Impact of Groynes on Hydrodynamics adjacent to a Concave Bank in a Braided River

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Abstract. The rivers of Bangladesh, particularly braided rivers, are highly dynamic and susceptible to frequent hydro-morphological changes, such as riverbank erosion, which poses significant challenges to riverbank protection. This persistent issue results in significant land loss and community displacement, prompting substantial investment by the mitigation authority for river management. This study aims to explore the effectiveness of groynes in managing riverbank erosion by analyzing their impact on water flow and scour dynamics. A physical model of a braided river was developed in a laboratory setting, featuring a concave bank with groynes at various spacing-to-length (S/L) ratios (1.0, 2.0, and 3.0). The experiments were conducted using an open-channel flume with sand-leveled beds, simulating flow conditions with an average discharge of 100m³/hour. The results indicate that groynes reduce upstream flow velocity by 91-95%, with gradual decreases downstream. The placement of groynes had minimal effect on overall water depth but significantly influenced flow velocity patterns. Scour measurements revealed that the maximum erosion occurred at the upstream toe of the groynes, with increased spacing between groynes leading to deeper and more extended scour zones. These observations suggest that the interaction between flow dynamics and groyne configurations plays a crucial role in mitigating erosion. The study concludes that optimal groyne spacing, particularly an S/L ratio of 3.0, is necessary to balance flow management and erosion control effectively. These findings provide key insights into designing riverbank protection systems for braided rivers, which are critical for mitigating the adverse effects of erosion on vulnerable communities and ecosystems. The research highlights the importance of strategic planning in hydraulic engineering for sustainable river management, addressing both sediment transport and the evolving challenges posed by river dynamics in Bangladesh.

Keywords: Hydrodynamics, concave bank, groyne, velocity, scour.

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1 Introduction

The rivers of Bangladesh are highly dynamic and prone to frequent hydro-morphological changes. Riverbank erosion, a recurring and natural hazard, has long been a persistent issue in the country, causing widespread loss of land and displacement of communities. To combat this, the Government of Bangladesh allocates significant financial resources through the Bangladesh Water Development Board (BWDB) each year to mitigate erosion and protect riverbanks from further damage. Braided rivers, a common feature in Bangladesh, are particularly challenging in this regard. These rivers are characterized by their complex, ever-shifting networks of interwoven channels that develop on alluvial plains composed primarily of gravel, sand, and silt [1]. The constantly changing patterns in braided rivers occur due to the rapid transportation and deposition of sediments, which form temporary islands or bars between the channels. These bars are frequently restructured by the river's flow, making the morphology of braided rivers highly unpredictable [2]. Providing a precise description of braided rivers is challenging. Some rivers with multiple channels are not typically classified as braided, while braided rivers can sometimes exhibit only a single wetted channel during periods of either very high or very low flow. Braided rivers are characterized by a distinct alluvial morphology, featuring an unpredictable network of multiple channels that are separated by temporary, shifting bars made of sediment [3]. From a morphodynamic perspective, rivers with complex and unpredictable behavior can be classified as braided due to the nonlinear interactions between various processes, such as in-channel flows, bank erosion, bifurcations, avulsions, and the influence of vegetation. These interactions result in a constantly shifting channel pattern that evolves over time [4]. Natural rivers are often populated by various riparian vegetation species that interact with morphodynamics and thus play a fundamental role in developing the river network. Such rivers are often severely affected by human activities that have altered both morphologically and ecologically the functionality [5]. They are significantly affected by both direct impacts such as gravel mining, embankment construction, and channeling and catchment scale variations due to land use modifications, torrents regulations, hydropower schemes construction, and climate change [6].

