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ABSTRACT

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The existence of embayed beaches is pronounced along the coast of Peninsular Malaysia. The stability of such beaches is yet to be confirmed. The present study aims at investigating the shoreline planform stability on the east and west coasts of Peninsular Malaysia. 190 embayed beaches were found along the Malaysian Peninsular coast, including natural beaches and man-made beaches. Of these, 139 beaches were on the west coast while 51 beaches were on the east coast. Results of the MEPBAY model show along the east coast, 45%, 51% and 4% were classified as the static, dynamic, and natural beach reshaping, respectively. Beaches on the west Peninsular coast that is mainly characterised by the muddy coast were more pronounced to be in the static state which comprised of 85% compared to the beaches on the east coast, that are mostly sandy. While, another 15 % were fall under dynamic equilibrium state. Sediment supply from the river, improper placement of coastal structures, sediment bypassing at headland are some possible factors that may cause the dynamic and instability of the embayed beaches studied.

ADDITIONAL INDEX WORDS: *Embayed beach, static bay, dynamic bay, planform stability, Malaysian beaches.*

INTRODUCTION

Malaysian coastline comprised of 4,809 km including Sabah and Sarawak. Approximately 30% of the coastlines is affected by various degree of coastal erosion. National Coastal Erosion Study (NCES) 1985 reported three main categories of coastal erosion classification for Malaysian coastlines i.e Category 1 (critical), Category 2 (significant), and Category 3 (acceptable) (EPU, 1985). Each category contributes 160 km, 242 km and 910 km length of coastline, respectively (EPU, 1985). On the other hand, a study in 2006 conducted by Department of Irrigation and Drainage (DID) Malaysia revealed that 288 km of coastline is eroded, increased by 44 %. However, the length of coastline for Category 2 and Category 3 is reduced to 193 km and 922 km, respectively (DID, 2006). Out of 4,809 km of coastline length, 1,972 km is within the Peninsular Malaysia coast. More than half of the coastline on the east and west Peninsular coast is eroding, both including straight coasts and embayed coasts with various degree of curvature. The presence of embayed beaches is pronounced along the coast of Peninsular Malaysia. Similar to open straight beaches, embayed beaches are subjected to accretional and erosional processes due to the dynamic changes of wave climate, tidal effect, interruptions of longshore and cross-shore transport, and implementations of multiple coastal structures on beaches. Headland sand bypassing (Short and Masselink, 2000), improper placement of coastal structures (Hsu

et al., 2000; Klein et al., 2010) and sediment supply from a river that flowing into a bay beach are some possible reasons that may affect the stability of embayed beaches. Therefore stability verification for an embayed beach is strongly recommended prior to the installation of any coastal structure in the preliminary design phase (Hsu et al., 2009)

Researches of embayed beach stability on Peninsular Malaysia coast is limited to recent studies on the stability of Cempedak bay beach (Ab Razak et al., (2011:2013)), and the stability of embayed beaches on the east coast of Peninsular Malaysia (Ab Razak et al., accepted). This paper therefore, combines findings obtained from previous and current researches and is extended by developing a single Peninsular map with stability marks of embayed beaches along the coast of Peninsular Malaysia. The total number of embayed beaches found in Peninsular Malaysia coast and the stability analyses of embayed beaches using the software MEPBAY are presented with the aim of contributing to and improving a coastal management plan for Malaysian beaches.

EMBAYED BEACH'S PLANFORM STABILITY

According to Hsu et al., (2008), the classification of shoreline planform stability of embayed beaches can be categorised into three states i.e static equilibrium, dynamic equilibrium, natural beach reshaping or unstable. Details description of these stability states can be found in Hsu et al., (2008) and Lausman et al., (2009). In a static equilibrium state, the bay shape modelled by the parabolic bay shape model coincides with the original shape of the shoreline. If the predicted curve is landward of the existing beach which has remained stable over a long time, the beach is said to be in dynamic equilibrium. When the shoreline

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displacement is significantly verified, the beach is classified under natural beach reshaping state or unstable state,.

