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PLANFORM STABILITY OF EMBAYED BEACHES ALONG THE EAST COAST OF PENINSULAR MALAYSIA

M. S. AB RAZAK*, N. A. Z. MOHD NOR, N. JAMALUDDIN

Department of Civil Engineering, Faculty of Engineering,
University Putra Malaysia, 43400, Serdang, Selangor DE, Malaysia
*Corresponding Author: ar_shahrizal@upm.edu.my

Abstract

The presence of embayed beaches along the East coast of Peninsular Malaysia has proven the significant influence of wave variability due to the Northeast monsoon. These beaches, which some of them are among the popular beaches for tourism and recreational activities, have not been categorised according to its planform stability. Categorising this type of beach is a preliminary step towards the long-term shoreline management plan. This study presents the outputs of the application of the parabolic bay model to satellite images of the embayed beaches. It focuses on the determination of the total number of embayed beaches along the East coast of Peninsular Malaysia including identification of beach planform stability using the model of equilibrium bay beach (MEPBAY) program. The model was used as a tool to propose engineering solutions and to investigate the applicability of the existing coastal structures for the beach in dynamic or unstable state. MEPBAY analysis showed that out of 51 beaches - 26 of them are dynamic, 23 are static and another two are in unstable state of planform equilibrium. Beaches with static planform equilibrium include Batu Buruk beach, Irama beach, Resang cape, Jemaluang beach and Kg Punggai in which the beaches undergo no addition or erosion of sediment towards the bay and littoral drift of the beach is almost non-existent. Results presented indicated that beaches with dynamic equilibrium state was achieved when the shoreline experiences degradation or undergo erosion due to the changes in the equilibrium orientation and shoreline planform of the bay as shown by Senok beach, Jara beach, Sedili cape, Cherating beach, Endau-Rompin beach, Bukit Tengah beach, Kalung bay and Teluk Lipat beach. Unstable equilibrium embayed beaches on the other hand, is a condition when the curved planform of the beach experienced accretion in the lee accompanied by erosion downdrift as showed by the Tok Jembal beach. This condition is a result of wave sheltering or changes in the geometric configuration of the beach. The numerical modelling exercises through MEPBAY have given us an understanding on the variation of planform stability towards the embayed beaches morphodynamics.

Keywords: MEPBAY, long term empirical bay models, static equilibrium state, dynamic equilibrium state, unstable state.

Nomenclatures

b	units of 1/length (hyperbolic tangent model)
C_o, C_1, C_2	Constant value depending on β
E	Down-drift control point
$H1/H2$	Up-drift control point
m	Dimensionless (hyperbolic tangent model)
R_1	Radii 1
R_2	Radii 2
R_n	Radius line (parabolic bay model)
R_β	Control length (parabolic bay model)
$S1/S2$	Static line
W	Down-drift tangent point
x	Distance alongshore (hyperbolic tangent model)
y	Distance cross-shore (hyperbolic tangent model)

Greek Symbols

α	Outer tangent angle (logarithmic spiral bay model)
β	Reference wave obliquely angle (parabolic bay model)
θ	Angle on the curve (logarithmic spiral bay model)
θ_n	Angle from the same wave crest line radiating out from the wave diffraction point (parabolic bay model)

Abbreviations

HBB	Headland Bay Beach
MEPBAY	Model for Equilibrium Bay Beaches
NOAA	National Oceanic Administration Agency
SEP	Static Equilibrium Planform

1. Introduction

In the East coast of Peninsular Malaysia, most sediments are transported by big rivers such as Sg Pahang, Sg Kelantan and Sg Kemaman. Beaches along the East coast of Peninsular Malaysia essentially consist of one continuous sandy beach from Kota Bharu to Kuala Terengganu until the East parts of Johor Bahru, which mainly is composed of coarser sands. The presence of curved beaches or so called embayed beaches along the East coast of Peninsular Malaysia is abundance and the morphological beach shape is believed to be formed due to the predominant waves from the South China Sea and the geological condition of the coast. Embayed beach or headland bay beach (HBB) is defined as a beach lying in the lee of a headland subjected to a predominant direction of wave attack. It is bounded by two intervening headlands as can be seen in Fig. 1. It can be found anywhere along the water edge, oceanic area, enclosed seas, lakes or parts of a riverain system. The existence requires a headland and sufficient beach material to work together under a persistent wave condition.

