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主旨：有關本部公司行號及有限合夥營業項目代碼「E402010沙石、淤泥海拋業」之英文翻譯「Ballast and Mud Construction on Sea」，似與所謂現有海洋工程所用名詞「Sand Nourishment and Land Reclamation」不符一案，請貴單位於文到20日內，就附件相關內容惠予提供建議憑辦，請查照惠復。



說明：

- 一、依據本部商業司案陳豐欣營造有限公司108年7月31日豐108字第20190731號函辦理。
- 二、依本部公司行號及有限合夥營業項目代碼表所載，營業項目「E402010沙石、淤泥海拋業」係歸屬於「E營造及工程業」中「E4海事工程業」之分類，先予敘明。
- 三、而據前揭公司來函所述，沙石、淤泥海拋業實為執行養灘及造陸工作，其主張本部公司行號及有限合夥營業項目代碼表內「E402010沙石、淤泥海拋業」之英譯「Ballast and Mud Construction on Sea」應修正變更為「Sand

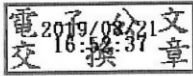




Nourishment and Land Reclamation」。惟以上所述於營造業及海洋(海事)工程相關實務及學術領域是否確實？針對現行營業項目「E402010沙石、淤泥海拋業」是否有修正其定義或英譯名稱之必要？敬請貴單位惠賜卓見，俾利後續。

正本：內政部營建署、行政院公共工程委員會、行政院環境保護署、海洋委員會、臺灣區綜合營造業同業公會、社團法人台灣海洋工程學會、社團法人台灣營造工程協會

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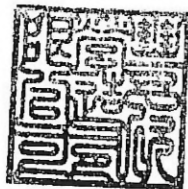
附件：Sand Nourishment paper 三份、Land Reclamation paper 三份

主旨：有關本公司新增加之營業項目，第20項 E402010 沙石、淤泥海拋業貴司之英文翻譯為 Ballast and Mud Construction On Sea 與現有海洋工程所用名詞 Sand Nourishment and Land Reclamation 不符，敬請更正為禱。

說明：

- 一、本公司正開拓海外業務，現正參加馬爾地夫設計案與將來施工標案。
- 二、對營造業而言，沙石、淤泥海拋業實際上就是執行養灘及造陸工作。英文的專有名詞為 Sand Nourishment 及 Land Reclamation，僅提供各三篇 paper 做參考。
- ✓三、現貴司所提供之英文名詞 Ballast and Mud Construction On Sea 與海洋工程專有名詞不符，所以本公司無法投標施工案，敬請貴司能體恤變更為通用英文名詞，以利開拓國際業務。

正本：經濟部商業司





中華民國經濟部
Ministry of Economic Affairs, R.O.C.

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營業項目代碼	E402010
營業項目	沙石、淤泥海拋業
英文營業項目	Ballast and Mud Construction on Sea
與主計處行業對照	3400 產業用機械設備維修及安裝業 4220 公用事業設施工程業 4310 整地、基礎及結構工程業 4390 其他專門營造業
定義內容	沙石、淤泥海拋等業務。

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一種預測直線型沙灘養灘的數學模型

工程師-中華工程師學會，斯里蘭卡 XXXXIII (3) : 1-8 · 2010 年 4 月

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摘要

通過穩定海灘，沙灘養灘是一個可行的海岸保護工程解決方案。然而，對於某些場地，特別是那些侵蝕率高的場地，沙灘養灘可能在技術上或經濟上不可行或不合理。重新養灘的頻率是可用於證明特定海岸線沙灘養灘過程合理性的重要參數之一。數學模型可以有效地用於上述目的。建立了一個數學模型，用於模擬由於沿岸和岸上沉積物運輸引起的海岸線變化，並且可以估算出再養灘的頻率。該模型是典型的“單線模型”的改進版本。該模型已經過校對，並根據 2003 年在斯里蘭卡西海岸從 Maha Oya 到 Lansigama 的沿海地區實施的沙灘養灘項目收集的實地數據進行了校準。模型結果證明該模型能夠以合理的精度模擬海岸線變化。與其他輸入參數相比，沙灘中值粒度和閉合深度對模型預測更敏感。該模型的適用性僅限於沒有結構的直線型海岸線。1.引言海灘侵蝕已成為世界上許多沿海地區的主要問題。隨著海灘變得狹窄和消失，沿海社區及其財產越來越容易受到洪水和風暴潮等沿海災害的影響。它威脅私人財產，公共設施，基礎設施以及對世界各地沿海社區長期生存至關重要的經濟和自然資源。嚴重的侵蝕已經成為沿著斯里蘭卡沿海地帶沿海灘和基礎設施建立的數千個家庭和小規模工業的危險。斯里蘭卡沿海地區是經濟發展的焦點，佔國內生產總值的 40%，工業總產值的 70% 來自沿海地區。超過 80% 的旅遊相關基礎設施位於 Samaranayake 區域 (2007 年)。此外，海洋生態系統也受到侵蝕的威脅。據估計，在斯里蘭卡海岸線 1,562 公里範圍內，大約 500 公里受到中

度到嚴重的海岸侵蝕，特別是在南部，西海岸和西北海岸（CCD，1986）。因此，採取適當措施保護海岸免受侵蝕是很重要的。

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A Mathematical Model to Predict Frequency of Sand Nourishment in Straight Beaches

Article in *Engineer - Journal of the Institution of Engineers, Sri Lanka* · April 2010

