DETERMINATION OF DEPTHS OF CLOSURE ALONG THE KELANTAN COAST

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In the name of Allah, the Compassionate, the Merciful

Dedicated to my loving wife Noriah Abu Bakar for sharing my life and dreams, to my father and my mother for their relentless faith in me, and my sons Hazim, Nadim and Aqil Zuhair for their unconditional love.

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ABSTRACT

The design of beach-fill in beach nourishment works requires knowledge of the cross-shore sediment transport process. By the theory of equilibrium profiles, beach-fill material will be redistributed across the shore profile up to a seaward limit known as the depth of closure or D_c. The determination of the depth of closure is a key component of beach-fill design and is measured in the field from the study of periodical surveys over the same beach profiles. The Hallermeier equation which relies on the incident pre-breaking wave height is the only analytical means to predict the depth of closure. This study has examined the applicability of the Hallermeier equation in predicting depth of closure for the coastline of Pantai Sabak, Kelantan using nearshore waves which were transformed from offshore waves through numerical modelling. The predicted depth of closure was compared against measured depth of closure at 13 profiles that were surveyed in 1998, 1999, 2000 and 2004. The widely-accepted Standard Deviation of Depth Change (SDDC) and Fixed Depth Change (FDC) methods to determine D_c were both explored and the D_c for monsoon, annual and 5-year events were investigated. The research found that along the study shoreline at Pantai Sabak, more than one closure point can occur across the same profile over the seasonal and annual period. Hallermeier's equation overpredicts annual D_c by 43% and affirms previous findings that the predictive equation determines an upper limit value of D_c. Within the limitations of the survey data available, the annual depth of closure at Pantai Sabak can be equated to 1.5 times $H_{0.137}$.

ABSTRAK

Pengetahuan mengenai proses pergerakan ampaian rentas pantai adalah penting dalam kerja-kerja merekabentuk penambakan pasir pantai. Berpandukan teori keseimbangan profil, pasir penambakan dijangka akan diangkut dan diendapkan ke seluruh profil pantai sehingga satu lokasi kedalaman yang dinamakan kedalaman tertutup atau D_c. Penentuan kedalaman tertutup merupakan salah satu komponen penting dalam rekabentuk penambakan pasir dan ianya diperolehi melalui kajian ke atas data ukur bersiri yang diperolehi daripada profil-profil pantai yang sama. Persamaan Hallermeier yang bergantung kepada keadaan ombak sebelum pecah merupakan satu-satunya kaedah analitikal yang ada untuk menentukan kedalaman tertutup. Kajian ini telah menguji kesesuaian persamaan Hallermeier ini dalam meramalkan kedalaman tertutup bagi Pantai Sabak, Kelantan dengan menggunakan ketinggian ombak di kawasan dekat pantai yang diperolehi melalui permodelan numerikal yang berasaskan ombak lepas pantai. Kedalaman tertutup yang dikira dengan menggunakan persamaan Hallermeier telah dibandingkan dengan kedalaman tertutup yang dianalisa di 13 profil pantai yang diukur dalam tahun 1998, 1999, 2000 and 2004. Kaedah Persisihan Piawai Perubahan Kedalaman dan Perubahan Kedalaman Tetap telah digunakan untuk menentukan D_c bagi keadaan tengkujuh atau monsun timur-laut, tempoh tahunan dan untuk tempoh 5 tahun. Penyiasatan ini telah mendapati bahawa lebih daripada satu kedalaman tertutup boleh wujud dalam profil yang sama. Ramalan D_c tahunan dengan menggunakan Persamaan Hallermeier didapati tinggi dengan lebihan purata 43% dan ini mengesahkan hasil kajian-kajian terdahulu yang menyatakan bahawa persamaan ini boleh menentukan nilai had teratas untuk D_c. Tertakluk kepada data ukur yang terhad di Pantai Sabak, kedalaman tertutup tahunan boleh disamakan dengan 1.5 kali ketinggian ombak $H_{0.137}$.

