Bulletin of Earth Sciences of Thailand

# Application of MEPBAY for beach stability evaluation: a preliminary test on Rayong Beach, Eastern Thailand

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## Abstract

The coastline of Rayong Province, eastern Thailand has been subjected to erosion for decades. Erosion results from two primary causes: natural processes such as coastal currents, tides, waves, storms, and monsoons; and human activities such as the failure of sea wall construction and the impacts of climate change. The objective of this study was to apply the MEPBAY program to test the stability of beaches in Rayong Province where several sea walls were constructed. As a result, beaches exhibiting static planform equilibrium remain relatively unaltered except during monsoons. Beaches subject to dynamic equilibrium are primarily situated near river mouths, where their condition hinges on sediment discharge from the rivers. Conversely, the unstable of beaches arises from their reliance on hard structures, necessitating adjustments for the beach to achieve a state of static equilibrium.

**Keywords:** MEPBAY, beach stability, breakwater sea wall, Rayong

## 1 Introduction

The primary factors contributing to coastal changes can be categorized into two main factors, 1) natural processes, including longshore currents, tides, waves, storms, and monsoons, and 2) human activities, which represent a prevalent cause of coastal changes, including coastal development, dam construction, upstream weir or reservoir establishment, encroachment upon mangrove forest areas, groundwater extraction, and the impacts of climate change (Albino et al., 2016; Balaji et al., 2017; Ritphring, 2019).

The coastline is a crucial area with diverse functions, serving as tourist attractions, economic resources, industrial hubs, community assets, transportation networks, and nurseries for aquatic species. However, it is currently grappling with the challenges posed by climate change, which encompass intensified wind, waves, and severe storms (Silvester, 1960). Additionally, human-induced alterations in coastal areas are exacerbating erosion (Albino et al., 2016).

Coastal management solutions for mitigating shoreline erosion are typically categorized into three approaches: (1) retreat or relocation (Silvester, 1960). These approaches involve the removal of human settlements from coastal erosion areas for the natural recovery of the coastline. (2) Soft stabilization: This method involves the creation of artificial beaches by replenishing sand. However, it is important to note that this method provides only temporary stabilization, as the added sand can be eroded over time. (3) Hard stabilization: The most adopted solution involves the use of permanent, solid structures such as seawalls, breakwaters, groins, and jetties to protect properties and structures along the coastline (Pailoplee, 2019a). However, it is worth acknowledging that, in some instances, hard stabilization can inadvertently contribute to accelerated changes in the coastline (Hsu et al., 2010). The effectiveness of such structures may be contingent upon meticulous design and considerations of factors such as coastal weather patterns and storm events.

In terms of beach stability, headland-bay beaches may be classified as being in static equilibrium, dynamic equilibrium, and unstable (Silvester & Hsu, 1993; 1997; cited in Klein et al., 2003). Static equilibrium is a state in which predominant waves break simultaneously around the entire periphery of the bay. During this condition, littoral drift is almost non-existent, and the curved beach remains stable, experiencing minimal long-term erosion or deposition, except during storm periods. For bays in dynamic equilibrium, maintaining shoreline stability relies significantly on maintaining balance within the sediment budget. Nevertheless, shorelines in dynamic equilibrium may experience retreat when sediment supply diminishes from up coast sources or from rivers within the embayment, eventually regressing toward the limit defined by static equilibrium if the supply is completely depleted. On the other hand, bays classified as unstable, often due to wave sheltering caused by the addition or extension of a structure along the beach, exhibit a curved shoreline that undergoes accretion in the lee of the structure, concomitant with erosion downcoast, as part of the natural reshaping process (Ab Razak et al., 2018).