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A Mathematical Model to Predict Frequency of Sand Nourishment in Straight Beaches

A.L. Dissanayake and K.P.P. Pathirana

Abstract: Beach nourishment is a viable engineering solution for shore protection by stabilizing beaches. However, beach nourishment may not be technically or economically feasible or justified for some sites, particularly those with high erosion rates. The frequency of re-nourishment is one of the important parameters that could be used to justify beach nourishment process for a given shoreline. Mathematical models could be effectively used for the above purpose. A mathematical model was developed for the simulation of shoreline changes due to both the longshore and cross-shore sediment transport and there by, frequency of re-nourishment could be estimated. This model is an improved version to the typical 'one-line model'. The model has been calibrated and verified against the field data collected from a beach nourishment project implemented in 2003 in a coastal stretch leading from Maha Oya to Lansigama in the west coast of Sri Lanka. The model results proved that the model is capable of simulating shoreline changes with a reasonable accuracy. Median grain size of beach sand and depth of closure are more sensitive to the model predictions compare to other input parameters. The applicability of the model is limited to straight coastlines without the presence of structures.

Keywords: Beach nourishment, sediment transport, beach erosion

1. Introduction

Beach erosion has become a major problem in many coastal regions in the world. As beaches become narrow and disappear, coastal communities and their properties become increasingly vulnerable to coastal hazards such as flooding and storm surges. It has threatened private properties, public facilities, infrastructure, and the economic and natural resources essential to the long-term viability of coastal communities around the world.

Severe erosion has become a hazard to thousands of families and small scale industries established along the beach and infrastructure along the Sri Lanka's coastal belt as well. Sri Lanka's, coastal zone serves as a focal point for economic development as 40% of the Gross Domestic Production with 70% total industrial output is coming from coastal region. More than 80% of the tourism-related infrastructure is located within this zone Samaranayake (2007). Moreover, marine ecosystems are also threatened by erosion. It is estimated that, out of the 1,562 km of Sri Lanka's coastline, approximately 500 km are subject to moderate to severe coastal erosion especially in the South, West and North-Western coasts (CCD, 1986). Therefore, it is important to take appropriate measures to protect coasts from erosion.

A number of engineering approaches are available to counteract the effects of erosion by stabilising beaches. Traditional approach to protect beaches from erosion has included 'hard structures' such as, seawalls, revetments, groins, and detached breakwaters. These structures can reduce wave attack and coastal flooding and thereby stabilise the beaches. However, these protective structures do not allow the natural movement of sediments in shorelines to takes place, causing severe erosion in adjacent beaches.

Beach nourishment is an alternative to shore protection structures that directly addresses the problem of sand budget deficit causing beach erosion as it is a process of adding sand from external sources. This results a wider beach that improves natural protection and provides additional recreational area. The presence of adequate sand reserves on beaches can allow for natural sediment movement to take place without any barriers. However, as a result of varying hydrodynamic condition in the near shore region in different seasons, the net long-term result would be the gradual loss of sand

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from beaches, demanding the re-nourishment process to continue in order to maintain stable beaches. However, the performance of beach nourishment projects can be substantially enhanced by the use of structures when they are appropriately designed and placed at suitable locations, thereby increasing the re-nourishment frequency. As the capital investments involved in these projects the model predictions are highly sensitive to the median size of beach sand compare with the other parameters. The depth of closure is the next parameter to influence models results and hence, these two parameters need to be accurately represented in the model for reliable model predictions. are generally high, it very important that a reliable estimation of sand re-nourishment frequency be known for economic justification of these projects. Mathematical models could be effectively used to compute frequency of sand re-nourishment for a given coastal stretch.

Most of the mathematical models available at present in simulating shoreline changes are based on the effect of longshore sediment transport only ('one-line model') and hence, the predictive capability of these models are limited where cross-shore sediment transport is significant. Few other models, namely, 'N-line models', reported in literature are capable of simulating shoreline changes due to both longshore sediment movement and also cross-shore sediment transport. Detailed description of most of these models can be found in Hanson et al (1999), Dabees et al (2000). These models incorporate many empirical formulae to quantify sediment transport rates based on site specific details and hence, the general applicability of these models is rather limited.

The model presented in this paper is a N-line model developed by incorporating both the longshore and cross-shore sediment movements to simulate shoreline changes with the objective of estimating re-nourishment frequency in beach nourishment projects.

2. Model Development

A basic assumption in one-line model is that the active beach profile moves in parallel to itself within a certain closure depth, beyond which the longshore sediment transport can be ignored and the profile does not change. Applying the sediment continuity equation where the volumes of sand entering and

leaving a particular cell are considered (Figure 1), the change of shoreline position can be computed using the following equation;

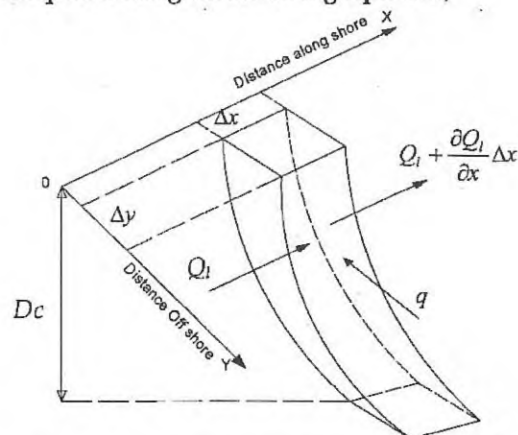


Figure 1 - Sketch of sediment balance

$$dy = \pm \frac{q}{z} - \frac{dQ_l}{z \cdot dx} dt \quad \dots\dots\dots (1)$$

where, Q_l is the volume rate of longshore transport, q is the volume rate of sediments from an external source, t is the time, D_c is the closure water depth. One of the major shortcomings of this model is the omission of cross-shore sediment movement which is an important physical process in certain coastal stretches.