In terms of beach stability, embayed beaches may be classified as being in static equilibrium, dynamic equilibrium or unstable [1]. Static equilibrium is a state when a predominant wave breaks simultaneously around the whole bay periphery. The littoral drift is almost non-existent and in order to maintain its long-term stability, external sediment is not required for static equilibrium HBB. Dynamic equilibrium however could recede toward the limit defined by the static equilibrium under the same wave condition, where to maintain its stability; sediment is supplied from updrift or source within the embayment. Unstable state on the other hand is a state of unstable condition associated with wave sheltering due to the addition or extension of structures on the beach, where a curved planform may cause accretion as well as erosion downdrift.

Through the fitting for the existing beaches, the beach stability can be analysed. The dotted line shown in Fig. 2 indicates static equilibrium shoreline position, which is described through the parabolic bay shape equation. H-down-coast control point: W-down-coast tangent point: E-up-coast diffraction point.

Fig. 1. A plan view of an embayed beach, namely Teluk Gadong bounded by two intervening headlands. An aerial image is captured by Google Earth Pro.

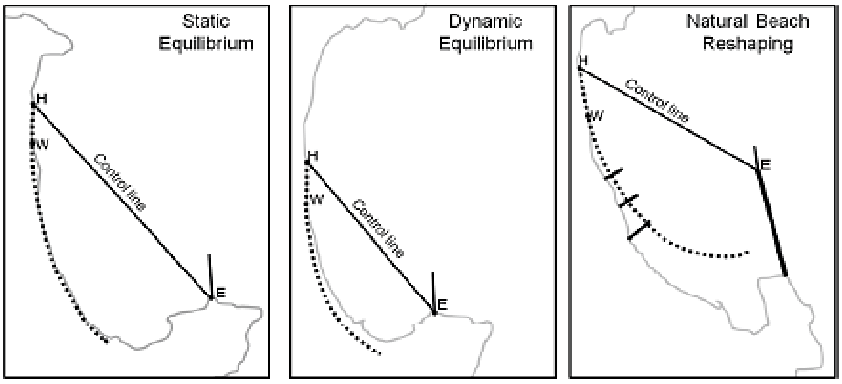

Fig. 2. Planform stabilities of embayed beaches [2].

The objective of this paper is two folds (i) to determine the number of embayed beaches along the East coast of Peninsular Malaysia and (ii) to determine its planform stability using an empirical bay model. Three research questions are formulated to achieve the main objectives which are: (1) how many embayed beaches can be found along the East coast of Peninsular Malaysia? (2) with the applications of MEPBAY program, what is the planform stability of embayed beaches that can be determined? and (3) are the existing coastal structures for dynamic or unstable states of beaches still applicable and if it is not, what are the engineering solutions that can be proposed? Studies on the stability of embayed beaches are extensive, e.g., [3-10] but researches on the planform stability on the East coast Peninsular Malaysia are scarce and limited to only one beach, i.e., Cempedak bay [2]. This is due to the fact that research trend in Malaysia depends on the current needs of the national. For example, exploration on renewable energy source using wave energy converter [11] is more important compared to embayed beach stability. This study however extends the future exploration of planform beach stability along the East coast of Peninsular Malaysia including the state of Kelantan, Terengganu, Pahang, and eastern part of Johor.

2. Long Term Empirical Bay Models

Due to the morphological significance of curved beaches, several empirical long-term models based on equilibrium formulations have been proposed to fit curves to their peripheries. Notably, parabolic model [1], logarithmic spiral model [12] and hyperbolic tangent model [13] provide mathematical expressions that can predict the static equilibrium coastline of beaches.