The local characteristics of braided rivers, such as sediment transport or the number of channels within a specific section, exhibit significant spatial and temporal variability, making them difficult to model in detail over extended periods. This behavior is typical of complex, nonlinear systems. As a result, the analysis of morphodynamic braided rivers often requires a statistical approach. For instance, reach-averaged or time-averaged properties—like river width, the total and active number of channels, or sediment transport rates—can be studied in relation to controlling factors such as the river’s slope or maximum available width [7]. The high rates of movement of sediments, flooding and degradation and the regular change of river channel locations in braided rivers present some significant problems for a wide range of disciplines. Given this, as opposed to the wealth of material on meandering rivers, braided rivers are easily known—the braided stream's ignorance [8]. Without this oblique flow is dangerous for river bank specially in braided rivers [9].

Various studies have been conducted by several hydraulic, bank protection irrigation engineers using groins (spur) on various hydraulic parameters [10]. Two mechanisms may explain the common observation that most bank retreats typically occur after the height of a flood, rather than during it. The first mechanism finds out that the highest flow discharges result in a displacement of the center of total flow velocity from the outer bank for bends with marked curvature, thus increasing the shear pressure of the sidewall boundary and fluvial erosion at the peak flow levels. The second mechanism concerns findings that bank failure episodes are triggered by unfavorable combinations of pore water and hydrostatic container pressures induced during the period between the withdrawal and rising phases of multi-stage flow events [11].

The objectives of this study are to develop a physical model of a braided river in a laboratory channel, analyze water depth and velocity variations across different configurations, optimize groyne spacing, and observe the patterns and extent of maximum scour for various experimental cases.

2 Methodology

In the laboratory, a physical model was constructed with a concave bank, measuring 90 cm in length and featuring a radius of curvature of 120 cm. This design was chosen for the following reasons:

- The model replicates an aggressively eroding bank commonly observed along curved river channels.
- The bank's characteristics closely resemble those found in many locations along the same river and other similar rivers in the region.

2.1 Physical Model Setup

Experiments have been conducted in an open-channel flume located in the hydraulic engineering laboratory of Dhaka University of Engineering and Technology, Gazipur. The flume is straight and of a rectangular cross-section. In this experimental investigation, a concave bank was prepared in the open channel flume made by bricks and the bed was levelled with sand.

The length of all groynes (L) was 30 cm, and the centre to centre spacing of the groynes (S) was maintained as 30 cm, 60 cm, and 90 cm.

Table 1. Combination of groynes for different cases

Model Setup	
Base condition	A concave bank without groyne
Case – 1	Concave bank with 2 Groynes having S/L = 1.0

Case – 2	Concave bank with 2 Groynes having S/L = 2.0
Case – 3	Concave bank with 2 Groynes having S/L = 3.0