2.2 N-Line Model

By taking into account both the longshore and cross-shore transportation of sediments, one line model can be developed into N-line model. In this model, a three dimensional coordinate system is considered, with z axis placed in the downward direction from mean sea level in addition to x and y axes running along the coastline and offshore directions. Furthermore, each strip of the coastline of width Δx used in the one-line model is divided into several cells with a height of Δz along z axis (Figure 2).

For a cell (i,j) having a width of Δx and height of Δz , incorporating both the cross-shore and longshore sediment transportation, the change in the shoreline position perpendicular to the shoreline is computed using Eq.(2) as follows,

$$dy = [(Q_{l,(i,j)} - Q_{l,(i-1,j-1)}) - (Q_{c,(i-1,j-1)} - Q_{c,(i,j)})] * \frac{dt}{\Delta z \cdot \Delta x} \pm \frac{q}{\Delta z} \quad \dots\dots\dots (2)$$

where, Q_l and Q_c are the volume rates of longshore and cross-shore sediment transport, respectively. New shoreline position after time duration of Δt , $y_{i+\Delta t, j}$, is computed as;

$$y_{t+\Delta t,i} = y_{t,i} + dy \quad \dots\dots\dots (3)$$

where, $y_{t,i}$ - shoreline position at a time step t .
The finite difference form of Eq.(2) was solved using MATLAB software package.

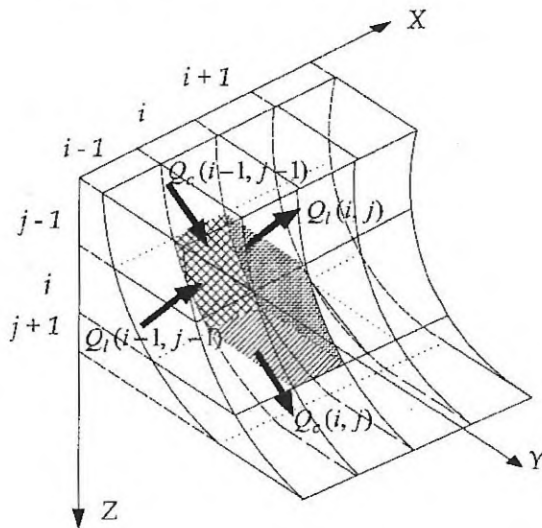


Figure 2 - Sediment entering and leaving a given element in N- Line model

a) Longshore Sediment Transport Rate (Q_l)

For the development of this model the volumetric rate of sediment transportation Q_l was derived from the along-shore sediment transport formula based on "CERC" formula, (Shore Protection Manual, 1984) which is expressed as in the Eq.(4).

$$Q_l = k \frac{\rho g^{\frac{1}{2}} H_b^{\frac{5}{2}}}{16(\rho_s - \rho) a \gamma_b^{0.5}} \sin(2\alpha_b) \quad \dots\dots\dots (4)$$

where, ρ_s and ρ are density of sediments and density of water, respectively and a is a correction factor for pore space of beach sand, approximately 0.6 for most beach deposits, α_b is the angle between breaking wave crests and shoreline, H_b is wave height at breaking, γ_b is breaker depth index which is taken as 0.78, according to Komar (1976) neglecting beach slope and k is a coefficient.

b) Cross-Shore Sediment Transport Rate (Q_c)

Cross-shore sediment transport rate at different depths of the shore profile is the calculated according to Hanson et al (1999) as;

$$Q_c = \xi \zeta q_0 \quad \dots\dots\dots (5)$$

where, q_0 - potential cross shore transport rate per unit length of the alongshore, ξ - Slope function and ζ - Vertical distribution function which are described below.

Potential Cross-Shore Sediment Transport Rate (q_0):

This is calculated according to the Eq.(6), which is based on the assumption that bed is horizontal and unlimited availability of sand.

$$q_0 = K_t w \left[\frac{H_b^3}{d_{50}} \right]^{0.5} \quad \dots\dots\dots (6)$$

where, K_t - calibration parameter, d_{50} - median grain size and w - sediment fall speed which is computed as follows;

$$w = \frac{1}{18} (\gamma_s - 1) g \frac{d_{50}^2}{\nu}; \text{ for } d_{50} < 0.0001$$

$$w = \frac{10\nu}{d_{50}} \left\{ 1 + \left(\frac{0.01(\gamma_s - 1) g d_{50}^3}{\nu^2} \right)^{0.5} - 1 \right\};$$

for $0.0001 < d_{50} < 0.001$

$$w = 1.1 \{ (\gamma_s - 1) g d_{50} \}^{0.5}; \text{ for } d_{50} > 0.001 \quad \dots\dots (7)$$

where, γ_s - specific weight of sediments and ν - Kinematic viscosity of water.