2.1. Logarithmic-spiral bay model

Log-spiral equation is the first proposed [14] with an equation as expressed in Eq. (1).

$$R_2 = R_1 \exp(\theta \cot \alpha) \quad (1)$$

As seen from this equation, the relationship between two consecutive radii R_1 and R_2 that is measured from the centre of a logarithmic spiral is specified. Both radii are apart with an angle θ on the curve which has a constant outer tangent of α. Figure 3 shows the definition sketch of logarithmic spiral bay model.

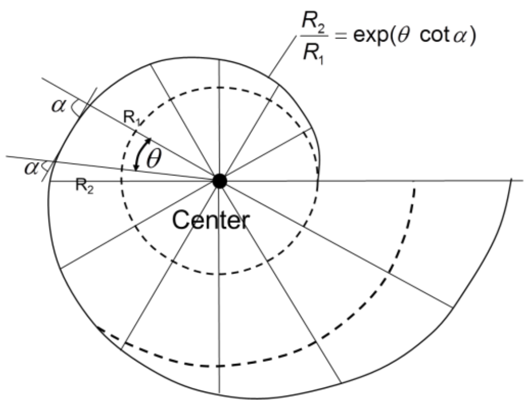

Fig. 3. Definition sketch for logarithmic-spiral model [12].

The equation was applied to examine four prototype bays on the East and West coast of United States. However, the centre of the four spirals did not coincide with the wave diffraction point giving out an offset ranging from 0.3 to 2000m, respectively. It has been observed that the wave direction and stability were not specified in the definition of the model. On top of that, the centre of spiral did not relate to the point of wave diffraction. With the logarithmic-spiral bay model, the stability of embayed beaches remains unknown.

2.2. Hyperbolic-tangent shape model

Hyperbolic-tangent shape model [13] is an alternative model developed about 35 years after the first embayed beach model, i.e., log-spiral bay model. This model is developed to overcome the lacking of the previous model where it failed to match the relatively straight downdrift section of embayed beach and the physical wave diffraction point at the updrift headland not used as the centre of the spiral. The hyperbolic tangent model is defined in a relative Cartesian coordinate system as in Eq. (2).

$$y = \pm a \tanh^m (bx) \qquad (2)$$

where y is the distance across shore, x is the distance alongshore; and a (units of length), b (units of 1/length) and m (dimensionless) are empirically determined coefficients. However, it was found that the model does not highlight the importance of the wave diffraction at the updrift headland in which it controls the process of planform evolution of a bay beach and this finding should not be ignored.

2.3. Parabolic bay shape model

The previous two models proposed are incapable to verify the stability of bay beach, neither to assess environmental impact of new headland nor the effect of extending existing structure on the downdrift beach. Nevertheless, parabolic bay shape model is developed to verify the bay beach stability and the effect of relocating an updrift control point on the downdrift beach. The parabolic model allows a judgement and prediction on the long-term equilibrium and stability of the curved coastline. This model is convenient for its ability to assess whether or not a curved beach is in or reaching static equilibrium planform (SEP). A manual application of parabolic bay shape equation [15] was developed for a headland-bay beach in static equilibrium in the form of

$$R_\eta/R_\beta = C_o + C_1(\beta/\theta_n) + C_2(\beta/\theta_n)^2 \qquad (3)$$

There are two primary physical parameters required in Eq. (3) which are the control line in length, R_β and the reference wave obliquity angle, β. The control line is angled β to the tangent at downdrift beach end while the radius R_η to any beach point around the bay periphery is angled θ_n from the same wave crest line radiating out from the wave diffraction point. As seen in Eq. (3), β and R_β compensate each other, for example a slight decrease in β would decrease R_β, and vice versa. Figure 4 shows the definition of parameters applied in the parabolic bay shape equation. Equation (3) consists of three constants, C generated by regression analysis to fit the outer boundaries of 27 prototypes and model bays. These C values are usually ranging between 2.5 and -1.0 at usual range of β values of 10° to 80° which is commonly applied to most field conditions. Numerically, these coefficients can be expressed through fourth-order polynomials as shown in Eqs. (4), (5) and (6).