METHODS

This study employed a parabolic bay model widely known as model for equilibrium bay (MEPBAY) which was developed by Klein *et al.,* (2003), significantly reduces the computational time needed for practical applications. The direct application of MEPBAY requires information such as aerial or satellite images of embayed beaches, three controlling points to be located on an image and wave direction. High quality of aerial images are captured using Google Earth Pro. The states of stability of an embayed beach are determined based on the definition given by Hsu *et al.,* (2008). The study area covers embayed beaches that exist along the east and west coast of Peninsular Malaysia as shown in Fig. 1.
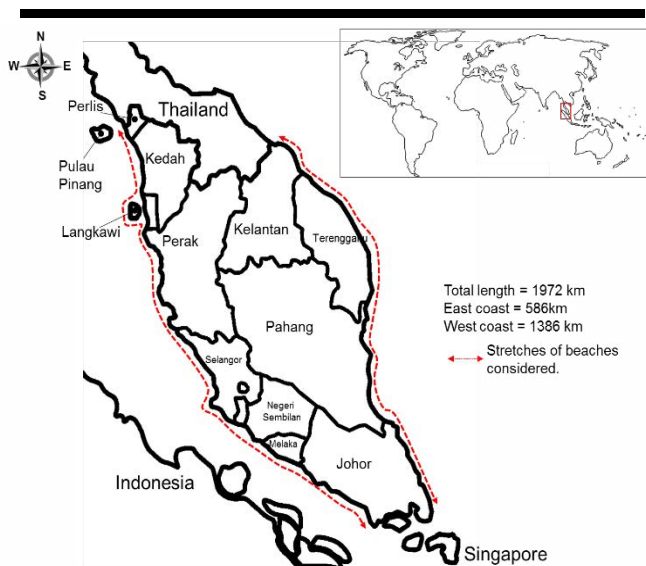

Figure 1. Study area covering east and west coast of Peninsular Malaysia.

The Malaysian coast is affected by the monsoonal system. Waves on the east coast are more stronger than the west coast due to the fact that it is exposed to the South China Sea. The type of tides common in Malaysia are diurnal, semi-diurnal, and mixed. East coast is dominated by the diurnal type while water level fluctuation along the west coast is influenced by semi-diurnal tide and mixed tide. The Peninsular Malaysia coastline is classified as micro-tidal i.e spring tidal range less than 3m based on tidal range classification of Short (1991) and wave dominated. The tidal range is varying from 1.97 m to 2.84 m.

Model for Equilibrium Planform of Embayed Beaches (MEPBAY)

MEPBAY (Klein *et al.,* 2003) was developed based on the parabolic bay equation as derived in Equation 1(Hsu and Evans, 1989).

$$\frac{R}{R_\beta} = C_o + C_1\left(\frac{\beta}{\theta_n}\right) + C_2\left(\frac{\beta}{\theta_n}\right)^2 \qquad (1)$$

The major physical parameters such as R, R_β, β, and θ are defined in Fig. 2. The coefficients of C_o, C_1, and C_2 are determined based on the regression analysis that fitted 27 prototypes and bay models of embayed beaches periphery (Hsu and Evans, 1989).
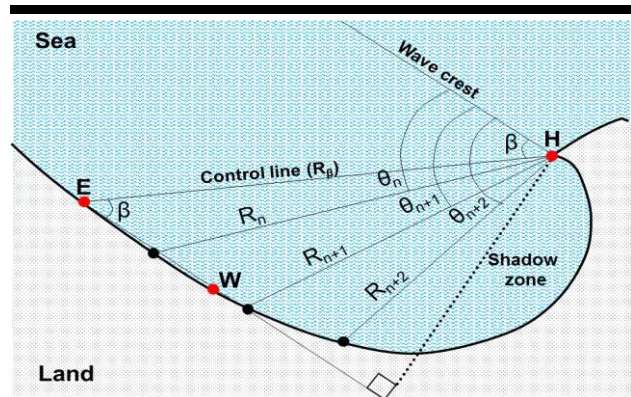

Figure 2. Definition sketch for parabolic bay shape model, showing major physical parameters (modified after Hsu and Evan, 1989).