Slope Function, ξ :

The slope function in the Eq.(5) is expressed according to Alkyon (1998) as follows;

$$\xi = - \left[\frac{S}{S_e} - 1 \right] \left| \frac{S}{S_e} - 1 \right| \quad \dots\dots\dots (8)$$

where, S and S_e are the actual local inverted bed slope and the local inverted equilibrium slope respectively. In this equation if $S < S_e$, an offshore sediment transportation is obtained.

Equilibrium Slope, S_e

The concept of equilibrium beach profile (EBP) has been used as a basis for assessing a characteristics shape to a beach. According to the definition of EBP given by Larson et al (1999), it is a profile shape that displays no net change in time, although sediment will be in motion. Using the EBP deduced by Bruun (1954) and Dean (1977), the average profile shape for a wide variety of beaches can in general be represented by,

$$h = Ay^{\frac{2}{3}} \dots\dots\dots (9)$$

where, h - water depth, A - empirical scale parameter and y - horizontal distance from the shoreline. The scale parameter ' A ' is calculated according to Moore (1982) which is reported to be dependent on median size of beach sand.

Vertical Distribution Function, ζ

The distribution of cross-shore transport rate across a given profile is expressed by the vertical distribution function included in the Eq.(5). Hanson et al (1999) expresses the vertical distribution function as follows;

$$\begin{aligned} \zeta &= 0.5 \cos\left(\frac{2\pi h}{h^*}\right), \quad h \leq 0.75h^* \\ \zeta &= 0.5e^{-4\left(\frac{h}{h^*}-0.75\right)}, \quad h > 0.75h^* \end{aligned} \dots\dots\dots (10)$$

where, $h^* = 2.28h$ and h^* - Instantaneous depth of closure and h - local water depth.

3. Data Collection

3.1 Study Area

In order to calibrate and verify the proposed model, necessary data were collected from a beach nourishment project carried out in the west coast of Sri Lanka in 2003 which was initiated by the Coast Conservation Department (CCD) with the financial support from the Asian Development Bank. As a part of the coastline stabilization component of this major project, approximately 14 km long coastal stretch, from Maha Oya to Lansigama which is located between Negombo and Chilaw was nourished using offshore sand (Figure 3).

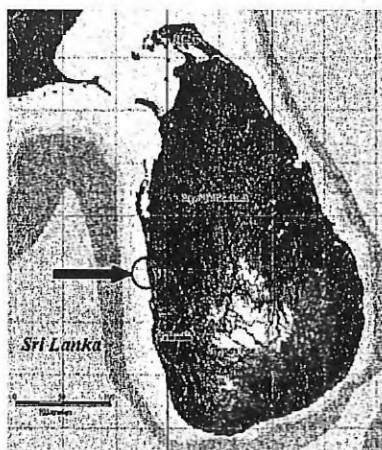


Figure 3 - Location of the Study Area

Under the aforesaid coast stabilization scheme, a series of groynes, detached breakwaters and revetments were also constructed in this coastal stretch in addition to about 2 million cubic meters of sand pumped from offshore creating a new beach of width varying approximately 40 to 50 m. The field data gathered in carrying out the beach nourishment project was collected for the present study.

3.2 Data Collection

Out of 14 km long coastline, first 12 km stretch closer to Maha Oya in the southern end of the study area was incorporated with the coastal structures whereas, for the remaining 2 km long shoreline to the north near Lansigama, only the sand nourishment was done without any structures. As the proposed mathematical model is able to simulate shoreline changes in fairly straight beaches without any structures, 2km long shoreline in the north of the area was selected for the present study.

The shore profiles of the selected coastal stretch were extracted from the data gathered for Coastal Resources Management Project [CRMP, 2007]. The repeated measurements of shore profiles were taken before and after the sand nourishment process in 2003 and also 3 years after the project, in 2006. The interval between the beach profiles is 50 m and these profiles extend to a depth of 6 m below mean sea level.

The representative wave statistics for the study area during Southwest and Northeast monsoons which were derived based on the pre-established wave statistics in Chilaw and Colombo. The coastal sediments in this area are mainly of quartz sand and the median grain sizes were obtained from the dredging and reclamation records of the project. The median grain sizes of sand vary between 0.5 mm and 1.6 mm.

4. Model Calibration and Verification

4.1 Model Calibration

The 2 km long coastal stretch selected for model application was divided into 42 strips having a width (Δx) of 50 m and each strip was further divided into 10 cells with equal heights ($\Delta z = 0.5$ m), up to water depth of 5 m from the mean sea level. It has been observed from the shore profiles collected in 2003 and 2006 that no significant changes were shown in these profiles beyond the 5 m water depth below

mean sea level, and hence, the depth of closure in the model was taken as 5 m.

Since only one set of field data was available for the present study to carry out both model calibration and verification, it was decided to use first 21 strips for model calibration while the remaining strips for model verification. It would have been much better if completely independent data set were available for model verification but failing which, the above approach was the only option available for us to carry out the present task. The coordinates of the coastal stretch used for model calibration are ranging from 94997.5 E, 242100.98 N to 95192.6 E, 241122.1 N.

Deep water wave climates during Southwest and Northeast monsoon seasons were transformed to the nearshore region just outside the wave breaker zone. The wave heights and approach angles at breaking were computed using a simple wave breaking criteria. The beach profiles measured in 2003 after sand nourishment and in 2006 were used for model calibration. The parameter K_I in Eq.(6) was used as the calibration parameter. Taking the shoreline position measured in 2003 as the initial shoreline, model simulations were performed to predict the shoreline position in 2006 such that the difference between the predicted and measured shoreline positions in 2006 was minimum. Figure 4 shows a comparison between the simulated and actual positions of the shoreline in 2006 during the calibration of the model. The percentage error between the actual and predicted shoreline positions varies between 12% and 31%.