$$C_0 = 0.0707 - 0.0047\beta + 0.000349\beta^2 - 0.00000875\beta^3 + 0.000000004765\beta^4 \quad (4)$$

$$C_1 = 0.9536 + 0.0078\beta - 0.00004879\beta^2 - 0.0000182\beta^3 + 0.000001281\beta^4 \quad (5)$$

$$C_2 = 0.0214 - 0.0078\beta + 0.0003004\beta^2 - 0.00001183\beta^3 + 0.00000009343\beta^4 \quad (6)$$

However, being found to be repetitive and tedious, this application is improved in terms of its efficiency by integrating the concept and being computerized by a software package known as Model of Equilibrium Bay Beach (MEPBAY) [16].

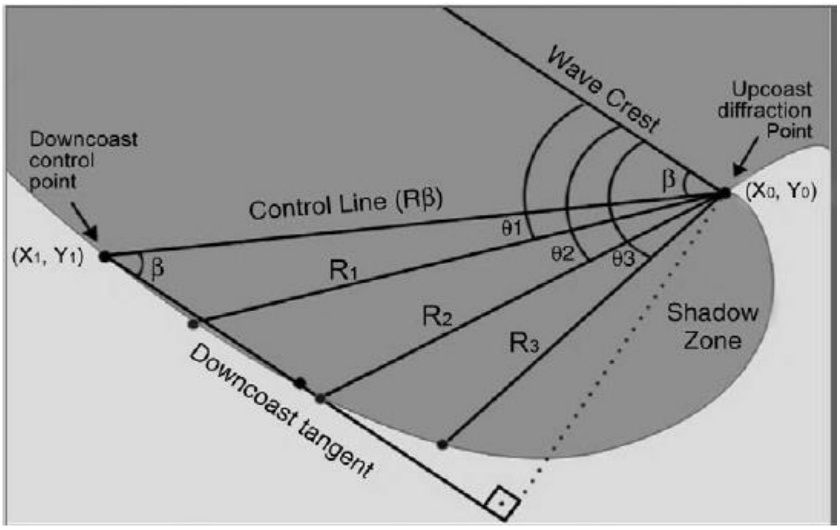

Fig. 4. Sketch for parabolic bay shape model showing major physical parameters [15].

3. Model Description and Inputs

3.1. MEPBAY (Model for Equilibrium Bay Beaches)

MEPBAY program was developed in 2003 as educational software [16]. It has been found that the program is a convenient tool in verifying the planform stability of the embayed beach. It is able to analyse the effect of new or existing wave diffraction points on the downdrift beach where in most cases, MEPBAY can be operated using only bay beach imagery and physical knowledge of wave refraction and diffraction. It uses computer graphics to display both the existing bayed beach and the results of the parabolic equation. This allows the stability of a bay to be visually assessed by comparing its actual shoreline with the idealized planform in static equilibrium [2]. This software helps to gain insights on physical processes of beach changes as well as proposed solutions for coastal management and shoreline protection.

3.2. MEPBAY application and identification of embayed beach stability

MEPBAY application is able to assist in the identification of the beach stability of embayed beaches. The SEP is parallel or almost perfectly fits the existing shoreline of beach shows that the embayed beach is under static equilibrium planform. If the predicted embayed beach is in dynamic equilibrium, the static equilibrium planform (SEP) is landward of the existing shoreline, existing sediment balance is maintained or retreat as supply diminished. In addition to that, if the SEP is predicted seaward of the existing boundary, then the embayed beach is under the state of unstable or natural beach reshaping, unless artificial nourishment is carried out to fill the space between the predicted and existing planform. The operational procedure of MEPBAY is outlined in [16].

3.3. Wave climate and satellite beach images

Prior to identification of embayed beach stability, information on the wave climate for the selected study area is essential, mainly wave directions. In the application of MEPBAY, the predominant wave direction is required in order to locate the three main wave diffraction points. Wave data were obtained from the National Oceanic Administration Agency (NOAA). The wave rose is plotted based on the annual wave data of 2010 collected at a water depth of 40 m with the frequency of 3 hours interval.