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LIST OF ABBREVIATIONS

CED	Coastal Engineering Division
CEM	Coastal Engineering Manual
cm	centimeter
DHI	Danish Hydraulic Institute
DID	Department of Irrigation and Drainage Malaysia
DSMM	Department of Survey and Mapping Malaysia
HAT	Highest Astronomical Tide
Kg.	Kampung; village (malay)
LAT	Lowest Astronomical Tide
LSD	Land Survey Datum
m	meter
mm	millimeter
MSL	Mean Sea Level
MHW	Mean High Water
MHHW	Mean Higher High Water
MLHW	Mean Lower High Water
MLW	Mean Low Water
MHLW	Mean Higher Low Water
MLLW	Mean Lower Low Water
Sg.	Sungai; river (malay)
SSMO	Synoptic Shipboard Meteorological Observation
UKMO	United Kingdom Meteorological Office

LIST OF SYMBOLS

D_c	depth of closure
$D_{c,1\text{-}yr}$	depth of closure over 1 year
$D_{c,5\text{-}yr}$	depth of closure over 5 years
D_{ci}	depth of closure, innershore; from profile survey
D_{cm}	depth of closure, middleshore; from profile survey
D_{co}	depth of closure, outershore; from profile survey
D_l	predicted depth of closure; water depth at the seaward limit of significant sediment transport
$D_{l,t}$	predicted depth of closure over t years
$D_{l,1\text{-}yr}$	predicted depth of closure over 1 year
$D_{l,5\text{-}yr}$	predicted depth of closure over 5 years
d	water depth
d_i	lower limit of the shoal zone
d_l	lower limit of the littoral zone
d_{50}	size of material of which 50% is finer
g	acceleration due to gravity
H	predicted depth of closure (Birkemeier's equation)
h_c	predicted depth of closure (Hallermeier's equation)
H_{m0}	energy-based wave height of the zeroth moment
H_s	significant wave height
H_{s50}	median annual significant wave height
$H_{l,t}$	significant wave height exceeded 12 hours over t years
$H_{0.137}$	significant wave height exceeded 12 hours in a year
$H_{0.027}$	significant wave height exceeded 12 hours in t = 5 years
$H_{e,t}$	non-breaking significant wave height that is exceeded 12 hours per t years or (100/730t) % of the time
k_N	Nikuradse's roughness parameter

s	standard deviation
t	time
T	wave period associated with a particular wave height
$T_{e,t}$	wave period corresponding to He,t
T_m	mean wave period
T_p	peak wave period
U_b	maximum horizontal wave-induced near-bed velocity
x_i	measurement
x_m	mean of all measurements
n	number of measurements
σ_H	annual standard deviation of significant wave height
Φ_c	sediment entrainment parameter
γ'	ratio of the difference in density between sediment and fluid density
γ_1	wave breaking parameter which controls wave steepness condition
γ_2	wave breaking parameter which controls limiting water depth condition
α	adjustable constant in energy dissipation equation

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Beach nourishment is a preferred coastal protection measure for recreational beaches. The provision of a wider dry beach, by placing sand on the eroding shore that extends beyond the existing beach berm, is the main component of a beach nourishment scheme. A re-nourished beach presents a wider surface area that both dissipates wave energy impacting on the shoreline and creates more space for recreational activities. Sand re-nourished beaches remain as a part of the nearshore coastal system within which sediment can be moved freely by wave and tidal action.

Inherent in the engineering design of beach nourishment is an element of prediction and projection based on the shoreline change trend of the concerned beach. Typical beach nourishment schemes may require annual refill as the nourished beach is exposed and continuously subjected to environmental forces. In Malaysia, beach nourishment schemes are expected to last 5 years before re-nourishment works are initiated again. In this approach, designs are based on a general rate of erosion for the beach and a five-year re-nourishment interval. An important aspect of beach nourishment design is the knowledge of the seaward limit to which the beach-fill is expected to move. This point is called the depth of closure and its determination involves the study of the nearshore profile over a period of time.