Since the 1940s, the significance of curved beaches in coastal morphology has driven the development of mathematical models to accurately describe the asymmetrical shapes of headland-bay beaches (Silveira et al., 2010). These models elucidate the distinctive features of such beaches, including the curved shadow zone, gently curved transition, and a relatively straight tangential portion at the downdrift end. Notably, models such as the logarithmic spiral bay equation, parabolic bay shape equation, and hyperbolic-tangent bay shape equation provide mathematical expressions for predicting the static equilibrium coastline of a bay beach (Klein et al., 2003). Of particular interest is the parabolic bay shape equation model proposed by Hsu and Evans (1989), as it stands as the only model that considers the wave crest direction, wave diffraction point (the tip of the headland), and the verification of stability for bayed beaches. Extensive measurements of wave height and period were conducted, revealing that no significant bay effect occurs in static equilibrium (Hsu and Evans, 1989).

## 2 Methodology

In this study, we applied the parabolic bay shape equation model (Hsu et al., 1987; Hsu and Evans, 1989; Hsu et al., 1993; Klein et al., 2003; Benedet et al., 2004). The parabolic bay shape equation, as formulated by Hsu and Evans (1989) for a headland-bay beach in static equilibrium, is expressed as follows:

$$R_n/R_\beta = C_0 + C_1(\beta/\theta_n) + C_2(\beta/\theta_n)^2$$

In the equation, two fundamental physical parameters are essential: the reference wave obliquity angle, denoted as $\beta$, and the length of the control line, denoted as $R_\beta$ (Figure 1). The angle $\beta$ is formed between the direction of the incident wave crest at the diffraction point and the control line $R_\beta$, which connects the upcoast diffraction point ($X_0$, $Y_0$) to the downcoast control point ($X_1$, $Y_1$) on the beach. The parameter is determined through the analysis of cartographic maps, vertical aerial photographs, or planning sketches for the purposes of stability verification and beach design. Additionally, the control line is also angled $\beta$ to the tangent line at the downcoast end of the beach. The radius $R_n$ extending to any point along the bay's periphery forms an angle $\theta_n$ with the wave crest line, both originating from the point of wave diffraction.

We tested the MEPBAY model on three different types of bay beaches from Rayong coastal area (Figure 2). First is the bay beach with breakwaters and T-head groins. Second is Bay Beach with Y-head groins and third is Bay Beach with jetties at an estuary.

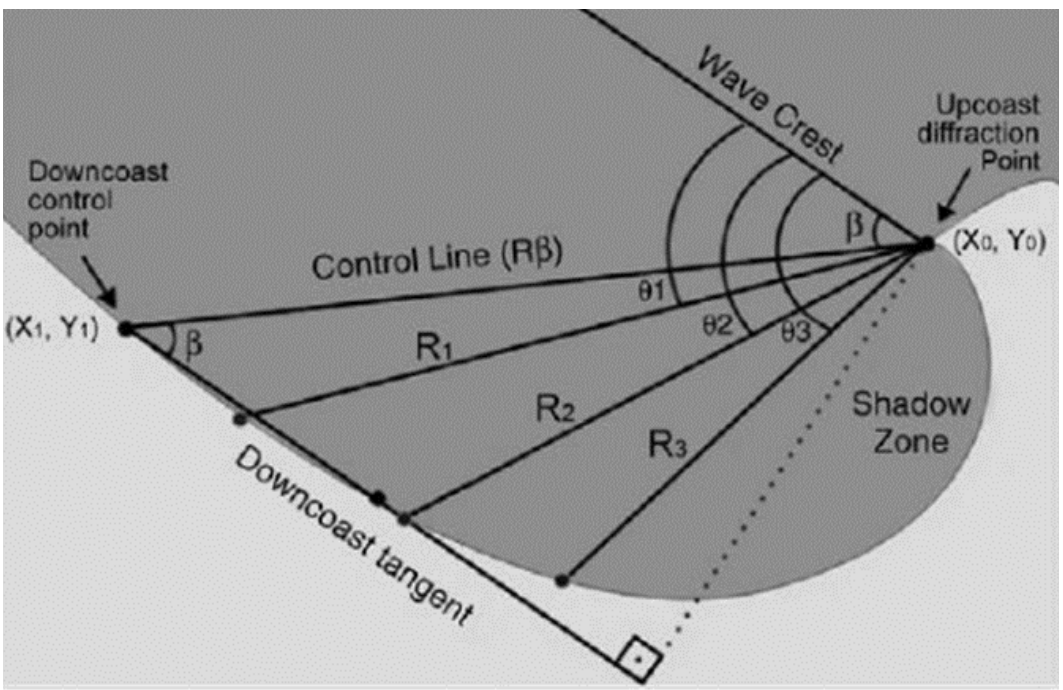


**Figure 1**. Definition sketch for parabolic bay shape model showing major physical parameters (Hsu and Evans,1989, as cited in Raabe et al., 2010).