Figures 5 (left) and (right) show the examples of wave rose plots for the two selected beaches, i.e., Tok Jembal and Pantai Irama, respectively. Waves predominantly come from the Northeast with the highest significant wave height of 2.5 m for both beaches.

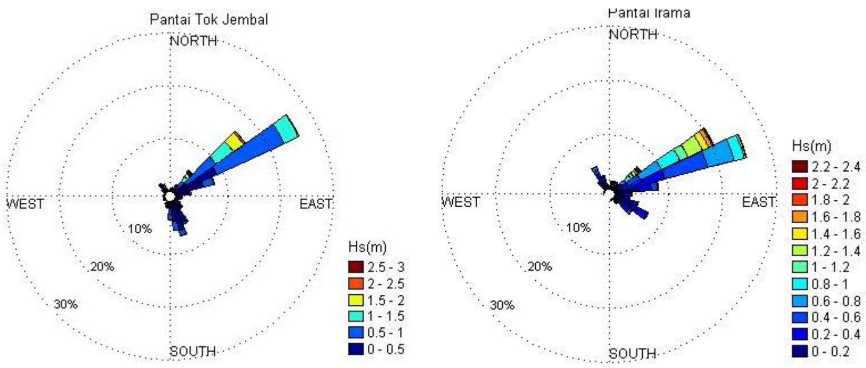

Fig. 5. Wave roses representing wave height and wave direction for two different locations, i.e., (left) Tok Jembal beach and (right) Irama beach.

Satellite images are captured from the Google Earth Pro and were imported into the MEPBAY program. The images were assured as sufficiently clear to easily locate the three main diffraction points. If possible, images with clear wave crest pattern near headlands are captured so that the incoming waves can be spotted in advance. However, this is hardly visible since the cloud coverage within the study area is cloudy resulting in poor quality of images.

4. Results and Discussion

4.1. Embayed beaches along the East Coast Peninsular Malaysia

Using Google Earth Pro, a total of 51 numbers of embayed beaches have been found along the East coast of Peninsular Malaysia as shown in Fig. 6. The embayed beaches found comprised of a total of 29 naturally developed beaches and 22 artificially developed embayed beaches. Artificially developed embayed beaches indicate the presence of existing coastal structures on the coast. The beaches found is further analysed through MEPBAY program in determining the planform stability of the beach and results obtained showed a total of 23 beaches are static, 26 beaches are dynamic and another two beaches are in an unstable state.

Out of 51 embayed beaches, only 14 beaches have been selected to be discussed further in the discussion. Table 1 shows the list and description of selected beaches. Out of 14 beaches selected, one is considered unstable, eight are in dynamic state and the other five are in static equilibrium state. These embayed beaches are selected according to its variation in beach nature, wave directions and different existing coastal structures. Beaches that are mostly documented to experience erosion and are highly in need of research for future improvement were selected.