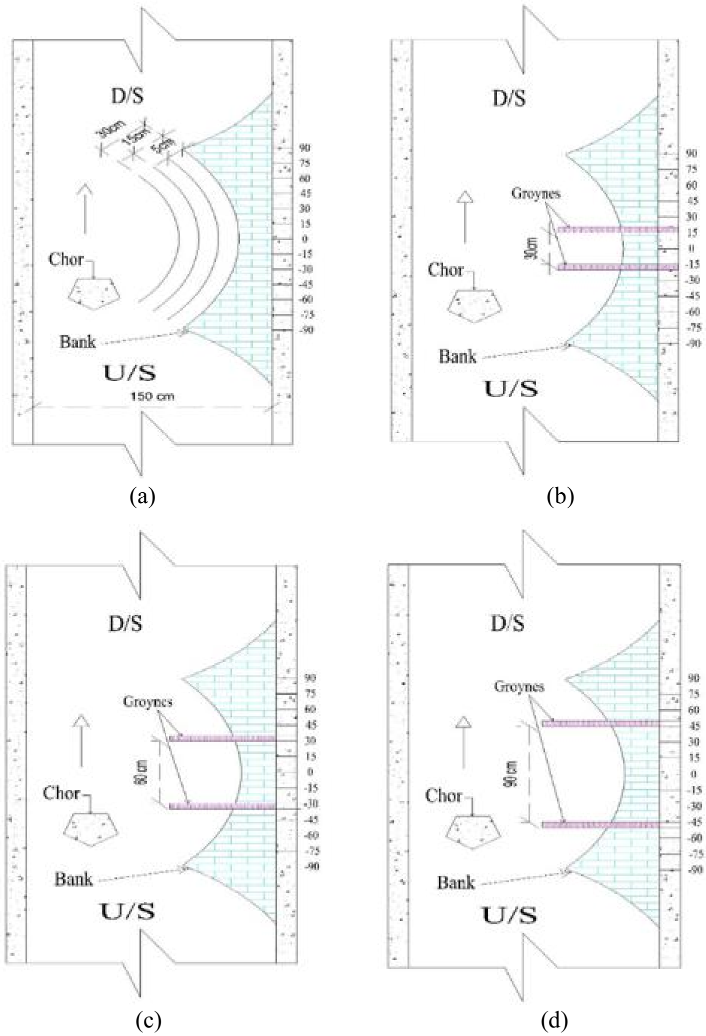

Fig. 1. Plan of the model set up for (a) Base condition, (b) Case-1, (c) Case-2, and (d) Case-3.

2.2 Physical Model Setup

The flow was given in the channel for approximately 2 hours and an average discharge 100m3/hour for all the simulations conducted in this study and observed the velocity and the scouring of the channel bed. Electromagnetic Current Meter which is an oceanographic device for flow measurement by mechanical, acoustical or electrical means. It is a measurement instrument for a liquid's flow rate (as water) in a channel.

(a) (b) (c) (d)

Fig. 2. Real laboratory set up for the model for (a) Base condition, (b) Case-1, (c) Case-2, and (d) Case-3.

3 Results and Discussion

3.1 Effects on Water Depth and Velocity

Fig. 3 illustrates the variation in water depth along the longitudinal axis of the channel for various experimental conditions. Across all cases, only slight fluctuations in water depth were observed, which can likely be attributed to factors such as discharge fluctuations and the presence of an erodible bed. The figures further reveal that the insertion of groins at different spacing intervals produced minimal changes in water depth, suggesting that the groynes had a limited impact on the overall flow depth within the channel.

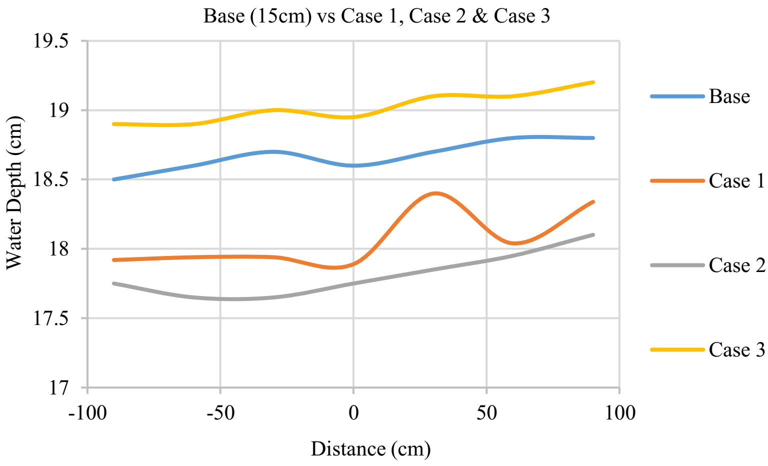

Fig. 3. Graph showing the change of water depth at 15cm distance from the concave bank for without groynes and two groynes spacing 30cm, 60cm, and 90cm respectively.