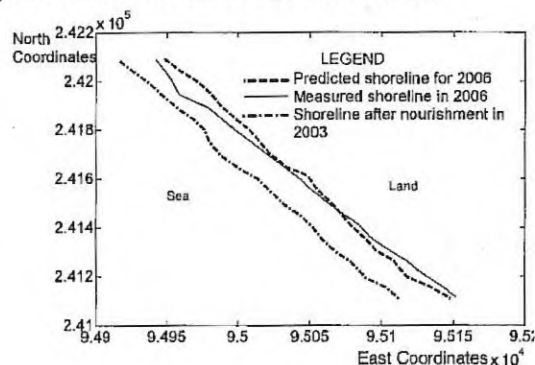


Figure 4 - Comparison between the simulated and measured shoreline positions in 2006 obtained during model calibration.

4.2 Model Verification

As mentioned in the previous section, the model was verified using the shoreline stretch with another 21 strips which was not used for

model calibration and the coordinates of the coastal stretch used for model verification are ranging from 95202.4 E, 241073.1 N to 95388.2 E, 240141.4 N. A comparison of the predicted and measured shoreline positions in 2006 is shown in Figure 5. It appears that the model predictions are quite reasonable. The percentage error between the measured and predicted shoreline positions obtained during model verification varies between 8% and 24%.

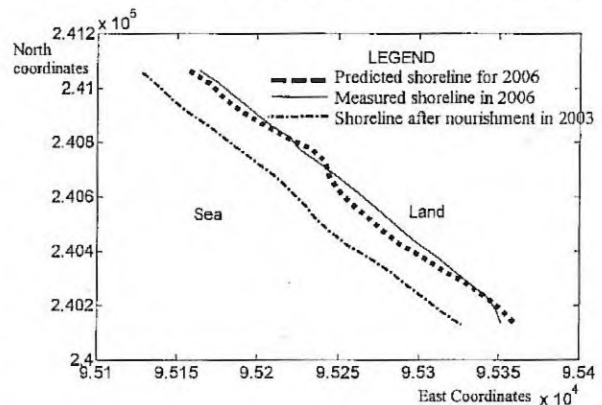


Figure 5 - Comparison between the simulated and measured shoreline positions in 2006 obtained during model verification.

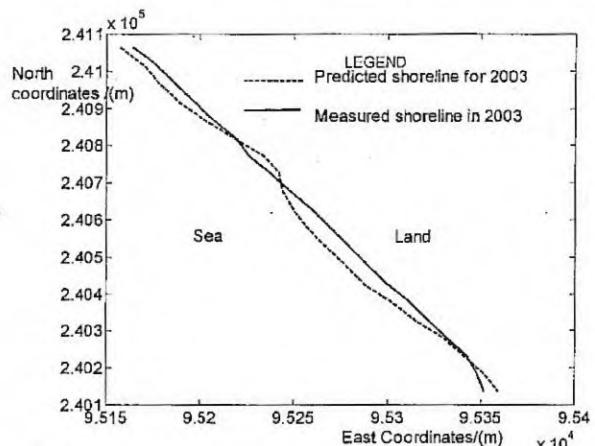


Figure 6 - Comparison of the measured shoreline position before sand nourishment in 2003 with the predicted shoreline after 4 years.

4.3 Frequency of Beach Nourishment

The proposed model was then applied to the same area to estimate the frequency of sand nourishment. This was done by using the shoreline position in 2003 after the sand nourishment as the initial profile and model simulations were carried out until the simulated shoreline was reasonably compares with the measured shoreline position in 2003 prior to sand nourishment. The frequency of sand nourishment predicted by the model was approximately 4 years. This duration appears to be reasonable with the value obtained from

independent studies reported for the same coastal stretch. The comparison between the simulated and measured shoreline positions are shown in Figure 6.

Sensitivity analysis was also carried out for different model parameters and it shows that the model predictions are highly sensitive to the median size of beach sand compare with the other parameters. The depth of closure is the next parameter to influence models results and hence, these two parameters need to be accurately represented in the model for reliable model predictions.

5. Summary and Conclusions

A mathematical model was developed for the simulation of shoreline changes due to both the longshore and cross-shore sediment transport. This is an improved version of the conventional 'one-line model' which incorporates only the longshore sediment movement. In the proposed model, the shoreline is divided into a number of strips and each strip is again spilt into several cells in the vertical direction. Applying the sediment continuity equation to each cell where the volumes of sand entering and leaving a cell in longshore and cross-shore directions are considered, the change in shoreline position perpendicular to the coast is computed. This model can be used to estimate the frequency of re-nourishment in beach fill projects.

The model has been calibrated and verified against the field data collected from a beach nourishment project implemented in 2003 in a coastal stretch leading from Maha Oya to Lansigama in the west coast of Sri Lanka. The beach profiles measured at every 50 m interval, in the year 2003 before and after sand nourishment and again in 2006 were used for model calibration and verification. Deep water wave climates during the Southwest and Northeast monsoon seasons were transformed to the wave breaker zone and the resulting wave parameters were given to the model as input parameters. The model results appear to be more realistic indicating that the model is capable of simulating shoreline changes with a reasonable accuracy.