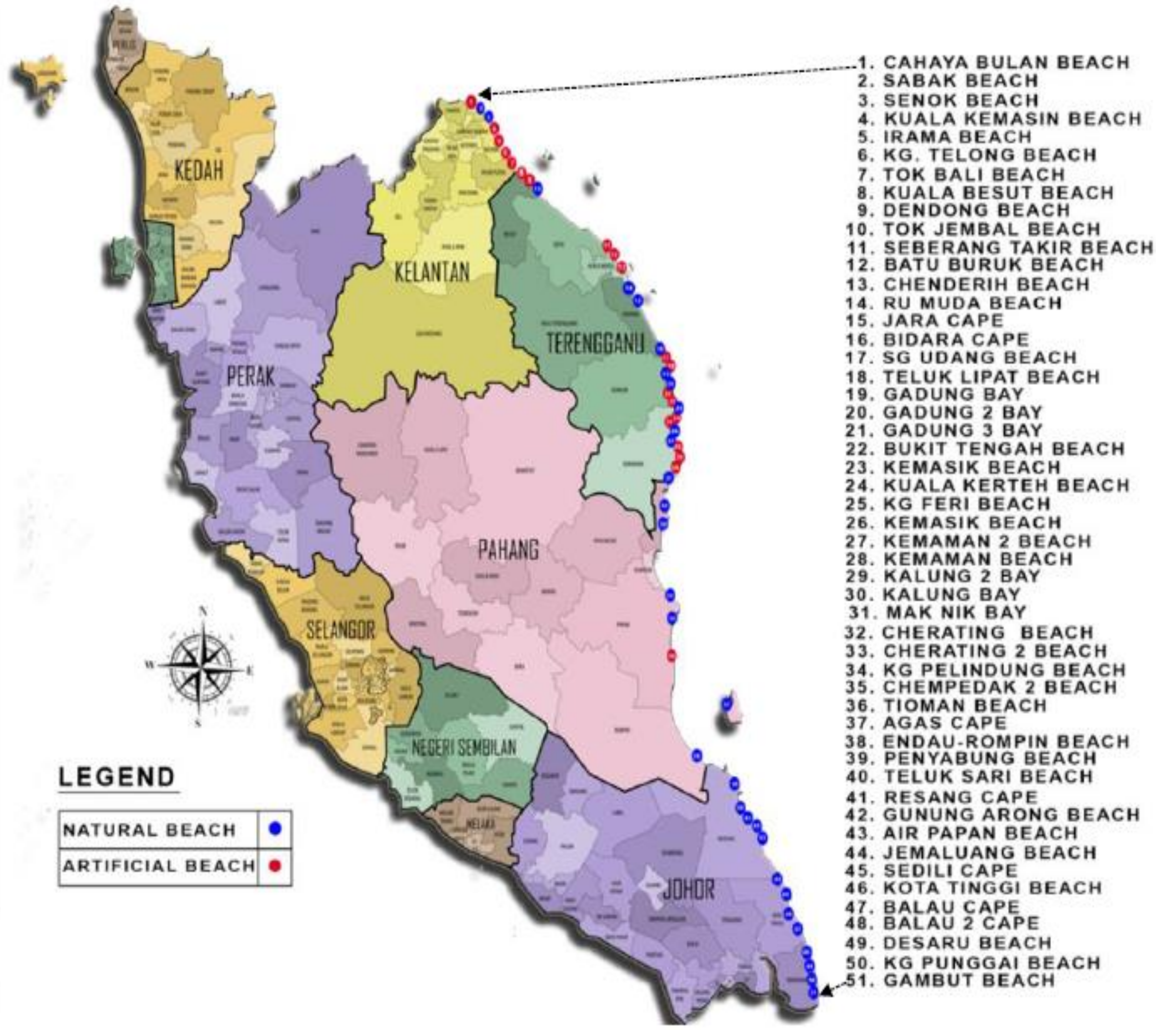

Fig. 6. Distribution of embayed beaches along the East coast of Peninsular Malaysia that comprised of natural and artificial embayed beaches.

Table 1. Selected beaches and brief descriptions.

	Beach	Description	Equilibrium state
1.	Batu Buruk	-behind the shore connected breakwater -wave breaks around the whole bay	Static
2.	Irama	-artificial beach with offshore breakwater -no littoral drift	Static
3.	Resang cape	-stable beach; wave breaking around the bay is pronounced.	Static
4.	Jemaluang	- wave breaks simultaneously and less littoral drift within the bay	Static
5.	Kg. Punggai	-no littoral drift and historically stable beach	Static
6.	Senok	-located near river mouth	Dynamic
7.	Jara cape	-natural beach with sufficient supply of sand	Dynamic
8.	Bukit Tengah	-artificial beach with groyne structures - dynamic beach.	Dynamic
9.	Teluk Lipat	-blunt artificial headlands - active sediment transport and sand bypassing around headlands is pronounced.	Dynamic
10.	Cherating	-natural beach, active sediment supply from the updrift headland	Dynamic
11.	Endau-Rompin	- presence of sand spit and sediment bypassing at the updrift headland	Dynamic
12.	Sedili cape	-stable but potentially to be dynamic due to the presence of river outlet near updrift headland	Dynamic
13.	Kalung Bay	- experiencing severe erosion for many years. - instability due to the existing seawalls	Dynamic
14.	Tok Jembal	- artificially created beach with extension of breakwater. -dynamic sediment transport patterns. -high energy waves	Unstable