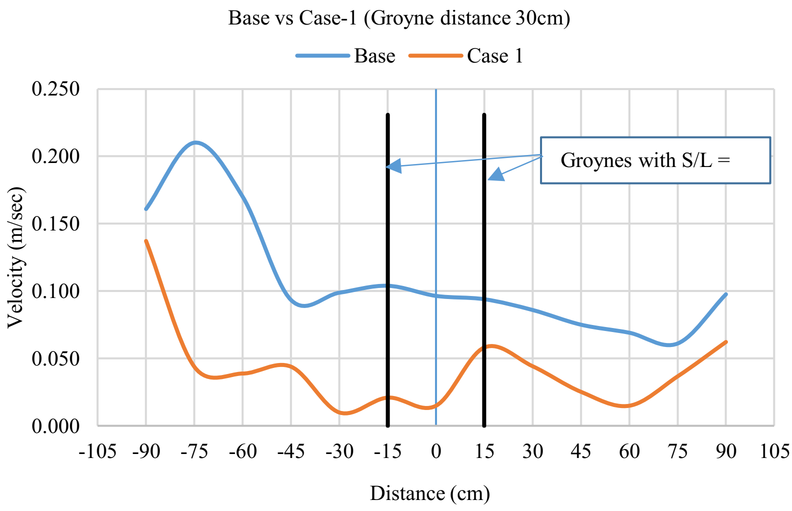

Fig. 4. Graph showing the effect of velocity at 5cm distance from the concave bank of groynes spacing 30cm.

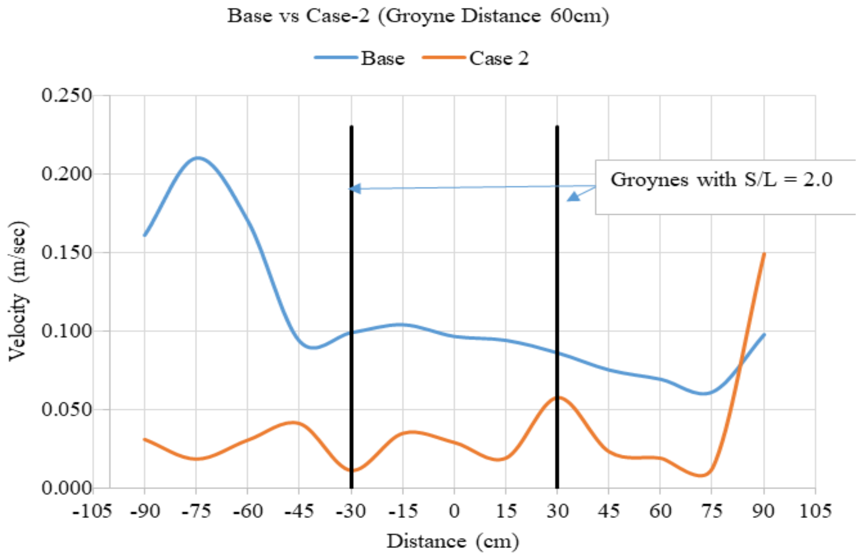

Fig. 5. Graph showing the effect of velocity at 5cm distance from the concave bank of groynes spacing 60cm.