The beach nourishment projects conducted by the Department of Irrigation and Drainage Malaysia (DID) in the past did not have the benefit of sufficient periodical survey data needed to determine the depths of closure. Hence, the predictive formula of depth of closure introduced by Hallermeier (Hallermeier, 1981) and its simplified forms (US Army Corps Of Engineers, 1984) have been widely used. Since the completion of the beach nourishment projects, periodical monitoring surveys have been conducted on selected re-nourished shorelines. The situation now presents opportunities for further study and analysis of the depths of closure with the view of improving the design of sand-fill in beach nourishment for local conditions. This research determines and studies the depths of closure from periodical surveys of a stretch of shoreline in Kelantan and examines the applicability of existing predictive equations to the Kelantan shoreline.

1.2 Background of the Problem

1.2.1 Erosion Control and Beach Nourishment in Malaysia

The National Coastal Erosion Study (Unit Perancang Ekonomi, 1985) determined that approximately 30% of Malaysia's 4,809 km of coastline was eroding. It proceeded to recommend immediate coastal erosion protection measures on critical sites and led to the development of the Coastal Erosion Control Program under the DID. Under this program, revetment-type protection and beach nourishment schemes were constructed along Malaysia's eroding coasts beginning in the late eighties. Among the major beach nourishment projects implemented by the Government of Malaysia under this program were:

(i) Kuala Terengganu to Kuala Ibai, Terengganu (1993);

(ii) Taman Robina, Seberang Perai Utara, Pulau Pinang (1994);

(iii) Pantai Kundur, Melaka (1995)

(iv) Batu 4, Port Dickson, Negeri Sembilan (1996 and 2005) and;

(v) Kg. Teritam to Kuala Sungai Pengkalan Datu, Kelantan (1997)

Since the emergence of tourism as a dominant sector of the Malaysian economy, the need to preserve the quality and aesthetics of public beaches have become an important agenda under the Coastal Erosion Control Program. Therefore, the understanding of the evolution of re-nourished beaches must be enhanced so as to improve future planning and design works.

1.2.2 Study Shoreline

The northeast coastline of Kelantan has been selected for this study due to its long-term erosion trend. This coastline is oriented along the northwest to southeast direction. Wind fetch lengths spanning over 1500 km across the South China Sea influence this stretch of coast. As a result, the long fetch and the predominant northeasterly winds during the northeast monsoon combine to generate high waves in the adjacent offshore area (Department of Irrigation and Drainage, 1993). Furthermore, there are no large islands off the Kelantan coast to offer any cover from the monsoonal waves.

The study is limited to the coastline from Kg. Pantai Dasar to Kg. S.P. Besar, Kelantan which is shown in Figure 1.1. Locally known as Pantai Sabak, this coastline has experienced erosion at an average rate of exceeding 5 meters per year (Unit Perancang Ekonomi, 1985). The situation was later exacerbated by the construction of a breakwater at Sungai Pengkalan Datu which was completed in 1986 as part of a flood mitigation and agricultural drainage project. The breakwaters created a terminus to the littoral transport in the area and depleted the supply of sediment to the adjacent shoreline of Pantai Sabak to the northwest. An erosion of 20 meters occurred within 7 months of the completion of the northern arm of the breakwaters and the completion of the southern arm 10 months after brought about an additional 60 meters of erosion in the following year (Lee, 1990). Studies by Universiti Teknologi Malaysia indicated that minor sediment bypassing of the Pengkalan Datu breakwaters in the northwest direction had begun within a few years of its completion (Ahmad Khairi Bin Abdul Wahab, 1989). Nevertheless, this was insufficient to reduce the erosion rate at Pantai Sabak.

In 1996, the DID implemented a beach nourishment project which laid 1.2 million m^3 of sand along a 2.1 km stretch within the study area. The constructed beach berms ranged from 70 m to 120 m. Whilst the study and design of the beach nourishment scheme took into account the reduction in sediment budget due to the breakwater, nearly 60% of the nourished volume was lost within a single monsoon (Jabatan Pengairan dan Saliran Malaysia, 2002).