According to the model simulations, the frequency of re-nourishment of the selected coastal stretch was obtained as 4 years, which is found to be comparable with the values obtained from other studies carried out for the

same beach. Sensitivity analysis carried out on the model parameters indicates that the median grain size of beach sand and depth of closure are more sensitive to the model predictions compare to other input parameters.

The applicability of the model is limited to straight coastlines without the presence of structures. The model could be further improved to make it applicable over shorelines with different configurations and also to include the coastal structures.

Acknowledgments

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黃金海岸沙灘養灘方法的實施和演變歷史

隨著休閒海灘變得越來越有價值和受到威脅的資源，沙灘養灘對於管理全球海灘將變得越來越重要。沙灘養灘是黃金海岸海灘管理的基本要素，單價與國際費率比都具有競爭力，因此當地疏浚業的發展已經開發出創新的疏浚技術和專業知識。沙灘養灘，從小規模到大規模，使用不同的來源和方法在黃金海岸進行，從 1970 年代早期開始將近 40 年，並涉及許多以前未經驗證的方法，如近岸剖面養灘，已經證實並已經從理論到常規。近岸養灘特別重要，因為它允許從海灘離岸的大量沙子以比河口或其他保護區低得多的成本得到利用。黃金海岸現在使用許多沙源來進行沙灘養灘，包括陸地/建築工地，河流/河口，沙子繞道系統，沙灘養灘通常與結構相結合，例如在防波堤和 Narrowneck Reef 上，以最大限度地提高效率。到目前為止，已經實施了約 49Mm³ 的沙子養灘，本文件記錄了這一歷史和經驗教訓，以便將來在黃金海岸和其他地區應用。迄今為止的主要發現和經驗教訓包括：黃金海岸海灘依賴於持續的海灘養灘，迄今為止約有 49Mm³。正在考慮提高養灘的長期效率和減少珊瑚礁等產量的替代策略和結構。當地疏浚業在黃金海岸實施沙灘養灘的發展帶來了豐富的經驗和專業知識。疏浚和沈澱方法已經有相當經驗。這導致了具有競爭性的疏浚率，並允許開發最佳實踐的創新。通過準確的定期調查監測海灘和養灘狀況的做法，特別是在暴風雨之後，提供了寶貴的長期數據和海灘的知識。這些數據已被用於確定養灘安置的最佳方法，並開發沙子繞道系統和替代策略，如珊瑚礁。該數據還被用於精確校準和驗證各種數值模型。海上和近岸沉澱的疏浚已被證明是一種有效的沙灘養灘方法。沿海地區充足的沙地儲備對於正在進行的養灘工作至關重要，需要採取政策保護這些資源，以便今後養灘和黃金海岸海灘的長期健全，因為沙土材料競爭用於其他目的，包括土地複墾，填埋，棲息地增強，景觀美化，建築材料和其他目的。兩個沙子旁通系統在維護黃金海岸海灘方面非常有效。

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A History of the Implementation and Evolution of Sand Nourishment Methods on the Gold Coast, Australia

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Abstract

Nourishment will become increasingly important to manage beaches worldwide as recreational beaches become an increasingly more valuable and threatened resource. Nourishment is an essential element of the management of the Gold Coast beaches and unit rates / m³ are competitive with international rates due to the growth of a local dredging industry that has developed innovative dredging techniques and expertise.

Beach nourishment, from small to large scale using different sources and methods carried out on the Gold Coast, spans almost 40 years from the early 1970's and has involved many previously untried methodologies, such as nearshore profile nourishment, that have been proven and have evolved from theoretical to routine. Nearshore nourishment has been particularly important as it allows the huge reserves of sand offshore from the beaches to be utilised at a much lower cost than estuarine or other reserves.

The Gold Coast uses a number of sand sources for beach nourishment including terrestrial / building sites, river / estuarine, sand bypassing, sand bypassing and offshore. Sand nourishment is often combined with structures, such as the Narrowneck Reef to maximise efficiency. To date about 49Mm³ of sand nourishment has been implemented and this paper documents this history and lessons learned for application on the Gold Coast and other areas in the future.

Keywords: nourishment, scarp, nearshore, profile, dredging

1. Introduction

Development upon the historic sand dune areas on the Gold Coast has resulted in the construction of seawalls to protect beachfront buildings during severe erosion. The seawalls act to constrain the natural behaviour of beaches during climate variability and major storms. With climate change and projected sea level rise, vulnerable beaches will be increasingly threatened. Nourishment is a key method to protect and improve beaches, either alone or in conjunction with structures such as groynes, emerged breakwaters and reef breakwaters.

Many beaches worldwide, and the associated economic benefits and infrastructure, will be lost due to lack of funding or lack of positive action. The beaches that are well managed and can be protected will have increased economic value.

For almost 40 years, large scale nourishment using a number of methods and sources has been an essential element of the management of the Gold Coast beaches and unit rates / m³ are competitive with international rates due to the implementation of innovative dredging techniques and the long term expertise gained.

The authors collectively span the 40 years of nourishment and have been actively involved. This paper documents the history and practical

lessons learned for future application on the Gold Coast and other areas.

To date, almost 50Mm³ of sand from various sand sources has been placed along the Gold Coast ocean beaches from mobile dredgers and from the 2 fixed bypass pumps.