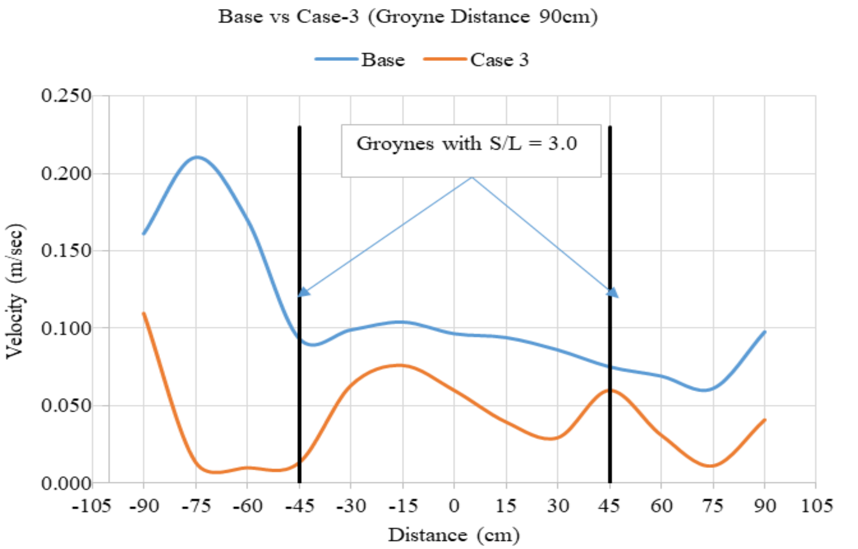

Fig. 6. Graph showing the effect of velocity at 5cm distance from the concave bank of groynes spacing 90cm.

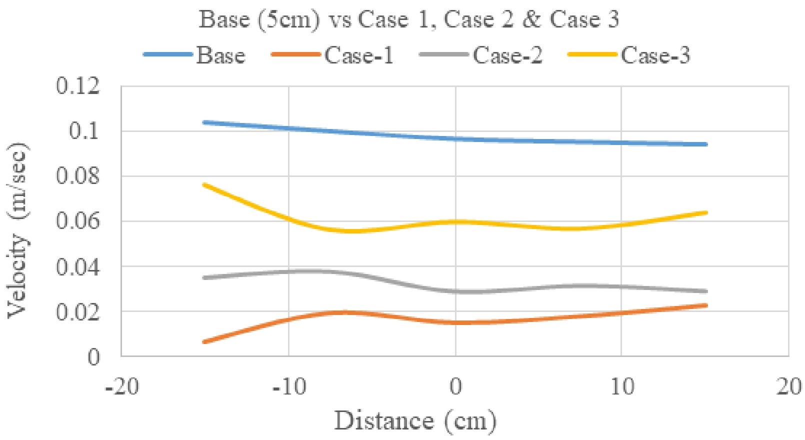

Fig. 7. Graph showing the effect of velocity at 5cm distance from the concave bank of groynes spacing 30cm, 60cm, and 90cm.

The analysis presented in Fig. 4, 5, and 6 demonstrates a significant reduction in maximum upstream (U/S) velocity due to the presence of groynes. Specifically, Fig. 4 indicates that the maximum upstream velocity decreases to 95% of the base velocity when groynes are implemented. Furthermore, the velocity between the groynes shows a reduction of 84% compared to the base condition, while the downstream maximum velocity decreases to 78% of the base velocity. In Fig. 5, similar trends are observed, with the maximum upstream velocity decreasing to 91% of the base velocity. The velocity measured between the groynes reveals a reduction of 80%, and the downstream velocity reduces to 72% of the baseline. Fig. 6 illustrates that the maximum upstream velocity drops to 93% of the base velocity, while the velocity between the groynes shows a notable decrease of 66%. The downstream maximum velocity in this case reduces to just 55% of the base velocity.

The differences in velocity profiles among Case-1, Case-2, and Case-3, as depicted in Fig. 7, suggest that if Case-4 (with a spacing-to-length ratio of 4) were to be further examined, the velocity line may approach the critical baseline. This observation implies that, for the specific curvature of the concave bank exhibited in these experiments, the optimal spacing for the groynes should be approximately three times their length. This recommendation is crucial for effectively managing bank erosion while maintaining desirable flow conditions in the river system. In summary, these findings underscore the importance of groyne design in influencing hydrodynamics and optimizing bank protection strategies in braided river systems.

3.2 Effects on Scouring at Riverbed

The findings of this study reveal important insights into the dynamics of scour around groynes in braided rivers. From Fig. 8, it has been observed that the maximum scour depth consistently occurs at the toe of the upstream groyne, which is the point where the flow velocity is highest and the erosive forces are most concentrated. As the spacing between groynes increases, the scour zone tends to extend further downstream, indicating a shift in the erosion pattern influenced by the river's flow dynamics. Additionally, it has been found that the maximum scour depth at the upstream groynes increases with greater spacing. This trend suggests that wider spacing between groynes not only alters the flow patterns but also intensifies the erosive forces acting on the riverbed, leading to deeper scour at the upstream locations.