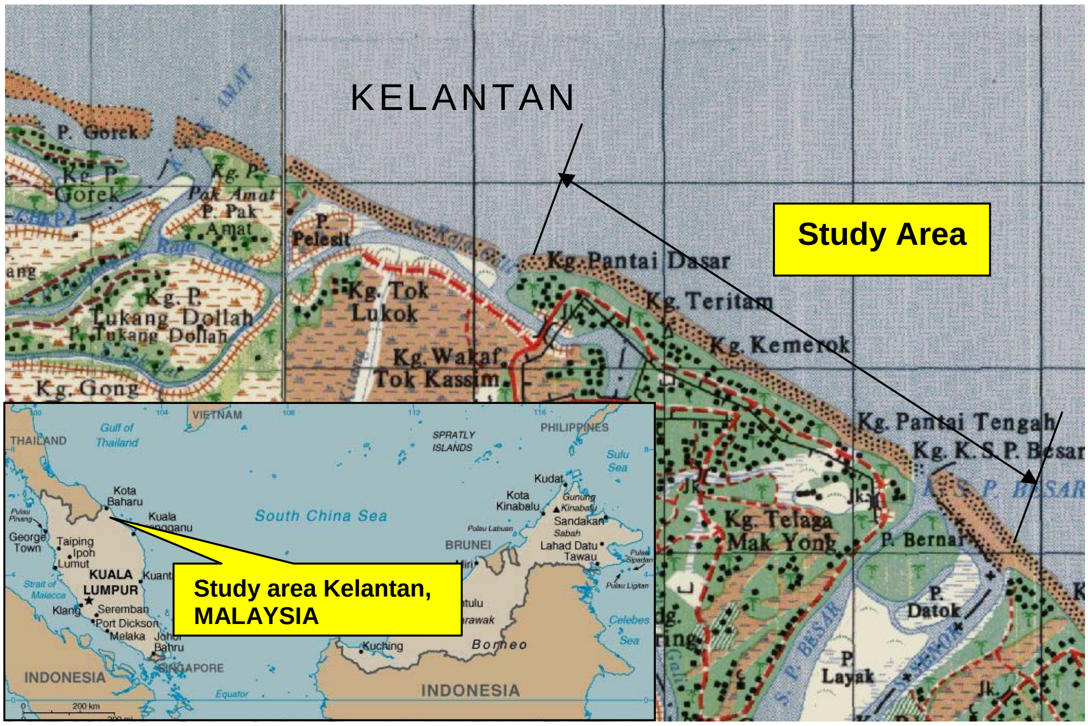

Figure 1.1: Study area - 4.5 km of shoreline from Pantai Dasar Sabak to South of Kg. K.S.P. Besar (Sungai Pengkalan Datu). (*Source: Topo Maps #4068 [1985], #3968 [1991], Jabatan Ukur dan Pemetaan Malaysia*)

1.2.3 Beach Nourishment Design and Depths of Closure

The design of a beach nourishment scheme requires the same engineering parameters as other coastal protection solutions. Apart from the established wave, wind and tidal conditions, the design criteria for a typical DID beach nourishment includes:

- a nourished beach slope as close as possible to the existing beach slope;

- available funds to provide the widest beach berm possible based on a pre-determined re-nourishment interval of 5 years;

- the availability of suitable sand-fill of grain size d_{50} greater than the native beach.

From the Shore Protection Manual (US Army Corps Of Engineers, 1984), the design approach can be summarised as follows: (i) determination of the beach berm elevation and width (ii) determination of nourishment volume based on native and borrow composite material characteristics (iii) determination of post-project beach evolution.

In practice, a pre-erosion shoreline is determined and the berm width is 'overbuilt' beyond the pre-erosion shoreline position based on local erosion rates and the expected interval of re-nourishment. Hence, if the local erosion rate is 5 meters per year and a re-nourishment is planned after every five years, the berm width will be built 25 meters beyond the desired shoreline. Artificial beach fills are created based on a construction cross-section. Over time and due to the action of waves and tides, the fill material forming the nourished profile of a constructed beach will be shaped by natural processes into a profile of generally concave upward shape called an equilibrium profile. This equilibrium profile concept was proposed by Bruun (1954) with further elaboration by Dean (1977) and is illustrated in Figure 1.2. In the application of this concept, it is assumed that there is a conservation of sediment