This paper summarises the operations of mobile dredgers providing nourishment for Ocean Beaches. This paper does not include details for

- Other dredging and nourishment carried out in canals and waterways of the Gold Coast.
- The 2 fixed sand bypass pumping operations at the Gold Coast Seaway and the Tweed River Entrance.

Mobile dredger types used have included:

- Suction and cutter suction (CSD) dredgers pumping through pipelines (and boosters as required) onto the beach
- Trailing suction hopper dredgers (TSHD); bottom dump, rainbowing and pumping through pipelines ashore

2. Brief History

A history and timeline of all significant Gold Coast coastal works was published in 2001 [2]. This paper will extend the beach nourishment history up

to 2013 and provide lessons and recommendations based on this history.

1950s and 60s; As a result of severe erosion associated with greater than average incidence of cyclones and severe storms, the Gold Coast beaches were in poor condition. The challenge to restore the Gold Coast beaches was a learning experience for the newly formed Qld Beach Protection Authority and the Gold Coast City Council (GCCC) Engineers and surveyors. GCCC hired its first designated Coastal Engineer, Sam Smith, to carry out beach protection works. In December 1970 the DHL report, known as 'The Delft Report', was finalised. This report provided the basis for the coastal protection works and has guided Gold Coast beach management since then. Some of the detailed work for this report was completed by the then Qld COG Chief Engineer, Brian McGrath who was embedded with Delft University in the Netherlands to provide local knowledge and facilitate coastal engineering knowledge transfer back to Queensland.

1970s; In 1974, the first nourishment on the Gold Coast was implemented using medium and large cutter suction dredgers pumping through pipes from the sheltered Nerang, Currumbin and Tweed estuaries. This was the first major beach nourishments in Australia and many practical operational problems were solved by the Council Engineers and hydrographic surveyors working on tight budgets and with only 25% State funding.

The Surfers Paradise dredging was done with a large cutter suction dredger by Westham Dredging, but the other projects were implemented by the local dredge contractors with medium sized cutter suction dredgers. These contractors had created the canal estates and these contractors were quick to adapt to ocean beach nourishment. The sand was pumped to the upper beach and out as far as practical into the surf zone. Placement in this area required beach visitors to be kept clear as it created hazardous quicksand conditions at the outlet and required heavy equipment on the beach. Also, the public and media were very quick to claim the expensive sand had been lost after the first storms cut scarps into the nourished beach redistributing it over the active profile. This did not help in the funding of ongoing works to implement the Delft recommendations.

In the 1970's about 3Mm³ of sand was pumped onto the ocean beaches from estuaries using cutter suction dredgers.

1980s; Works continued on the erosion hotspots with the severe erosion at North Kirra addressed in 1985. The north Kirra beach restoration used the first sand pumped from the offshore sand reserves that was pumped ashore using a large Belgium

TSHD. Conventional practice worldwide was for sand dredged from offshore to be pumped ashore or rainbowed into the surf zone. Both methods are expensive and to avoid costs and the perception of upper beach sand being "lost" it was decided to do a small trial with sand placed nearshore into 6-9m water depth as part of the Nth Kirra Beach Restoration Project [3]. Although such nearshore nourishment had not been used successfully anywhere else at the time, it was considered low risk if placed shoreward of about 9m water depth as artificial storm bars as detailed surveys showed that the large natural storm bars in this depth moved onshore over a period of about 18 months [6]. Surveys confirmed the shoreward movement and accretion of the visible beach inshore of the nourishment. Dyed sand samples were also used to track the sand movement. As a result of the success and significant cost savings, further large scale offshore dredging, deposited nearshore was carried out.

The Gold Coast seaway was constructed by the Gold Coast Waterways Authority and sand bypassing operations commenced in 1985/86, pumping sand via pipeline under the new entrance and depositing on the beach on the southern end of South Stradbroke Island. This has created a good navigation channel through the new entrance and a new surf location at the discharge.

Dredging of the Tweed R ebb tide delta was commenced in the late 80s as Stage 1 of the Tweed River Entrance Sand Bypassing Project (TRESBP), a joint NSW / Qld / GCCC funded project.

The 1980s saw the first use of offshore sand reserves for both onshore and nearshore nourishment using TSHD. Also the start of sand bypassing of the Nerang and Tweed River entrances. The introduction of policies to ensure that all sand excavated within 500m of the seawall line proved highly successful in providing sand to the dunal areas.

1990s; In this period annual maintenance "bypassing" dredging works from Currumbin and Tallebudgera estuaries continued pumping onto Palm Beach and Burleigh Beaches respectively with medium sized cutter suction dredgers.

The Nerang River entrance sand bypassing continued. Further dredging from the external delta of the Tweed River entrance was carried out by TSHD. These included the first Gold Coast owned shallow draft TSHDs. In December 1999, the NSW and Queensland State Governments awarded contracts to a consortium led by McConnell Dowell Constructors (Aust.) Pty Ltd for the development and operation of a permanent fixed sand bypassing system for the Tweed River entrance.