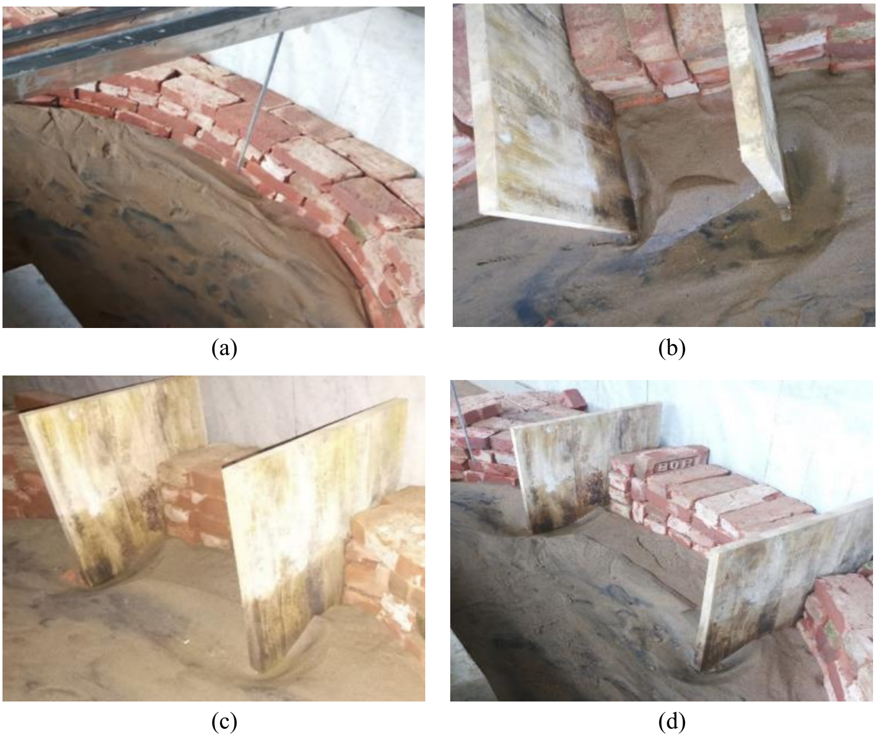

Fig. 8. Scour scenarios for the model after simulation for (a) Base condition, (b) Case-1, (c) Case-2, and (d) Case-3.

Understanding these relationships is critical for designing effective riverbank protection strategies, as excessive scour can compromise the structural integrity of the groynes and contribute to further erosion. Therefore, careful consideration of groyne spacing is essential in managing sediment transport and minimizing erosion in braided river systems. These findings underscore the need for a comprehensive approach to river management that accounts for the complex interactions between flow dynamics and sediment processes.

4 Conclusions

This study investigates the dynamics of braided rivers in Bangladesh, focusing on their vulnerability to hydro-morphological changes, especially riverbank erosion. Through simulations with a concave bank made of bricks and erodible sand, various configurations of groynes were tested to analyze their impact on flow velocity and sediment transport. The results revealed that implementing groynes significantly reduces upstream velocity by 91-95% and gradually decreases downstream. Maximum scour was consistently observed at the toe of the upstream groyne, with increased spacing leading to an extended scour zone and heightened erosion. This highlights the need for optimizing groyne spacing to effectively mitigate erosion while preserving flow dynamics. The findings underscore a strategic approach in designing groyne systems, which is crucial for the sustainable management of river systems in Bangladesh. By addressing the complex interactions between flow patterns and sediment processes, this research provides valuable insights and recommendations for enhancing riverbank protection strategies to safeguard vulnerable communities and ecosystems against erosion's adverse effects.

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