To apply a parabolic model, it is assumed that there is no further sediment is being added or eroded from the bay under the persistent swell condition, wave breaks simultanoeulsy around the bay pheriphery and littoral drift or longshore currents are almont non-exixtent. The operational procedure of MEPBAY can be found in Klein *et al.,* 2003. MEPBAY has been extensively applied around the globe e.g (Klein, 2003; Raabe *et al.,* 2010; Anh *et al.,* 2015; Klein *et al.,* 2003; Klein *et al.,* 2009; Jackson and Cooper, 2010), to be listed a few.

RESULTS AND DISCUSSIONS
Distribution of embayed beaches along the Malaysia Peninsular coast

All embayed beaches existed along the Peninsular coast of Malaysia consist of both natural and artificial beaches. Natural beaches are considered when the beach is bounded by prominent headlands while artificial beaches are those developed due to the presence of shore parallel or perpendicular structures such as groyne or breakwater. Along the 586 km of east coastline, 51 numbers of embayed beaches were existed. Beaches along the east coast are mainly comprised of sand. The number of natural beach were found to be 29 beaches while 21 of them are artificial. Much of the coast is a series of large and small hook-shaped bays. This is due to the fact that almost the entire length of coastline is exposed direct wave attack from the South China Sea. The coastal landscape is dominated by low elevation coastal plains, interrupted by numerous upland spurs and river outlets. For the west coast of Peninsular, along the stretch of 1,386 km coastline 139 embayed beaches were found. 102 of them are natural beaches and another 37 are artificial beaches. Contrasting to the beach condition along the east coast, beaches on the west coast are muddy. A majority of the coast is open to the waters of the Straits of Malacca and is comprised of low elevation coastal plains. The plains are formed from a deep marine clay stratum. On the lower part of the west coast the plain has been dissected by the numerous rivers and estuaries that cut the coast. Saltwater

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inundation of coastal lands between low and high tide is possible for up to two kilometres from the shoreline. These conditions, combined with the tropical climate, provide an ideal environment for the propagation and growth of broad mangrove forests. Sandy beaches can be found on the upper part of the west coast. In general, sandy beaches are formed as pocket beaches between prominent rocky headlands.

Comparing embayed beaches on the east coast with beaches on the west, beaches along the west are much smaller in size and abundant. Low to moderate waves may influence the geological setting of the coastal landscape as persistant diffracted waves cause the formation of the small bay. Beach slope, grain sizes, and vegetation covers on beaches are factors that increase the number of bays along the west coast.

Fig.6 shows the distribution of embayed beaches along the east and west coasts of Peninsular Malaysia. The detailed results of the planform stability analysis for all beaches studied are tabulated in Appendix A and can be downloaded at https://drive.google.com/drive/folders/1JqCeyUqaqJmoBdfV-_dpBxJ1iPFFvGR-

East coast of Peninsular Malaysia

51 beaches along the east coast were analysed and 45% were classified as in static equilibrium state. Beaches in static state lack any major sediment source i.e no direct river flows influence and it generally has long headlands that protruding into water bodies which may hinder sediment bypassing. Resang cape and Kampung Punggai are examples of static equilibrium beaches. The construction of coastal protection structures such as a series of breakwaters at Irama beach in Kelantan (see Fig. 3) and a shore connected breakwater at Batu Buruk beach in Terengganu showed promising results when both beaches reach static equilibrium after the construction of those coastal protection structures.