4.2. Beaches in static equilibrium state

Beaches which are found to be in static condition consist of Batu Buruk beach, Irama beach, Resang cape, Jemaluang beach as well as Kg Punggai beach. The artificially developed Batu Buruk and Irama beaches' curves are developed as the consequences of the installation of coastal structures developed on the area including groynes and shore connected breakwater. For every MEPBAY analysis computed, point H is the updrift control point, point E is the downdrift control point, W is the downdrift tangent point and green line is the static equilibrium line as can be seen in Fig. 7.

With shallow water depth and diminishing wave energy impacting the shoreline of the beaches, the beach undergoes no addition or erosion of sediment towards the bay and littoral drift of the beach is almost non-existent. Significant quantities of sand accumulations are observed and the beaches have not suffered erosion at the area where coastal structures are installed. Resang cape, Jemaluang beach and Kg. Punggai beach is also found to be in static state despite being naturally developed. These beaches lack any major sediment source - no direct river flows influence and it generally has long headlands which may hinder sediment bypassing.

(a) Batu Buruk beach, Terengganu **(b) Irama beach, Kelantan**

Fig. 7. MEPBAY analysis on static embayed beaches.

4.3. Beaches in dynamic equilibrium state

On the other hand, beaches which experience degradation, as the accumulation of sand coming in decreases or undergo erosion due to extreme change in the wave climate, are found to be in dynamic state. The sediment budget of the beach is negative and the available beach sediment is being reworked by wave action, causing erosion. Eight of the embayed beaches selected to be found in dynamic condition are Senok, Jara cape, Bukit Tengah, Kalung bay, Teluk Lipat, Cherating, Endau-Rompin and Sedili cape beach. Figure 8 shows beaches that are in dynamic state when the static equilibrium line (green line) is landward of the original shoreline.

4.4. Beaches in unstable state

Besides, only one of the selected embayed beaches is found to be unstable which is Tok Jembal beach, located in Terengganu. The curve shape beach of Tok Jembal with the presence of the breakwater installed as a coastal defence to reduce intensity of wave action in inshore waters does not effectively reduce the coastal erosion towards the beach. We believe that this sheltered area is developed for fishing, accommodating small boats to berth inside the harbour. Since the geometric configuration of the bay is suddenly changed with the presence of breakwater, the bay may become unstable and naturally readjust itself to the new conditions [2]. Figure 9 shows the result of beach planform after the application of MEPBAY. The instability of the bay can be inferred when the static equilibrium planform (SEP) line is seaward of the original shoreline.

(a) Senok beach, Kelantan **(b) Jara cape, Terengganu**

(c) Bukit Tengah beach, Terengganu

Fig. 8. MEPBAY analysis on dynamic embayed beaches.