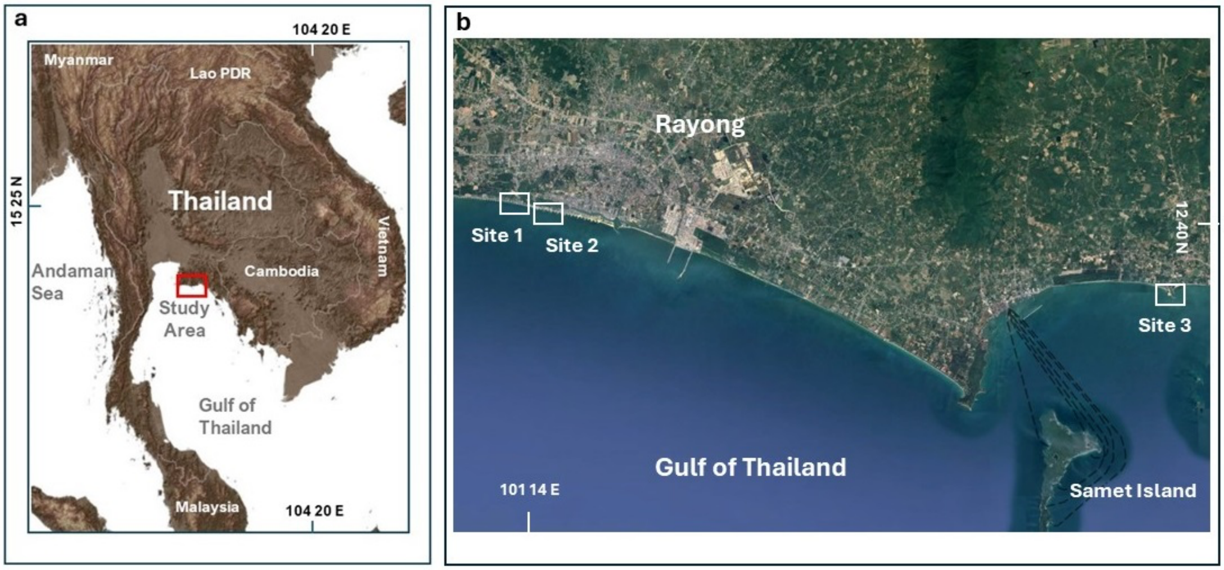


**Figure 2**. (a) Location of the study area (red square) and (b) close-up of Rayong beach with the focus sites 1-3 mentioned in the text.

**Model for Equilibrium Planform of Bay Beaches (MEPBAY)**

To streamline the labor-intensive process of manually calculating parabolic bay shape equations, Klein et al. (2003) developed a specialized software package known as MEPBAY. This tool serves as an educational aid for students learning to apply parabolic models across various beach environments and minimizes the computational workload (The software is available for download at http://siaiacad17.univali.br/mepbay) (Raabe et al., 2010). The program serves as an effective tool for assessing the platform stability of bay beaches (Hsu et al., 2010), allowing for the analysis of the impacts of new or existing wave diffraction points on downdrift beaches. Typically, MEPBAY can operate using just bay beach imagery and physical knowledge of wave refraction and diffraction processes. The software utilizes computer graphics to display both the current state of a bayed beach and the outcomes generated by the parabolic equation. This enables a visual assessment of a bay's stability by comparing its existing shoreline with an idealized planform in static equilibrium. As such, MEPBAY offers invaluable insights into the physical dynamics of beach changes and provides a robust platform for informed decision-making in the fields of coastal management and shoreline protection.

