability. The methodological approach consisted of five main components: Focus Group Discussion (FGD),

technology implementation, community assistance, monitoring and evaluation, and program sustainability.

1. Focus Group Discussion (FGD)

The Focus Group Discussion (FGD) was conducted as the initial stage to ensure that the community partner, namely the Ikatan Pemuda Pemudi Dusun Sengon (IPPDS), fully understood the objectives, scope, and implementation plan of the community engagement program. This stage also aimed to establish mutual commitment and coordination among stakeholders involved in the program. During the FGD, the community service team and student participants jointly formulated the implementation plan and presented the proposed work program to the community partner. Discussions focused on coastal abrasion mitigation strategies, coastal safety management, and the application of hybrid engineering concepts as adaptive coastal protection measures. In addition, the roles and responsibilities of each stakeholder were clarified to strengthen coordination and long-term commitment throughout the implementation process. The outcomes of the FGD served as the basis for refining the technical design and determining the most appropriate implementation strategy according to local coastal conditions.

2. Technology Implementation

The technology implementation stage focused on applying engineering-based innovations to mitigate coastal abrasion and improve shoreline protection through a hybrid engineering approach. This approach integrated structural coastal protection measures with environmentally adaptive materials. The implementation process began with the development of two-dimensional (2D) and three-dimensional (3D) design models of the bamboo breakwater system by considering site-specific coastal characteristics, including wave exposure, shoreline geometry, and nearshore hydrodynamic conditions. Following the design phase, construction materials such as bamboo elements, connectors, anchoring components, and supporting equipment were prepared. The bamboo breakwater structure was then fabricated and installed at the designated coastal site according to the approved technical design and construction guidelines. The installed structure was designed as a low-crested permeable breakwater intended to reduce wave energy, modify nearshore current patterns, and enhance sediment trapping in the protected coastal zone.

3. Community Assistance and Capacity Building

Following the installation phase, continuous community assistance was provided to strengthen the technical capacity of the partner organization. This stage involved on-site mentoring during construction activities, guidance on basic operation and maintenance procedures, and knowledge transfer related to coastal protection principles and safety practices. The assistance process aimed to ensure that IPPDS members were capable of independently maintaining and managing the installed bamboo breakwater system.

4. Monitoring and Evaluation

Monitoring and evaluation were conducted to assess the initial performance of the bamboo breakwater and the effectiveness of the implemented hybrid engineering approach. This stage included visual inspections of structural stability, observations of wave attenuation behavior, and qualitative assessment of sediment accumulation in the sheltered zone. Feedback from the community partner was also collected to evaluate the practicality and acceptance of the

technology. The monitoring results were used as a basis for recommending potential improvements and future scaling of the program.

5. Program Sustainability

Program sustainability was promoted through several strategic measures intended to maintain the long-term functionality of the installed coastal protection structures and strengthen community involvement in coastal management activities. Routine maintenance of the bamboo breakwater and supporting coastal safety facilities was assigned to the community partner to ensure continued structural performance. Furthermore, the implemented coastal protection measures were integrated into local ecotourism management practices to support sustainable tourism development. Efforts were also directed toward strengthening community ownership and institutional capacity to encourage continuous participation in coastal resilience initiatives. Through these sustainability measures, the program is expected to provide long-term benefits for coastal protection, disaster risk reduction, and community empowerment in Sukojati Village.

RESULT AND DISCUSSION

Result

Interviews and coordination sessions were conducted with the Chairperson of the Ikatan Pemuda Pemudi Dusun Sengon (IPPDS) and the Secretary of Sukojati Village as part of the preliminary assessment stage of the community engagement program, as shown in Figure 3. The discussion aimed to identify existing coastal abrasion problems, evaluate current mitigation efforts, and explore community needs and expectations regarding the implementation of the bamboo breakwater-based hybrid engineering approach. The interview results confirmed that coastal abrasion has significantly affected the shoreline condition and tourism activities at Cemara Gading Beach, while also highlighting the community's strong commitment to participating in sustainable coastal protection initiatives.

Figure 3. Interviews with the Chairperson of IPPDS and the Secretary of Sukojati Village

Based on the identified coastal abrasion problems and community needs, the program subsequently implemented a bamboo breakwater system as the primary technological output of the community engagement activity. The bamboo breakwater was applied as a coastal abrasion mitigation measure based on a hybrid engineering concept, integrating simple structural technology with ecological principles. This technology was selected due to its environmentally

friendly characteristics, relatively low construction cost, and ease of implementation through active community participation. The three-dimensional (3D) hybrid engineering model of the bamboo breakwater is presented in Figure 4, while the two-dimensional (2D) design, including cross-sectional and plan views, is shown in Figure 5.