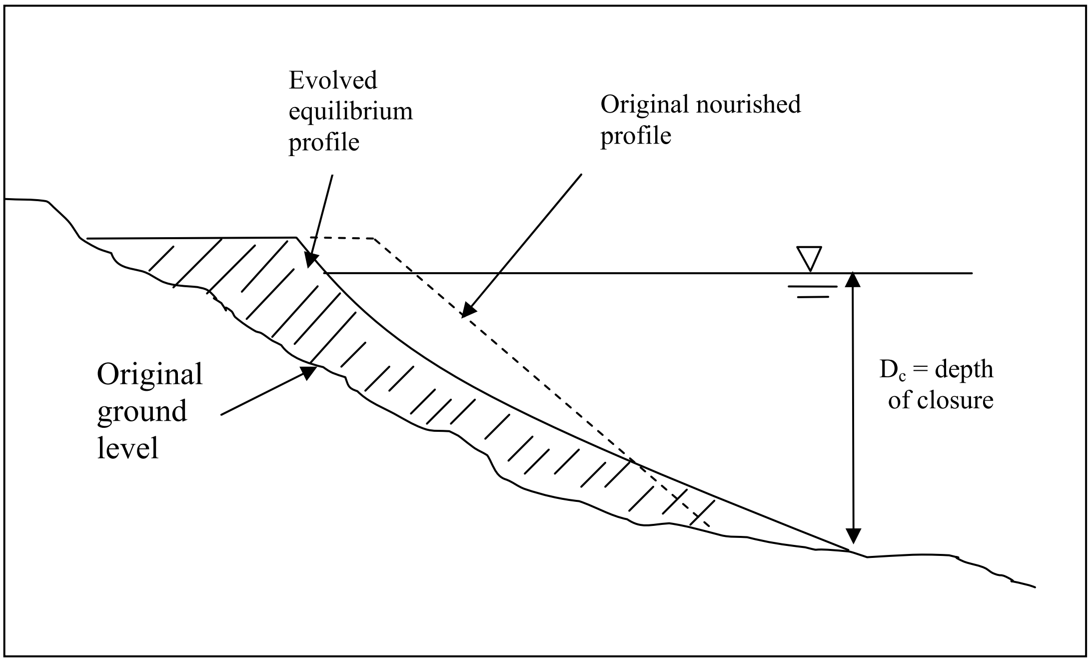

Figure 1.2: Evolution of beach-fill based on Theory of Equilibrium Profile

volume across the profile and that a loss of sand volume from the upper profile of the beach is associated with a similar gain in volume in the lower profile. The seaward limit for the volume exchange process is the depth of closure.

The depth of closure is effectively, the offshore limit of the active zone within which a nourished beach adjusts to equilibrium under the prevailing coastal conditions. Hence, a good estimate of the depth of closure is essential to a good estimate of the beach fill volume required. With respect to post-nourishment beach profiles, National Research Council (1995) refers to the depth of closure as a reference typically used by designers to estimate the limit of profile widening. These statements further confirm the importance of the depth of closure in beach nourishment design.

Beach nourishment schemes have been built in Malaysia since 1992 but their evolution has not been extensively studied. Due to the lack or absence of periodical surveys then, the depth of closure has typically been predicted from empirical equations. With regards to this, a comparative study of the predictive and measured depths of closure, in the writer's opinion, would contribute to the understanding of the performance of beach nourishment schemes. In the Malaysian context, such detailed comparisons have, to date, yet to be done and this dearth of knowledge is the impetus to this research.

1.3 Objectives of the Study

The purpose of this research is to determine the depths of closure of a 4.5 km stretch of sandy coast extending from north of Pantai Dasar Sabak to south of the Sungai Pengkalan Datu in the state of Kelantan. The study will analyse beach profile surveys, determine the depths of closure and to compare them against predicted values calculated from the Hallermeier equation. The research will examine the validity of this widely accepted equation for the Malaysian condition.

1.4 Benefits of the Study

In general, the study is expected to contribute towards an improved understanding of cross-shore sediment transport and shore profile changes in the Malaysian coastal environment. Knowledge of profile trends and depths of closure will facilitate the design of coastal protection works primarily beach nourishment, revetments, groynes and breakwaters. It is envisaged that from the results of this research, engineers will be able to utilise a modified analytical method, specific to the local conditions, to predict depths of closure with greater confidence for areas where historical shore profile data is lacking.