**Bay beaches**

To assess the stability of bay beaches in Rayong Province, satellite imagery data is obtained from Google Earth Pro, offering a comprehensive historical to contemporary record. Google Earth Pro, a software provided by Google, integrates extensive satellite data into a unified system. Originally developed as Keyhole, it incorporates imagery sourced from satellites or aircraft, including data from NOAA, NASA, the U.S. Navy, the U.S. Geological Survey (USGS), the Copernicus program, and others.

## 3 Results and Discussion

### 3.1 Bay beaches with breakwaters and T-head groins

Breakwaters are another prevalent coastal protection measure in Thailand. An example is evident at Saengchan Beach in Rayong Province where existing detached breakwaters positioned parallel to the shoreline, constructed explicitly to combat beach erosion. As depicted in Figure 3, sediment deposition is evident behind the breakwaters. Notably, the interspace between the breakwaters reveals a crescent-shaped erosion, which remarkably remained unchanged between 2007 and 2022 as indicated by the high-tide water level line. This observation is in alignment with the MEPBAY program's assessments, confirming the beach's status in a static state of equilibrium.

### 3.2 Bay beach with Y-head groins

Based on the assessment, Suchada Beach in Rayong province appears to be in an unstable state, primarily due to the presence of two adjacent Y-head groins. While these groins were constructed with the intent to reduce wave action and protect the beach, they have not effectively curtailed coastal erosion. The excessive curvature, likely caused by the presence of the Y-head groins, could contribute to the beaches unstable. Likely, the beach shape does not fit with the peripheries of the 27 prototype and model bays that are believed to be in a state of static equilibrium (Hsu and Evans, 1989). Despite the passage of time, the beach has not achieved a state of static equilibrium. Consequently, the current design of coastal protection measures seems unsuitable for this beach. A redesign is essential, aiming to reduce the curvature from points A and B (indicated by two green lines) to points C (red line) and D (orange line). This modification is expected to guide Suchada Beach toward achieving a state of static planform stability (Figure 4).

### 3.3 Bay beach with jetties at an estuary

Jetties serve multiple purposes; they are not solely used for altering the wave diffraction point. They are commonly constructed at river mouths to preserve navigation channels, which impact the adjacent beaches (Zhang et al., 2019). For instance, the Klaeng estuary in Rayong province (Figure 5). The construction of a jetty at the river mouth has led to progressive changes in the beach landscape until it reached a state of static equilibrium. After the construction of the jetty, there is a gradual increase in sediment deposition, aligning with predictions based on static bay shape analysis. However, given the transport of sediment due to the river's presence, the beach remains in a state of dynamic equilibrium.


**Figure 3**. MEPBAY analysis of existing detached breakwaters at Saengchan Beach in Rayong province (courtesy of Google Earth) (The distinct hues of the line represent different diffraction points).