Figure 4. The three-dimensional (3D) of breakwater

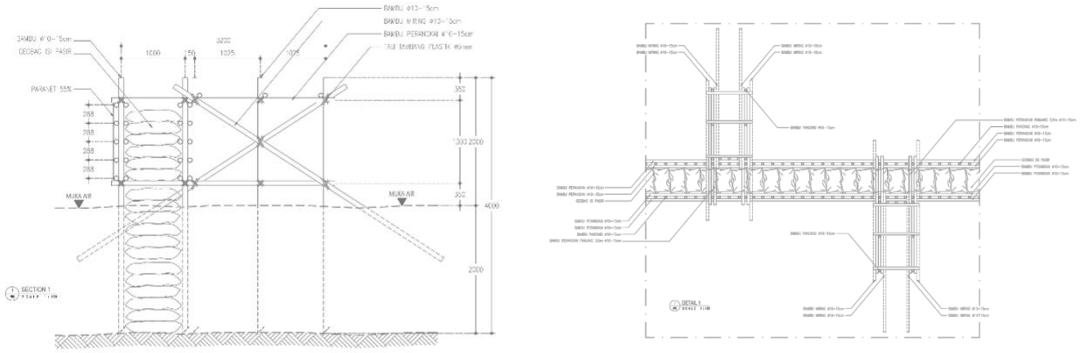

Figure 5. The two-dimensional (2D) of breakwater

The use of both 3D and 2D representations serves complementary technical purposes. The 3D model was developed to provide a comprehensive spatial visualization of the bamboo breakwater system, allowing stakeholders to clearly understand the overall configuration, structural layout, and interaction between the breakwater elements and the coastal environment. This representation was particularly useful during coordination with community partners and students, as it facilitated effective communication of the hybrid engineering concept and construction sequence. In contrast, the 2D drawings were employed to present detailed engineering information, including structural dimensions, spacing between bamboo elements, cross-sectional profiles, and alignment relative to the shoreline. These 2D representations functioned as technical references during fabrication and on-site installation, ensuring consistency with the approved design specifications.

The bamboo breakwater was installed parallel to the shoreline and functions as a wave energy attenuation structure. The structure extends approximately 10 meters, serving as a continuation of the existing breakwater to enhance the continuity of coastal protection. In addition to the bamboo framework, the breakwater incorporates sandbag infill within the

structure to improve structural stability, increase resistance against wave-induced forces, and control sediment transport processes in the protected zone.

Figure 6. the supporting frame fabrication process

Figure 7. The on-site installation

The construction process was carried out through a combination of off-site fabrication and on-site assembly. The supporting side frames of the bamboo breakwater were prefabricated in the Polytechnic Negeri Banyuwangi workshop to ensure dimensional accuracy, structural consistency, and construction quality control. These prefabricated frames were then transported to the coastal site and connected to the main breakwater frame during on-site installation. This staged construction approach improved installation efficiency, minimized on-site working time, and facilitated effective collaboration between students, community members, and technical personnel. Documentation of the supporting frame fabrication process (Figure 6) and the on-site installation and connection to the main structure (Figure 7) illustrates this construction sequence. The complete configuration of the installed breakwater structure is presented in Figure 8.

Figure 8. Breakwater structure

Discussion

The implementation of the bamboo breakwater at Cemara Gading Beach demonstrates the effectiveness of a hybrid engineering approach for mitigating coastal abrasion in a community-based context. Initial post-installation observations indicate reduced nearshore hydrodynamic intensity, as reflected by sediment accumulation behind the structure. This response can be explained by the permeable configuration of the bamboo breakwater, which dissipates wave energy and reduces current velocity, thereby promoting sediment retention and supporting natural shoreline accretion processes.

From a structural perspective, the bamboo breakwater exhibited satisfactory stability under regular wave conditions, indicating that the combination of bamboo elements and internal sandbag infill provides adequate short-term resistance to wave-induced forces. These findings are consistent with established principles of permeable and low-crested coastal protection structures and support the suitability of bamboo as a cost-effective and environmentally adaptive material for small-scale coastal protection.

In addition to technical performance, the participatory implementation process produced important social outcomes. The involvement of students and local community members in fabrication, installation, and maintenance activities enhanced local understanding of coastal abrasion mitigation and strengthened community capacity in basic coastal engineering practices. Although quantitative monitoring was not conducted during the limited observation period, the results suggest that bamboo breakwaters implemented through a hybrid engineering and community-based framework represent a practical and sustainable solution for coastal abrasion mitigation at Cemara Gading Beach.

CONCLUSION

This community engagement program demonstrates that the implementation of a bamboo breakwater based on a hybrid engineering approach can serve as an effective and practical measure for mitigating coastal abrasion at Cemara Gading Beach. The combination of bamboo structural elements and internal sandbag infill provided adequate short-term structural stability under regular wave conditions, while the staged construction approach enhanced constructability and installation efficiency. Moreover, the active involvement of students and local community members strengthened community capacity in basic coastal engineering practices and supported long-term program sustainability. Although further quantitative monitoring is required to assess long-term performance, the findings indicate that bamboo breakwaters implemented through a

hybrid engineering and community-based framework represent a sustainable and adaptable solution for coastal abrasion mitigation in vulnerable coastal areas.

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