Out of 51 beaches, 51% were categorised as dynamic equlibirum state. Beaches in dynamic state are controlled by sediment budget. Intermittent supply of sand to the beach causes the beach to become dynamic. Imbalance sediment that entering and leaving the coastal cell may prove that beach can lead to dynamic state. On the other hand, headland sediment bypassing process has proven to contribute to dynamic change of an embayed beach (Klein et al., 2003). The study conducted by Ab Razak et al., (2013) revealed that the dynamic stability of a headland bay beach named Teluk Cempedak on the east coast is caused by two factors (i) discharge by a small river creek at the northern part of the bay and (ii) sediment bypassing at both intervening headlands. The other example of a beach in dynamic state is Cherating beach. In analyzing an aerial image from this location, it was noted that there is sediment supply bypassed the headland. An obvious sand dispersion as can be seen in Fig. 4 was observed at the downdrift side of headland.

The surplus of sediment is expected to be discharged from the Kemamam river, located 16 km northwards. This is evidence due to the fact that a sand spit was initially developed which is connecting a small headland and Cendor beach in the north, supporting the hypothesis of sediment bypassing. The scheme of headland bypassing process is given by Short and Masselink (1999) based on the Australian's eastern coast.
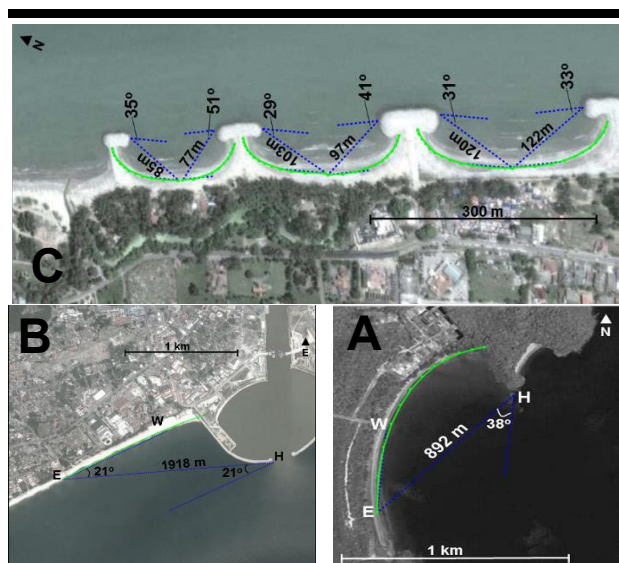

Figure 3. Example of static equilibrium planform after the breakwater construction at Irama beach in Kelantan, (C) and Batu Buruk beach in Terengganu (B). (A) indicates static stability of Resang Cape.
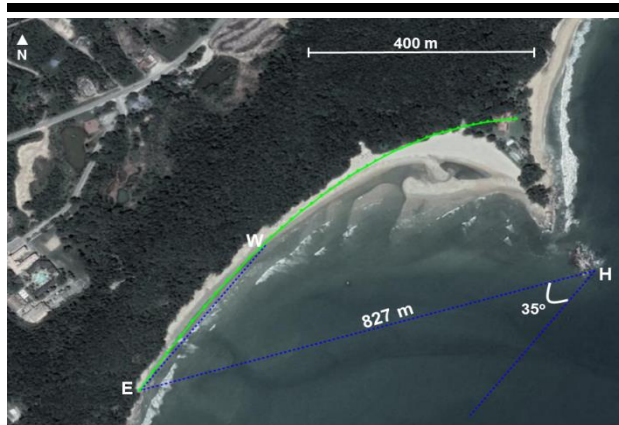

Figure 4. Example of dynamic equilibrium planform at Cherating beach. Headland sand bypassing process contributes the dynamic equilibrium of an embayed beach.