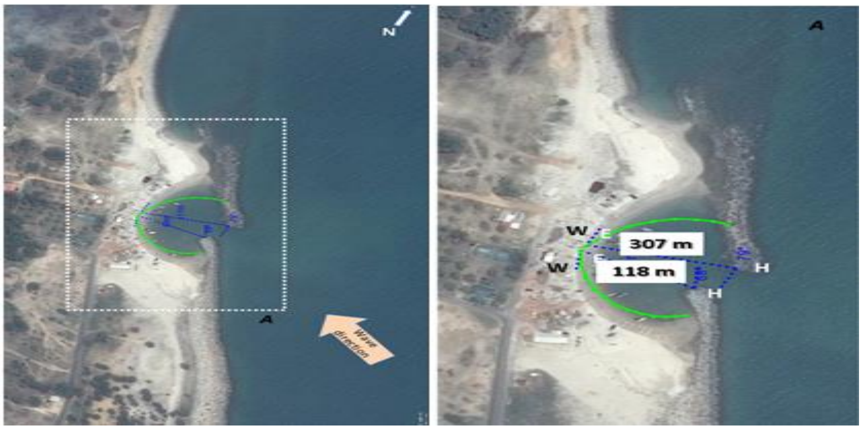

Fig. 9. MEPBAY analysis on Tok Jembal beach, an unstable beach.

4.5. Engineering applications for dynamic and unstable embayed beaches

Two of the selected embayed beaches are found to be significant in highlighting the engineering applications for dynamic and unstable condition of the beaches for the planform improvement, i.e., Kalung bay and Tok Jembal beach. Composing of mainly granular sandy materials that are easily erodible when subjected to wave forces, artificially developed Kalung bay of approximately 500 m in length is one of the beaches which has been experiencing severe erosion for many years [17]. The erosion process resulted in the instability of the existing seawalls constructed on the beach, which consisted of precast concrete slabs as stated by [17]. Erosion process persists to continue, thus represented by the latest dynamic state of the Kalung bay through MEPBAY analysis.

Problems faced by Kalung bay can be prevented by the application of groyne structure at the updrift headland as the replacement of the existing seawalls on the beach. Groynes are selected as alternative engineering applications to be installed at approximately 101 m length, measured from point H1 at an angle of 42° on the beach to deflect nearshore currents and reduce longshore transport on the beach. Two virtual diffraction points are assumed, namely H1 and H2 for the proposed improvement towards the beach as can be seen in Fig.10. Downdrift tangent point (point W) and downdrift control point E both remain at the same position. With the original application of the updrift indicated by H1, the static line (S1) is slightly shifted seaward. This condition represents the beach is under dynamic state condition. When the virtual updrift point proposed (H2) is applied, it is found that the static line (S2) is slightly shifted seaward, which leads the beach to its static form of equilibrium.

Fig. 10. MEPBAY analysis and the predicted SEP of Kalung bay.

In contrast, Tok Jembal beach which is located nearby the Sultan Mahmud Airport has undergone erosion which resulted in the narrowing of the beach area and steeper slope of the shore. The condition of the beach may happen as a result of high wave activity during monsoon storms, reduction of the sediment supply as well as improper design or selection of the suitable coastal protection measures for the beach. The design of the breakwater constructed parallel to the shore needs to be redesigned in terms of its length. The length of the breakwater should be reduced at a certain distance from point H1 to H2. In that way, Tok Jembal beach will be able to achieve its static planform stability state as shown in Fig. 11.

Fig. 11. MEPBAY analysis and the predicted SEP of Tok Jembal beach.

5. Conclusions

A research has been conducted to determine the planform stability of embayed beaches along the East coast of Peninsular Malaysia that comprises of four different states; Kelantan, Terengganu, Pahang and Johor. This is done by the application of an empirical parabolic bay shape model through the analysis of MEPBAY program. Some concluding analyses from the research are given as follows:

- Out of 51 embayed beaches found along the East coast of Peninsular Malaysia, a total of 23 beaches are static, 26 beaches are dynamic and another two beaches are in an unstable state.
- Sandy beaches with greater sediment input of the East coast of Peninsular Malaysia consist of mostly dynamic embayed beaches.
- The presence of existing coastal structure may influence the instability of embayed beaches.
- Management of Malaysian shorelines must proceed with care and embayed beaches in particular must be monitored. A small change in the sediment budget can cause rapid erosion.

Future researches are recommended to look into the details of embayed beach morphology especially the one that is categorised under dynamic state and unstable state. Furthermore, the applicability of MEPBAY software can be used to inspect the stability of embayed beaches for the other parts of Malaysian coast, i.e., Peninsular west and Sabah and Sarawak.

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