**Figure 4**. MEPBAY analysis of Suchada Beach in Rayong province, featuring Y-head groins (courtesy of Google Earth).

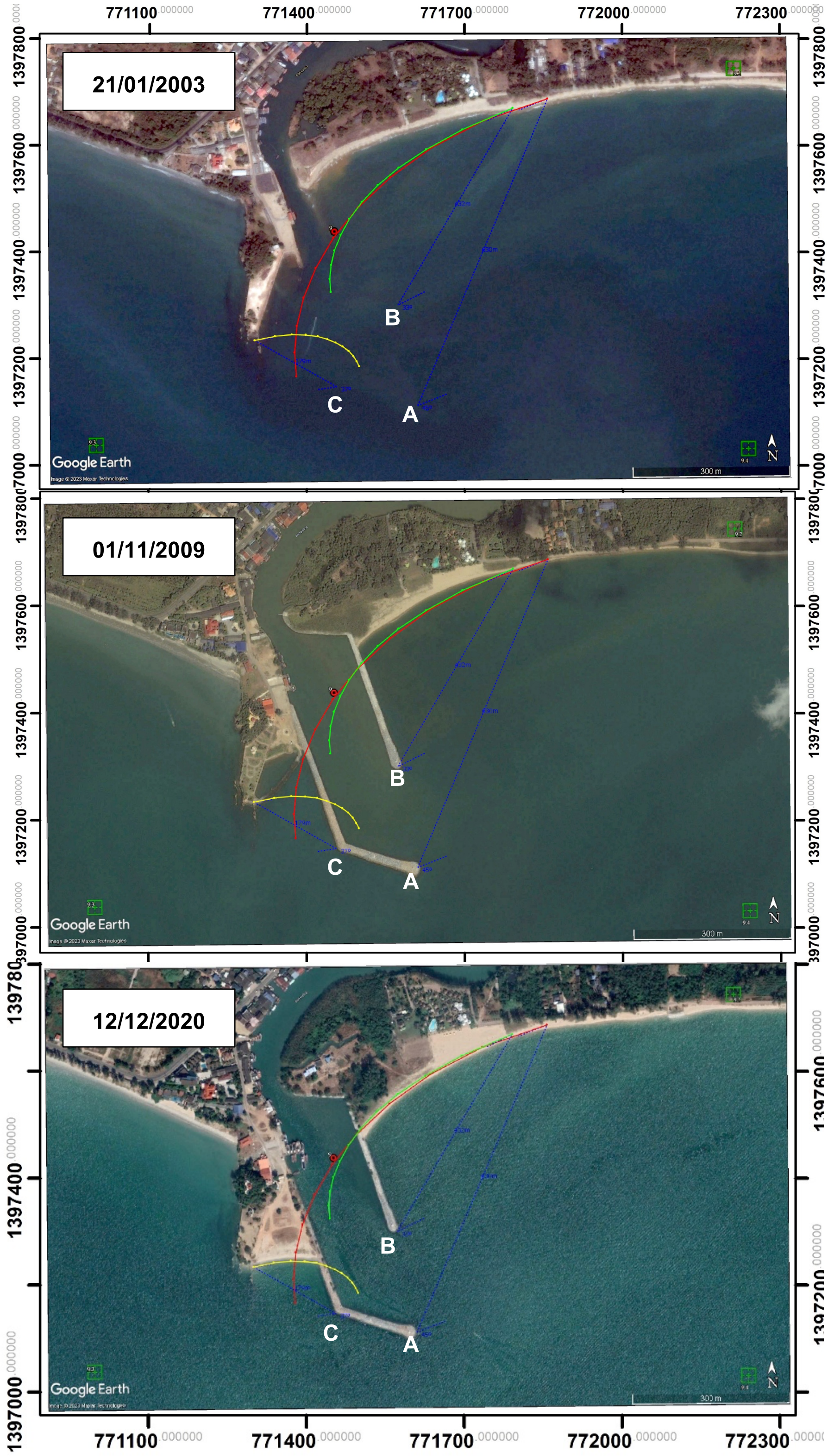


**Figure 5.** Illustrative Case: Jetty at the Klaeng Estuary in Rayong Province (courtesy of Google Earth)(The sediment took time to accumulate after the construction of the jetty.).

## 4. Conclusion

As bay beaches in Rayong province contain areas of significant economic importance due to their tourism, industry, and export sectors, we applied the parabolic bay beach shape model and analyzed results using the MEPBAY program. The primary conclusions from the research are as follows.

1) The MEPBAY program serves as an effective preliminary tool for assessing the stability of bay beaches, encompassing both natural and artificial beaches.

2) Prior to initiating any structural installations, an initial beach stability assessment is imperative.

3) The MEPBAY program aids in identifying the most conducive location for such structures to mitigate erosion.

4) While MEPBAY provides a rapid and cost-effective method for predicting static beach shapes, its efficiency also relies on the quality of aerial photography.

5) Monitoring of bay beach stability across other regions and comparisons with alternate beach analysis software should also be explored.

**Acknowledgments**

The Fundamental Fund66 program (FF66DIS66230013), Chulalongkorn University, and Thailand Science Research and Innovation (TSRI) provided the fund to MC. The authors would like to thank the MESA Center of Excellence of the Department of Geology, Faculty of Science, Chulalongkorn University for providing funding and logistics support. Thanks also to the anonymous reviewers who provided constructive comments that greatly improved the quality of this paper.

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