Natural beach reshaping state, however is verified when the modelled shoreline displacement is seaward from the original shoreline. Only 4% of the east coast beaches were fall under this category. The example of a beach in this state is Tok Jembal beach located in Terengganu coast. In this case, an offshore breakwater was built in combination with shore revetment to create a calm zone for small boats to berth after fishing. Near the beach, there is a small fisherman market for local people to get their fresh daily seafood supply. From the aerial image observation, the shoreline displacement within the bay is significantly verified. This beach has experienced erosion and is categorised as Catgeory 1 i.e critical by the DID Malaysia (DID, 2006).

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West coast of Peninsular Malaysia

139 beaches on the west coast of Peninsular Malaysia were analysed. Of these, 82% were classified as in the state of static equilibrium. The example of beaches in this state are Tanjung Bidara, Teluk Rubiah, Teluk Burau, Pantai Dato Syed Omar, and Sekinchan beach. Fig. 5 shows beaches in static state such as Tanjung Bidara and Teluk Rubiah.
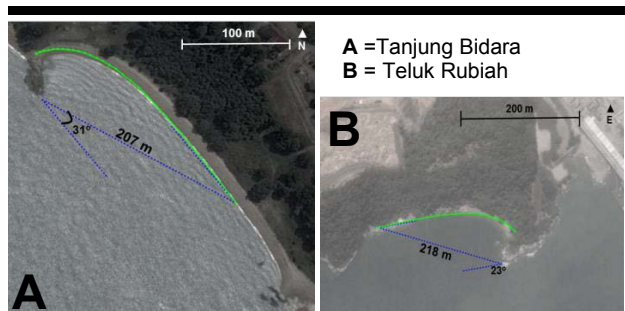

A = Tanjung Bidara
B = Teluk Rubiah

Figure 5. Example of static equilibrium planforms on the west coast.

Contrasting to the condition on the east coast, static equilibrium beaches are more dominant. Silveira *et al.,* (2010) indicated the planform stability is influenced by the topographic and bathymetric dimensions of adjacent headlands, which is valid. Short headlands allow sediment bypassing easily so that beaches tend to become dynamic equilibrium state. Long headlands impede sediment to bypass the headland thus work as closed cells wihout sediment input or output within the cell. As a result, beaches have a tendency to become static equilibrium.

From the study, it is learned that the majority of static equilibrium state on the west coast is due to the nature of beach soil condition. This is mainly because of the properties of the existing sediments present on the beach along the coastline that dominantly comprised of muddy soil. The second reason is the significant wave height along the straits of Malacca is low compared to those in the east coast. Therefore, the wave energy that arrives nearshore is low which may result the embayed beaches to be eroded in a short period , as a consequence beaches less impacted. Several coastal protection strcutures eg. groynes at Pantai Gemuk Negeri Sembilan, Bagan Ajam Pulau Pinang, Tanjung Bidara and Pengakalan Balak in Melaka and training jetties at Kuala Perlis were constructed along the west coast and these structures are found efficient as it serves its function. Merely 15 % of the beaches on the west coast comprised of dynamic equilibrium state. Those beaches are natural such as Teluk Batik and Teluk Senangin. It is believed that the dynamic beaches of Teluk Batik and Teluk Senangin are influenced by the major river effuent of Manjung River.

CONCLUSIONS

Applying the software MEPBAY to one hundred and ninety beaches of Peninsular Malaysia, it is summarized that the east coast beaches of Peninsular Malaysia require more attention compared to the west coast beaches. Findings reveal approximately all embayed beaches on the west coast are historically stable as the majority of beaches are in static equilibrium state. In contrast, more than half of beaches along the east coast are in dynamic equilibrium state. This thus gives signal to the management level to carefully manage and monitor shorelines of dynamic equilibrium embayed beaches.

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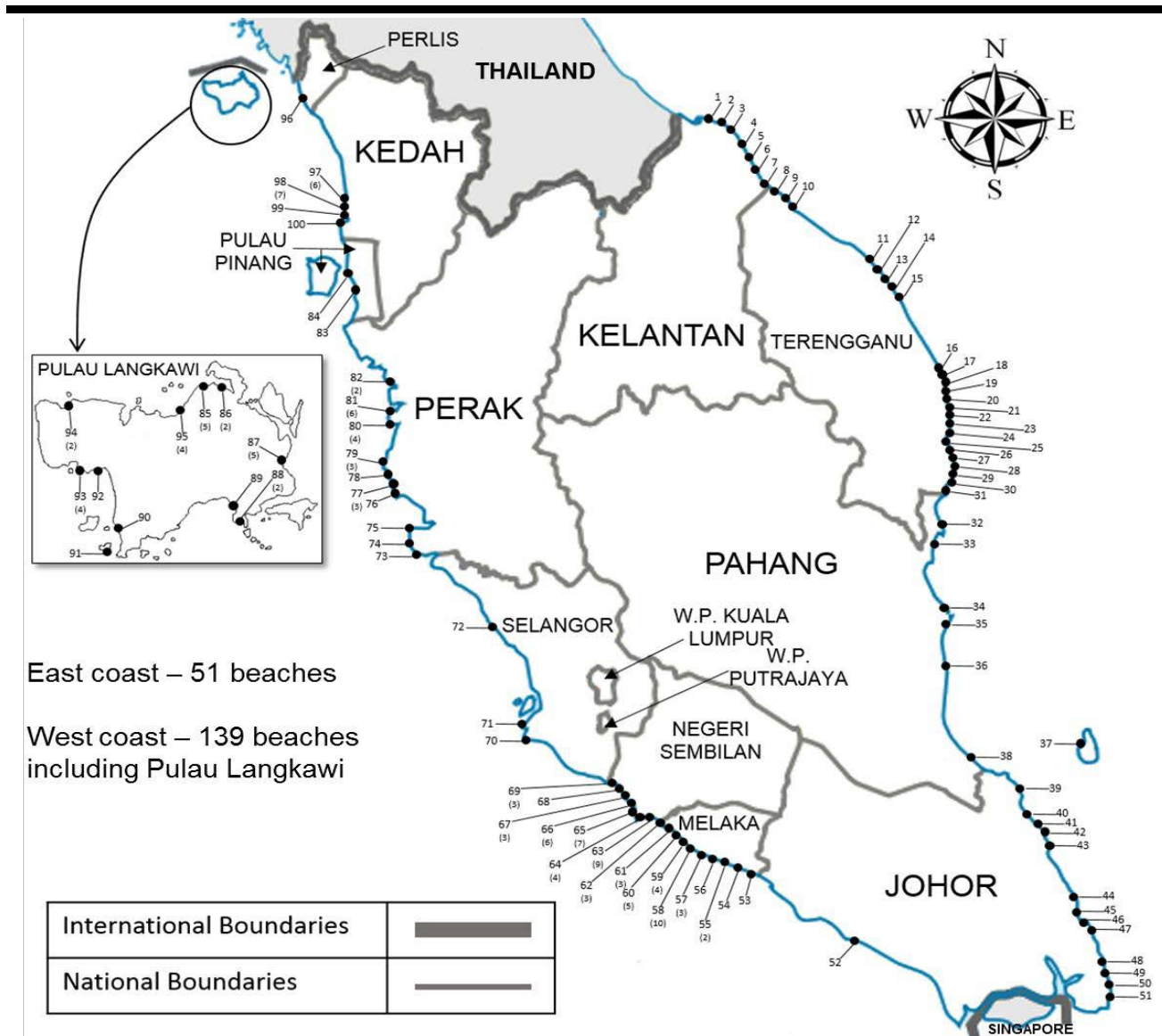
Figure 7. Distribution of embayed beaches along the coast of Peninsular Malaysia. Integer in bracket indicates number of beaches for that partciular coast. The list of beaches with its stability is given in Appendix A and can be downloaded at https://drive.google.com/drive/folders/1JqCeyUqaqJmoBdfV-_dpBxJ1iPFFvGR-

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