In 1999, 26 years after the original nourishment of the northern beaches, 1.1M m³ of sand was pumped from the Broadwater onto the Northern Gold Coast beaches by a local CSD. The dredging widened the eroded beaches and created wider navigation channels required by the increased boating activity resulting from the training and bypassing of the Nerang River entrance. This dredging was a joint Qld Transport Dept. / GCCC project using a local medium sized cutter suction dredger pumping up to about 5km using boosters depositing onto the beaches. The cost of this was about \$6/m³ compared to about \$1/m³ in 1974. A further 100,000m³ was provided at no direct cost from building excavations. This nourishment work was in conjunction with the Narrownneck reef construction using a local split hull TSHD that filled mega sandbags from offshore sand reserves and placed them nearshore. The availability of a local shallow draft split hull TSHD resulted in very low unit rates for the reef (approx. \$40/m³ [5])

2000 to 2013; The Nerang River entrance sand bypassing continued and the Tweed River bypassing operations using the fixed pumping system was commenced. As well as ongoing routine maintenance "bypass" dredging of Currumbin and Tallebudgera Creeks, an additional 370,000m³ of sand was dredged from offshore and placed nearshore at Palm Beach in about 6m water depth by a local shallow draft TSHD. As these small TSHD have low mobilisation and can deposit nearshore in the surf zone water by bottom dumping they are more cost effective for quantities up to about 250,000 – 400,000m³ than larger TSHD with high mobilisation costs and that need to rainbow or pump ashore.

To combat recent erosion of Surfers Paradise beaches sand from estuary channel dredging works was placed nearshore by small TSHD and onshore from trucks transporting sand from stockpiles filled by medium sized CSD. Present investigations are considering innovative strategies such as reefs to reduce the long term nourishment volumes.

1990 to 2013 saw further major nourishment works from fixed bypassing pumps, CSD, TSHD and trucks.

3. Sand Sources

A number of sand sources are used. Sand characteristics and grain size are generally similar and compatible. As well as estuaries and offshore, excess clean sand from building sites is also placed on the dune area. Prior to 1985 this only applied to buildings along the beachfront. In 1985 the policy was rewritten to include all excavation of clean sand from within 500m of the seawall line. This has provided about another 1.8 - 2Mm³ to the

dunal areas. This sand helped create wide dunes over previously exposed boulder walls and to buffer recent erosion.

After the dredging of the channels in the Nerang River estuary, the Broadwater, for the Northern Gold Coast Beach Protection Strategy, a policy was adopted that dredging of sand from navigation channels in estuaries should be used for beach nourishment. This has secured another good source of sand for nourishment only.

The offshore dredge areas along the whole developed coastal strip have been designated and preserved for beach nourishment only.

Volumes from the various sand sources are summarised in Table 1.

4. Placement locations

3 deposition options have been used:

- Onshore / Beach
- Nearshore
- Combination; profile

The early works were all onshore and this has developed with offshore dredging to a combination of placement locations preferred. All have different impacts, efficiencies and cost implications.

5. Lessons and Findings

Key findings and lessons include:

- The Gold Coast beaches have been dependent on ongoing beach nourishment with about 49Mm³ to date. Alternate strategies and structures to increase the long term efficiency of nourishments, such as reefs, are being considered.
- Considerable experience and expertise has been developed by the growth of the local dredging industry implementing beach nourishment on the Gold Coast. The dredging and deposition methodologies have expanded with experience. This has resulted in competitive dredging rates and allowed innovations in best practice to be developed.
- The practice of monitoring the behaviour of the beaches and nourishments with accurate regular surveys, particularly after storms, has provided invaluable long term data and knowledge of the behaviour of the beaches [3]. This data has been used to determine the best methods of nourishment placement and to develop sand bypassing systems and alternate strategies such as reefs. The data has also been used to accurately calibrate and validate various numerical models.
- Dredging from offshore and nearshore deposition has proven to be an efficient method of beach nourishment.

- Adequate sand reserves in the coastal zone are vital to ongoing nourishment works and policies are needed to protect these resources for future nourishment and the long term health of Gold Coast beaches as there is competition for sand materials for usage for other purposes including land reclamation, land fill, habitat enhancement, landscaping, building materials and other purposes.
- The 2 sand bypassing systems have been very effective in maintaining the Gold Coast beaches [1].

Table 1 Sand to Gold Coast beaches by Source

Sand Source	Approx. Volumes 1974 to Jun 20013 Mm3	
Estuaries	6.7	14%
Offshore [excluding Tweed & Nerang R entrances]	6.4	13%
Building sites	2	4%
Sand bypass systems		
Tweed R entrance (NSW) ¹		
Offshore by dredgers	5.1	10%
From fixed pumps on jetty	7	14%
Nerang R Seaway ²		
Inshore by dredgers (new channel construction)	4.5	9%
Offshore by dredgers (backpassing)	minor	
From fixed pumps on jetty	17.1	35%
TOTAL	48.8	100%

¹http://www.tweedsandbypass.nsw.gov.au/sand_delivery

²http://www.transport.qld.gov.au/Home/Projects_and_initiatives/Projects/Gold_coast_dredging_initiatives/

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Table 2. Sand Nourishment Projects to 2012 (excluding sand bypassing systems)

Year	Location		Source		Qty	method
	B = beach N = nearshore		E= estuary O = offshore BS = building sites		m3	CSD = cutter suction TSHD = Trailing suction hopper dredge
1973/74	Palm Beach	B	Currumbin Estuary	E	250,000	CSD
1974/75	Surfers Paradise / Narrowneck / Main Beach	B	Nerang Broadwater	R E	1,400,000	CSD
	Kirra Beach	B	Tweed R estuary	E	1,000,000	CSD
1975/76	Currumbin Spit	B	Currumbin Estuary		150,000	CSD
1976	Southport Spit	B	Nerang Broadwater	R E	90,000	CSD
	Palm Beach	B	Currumbin Estuary	E	100,000	CSD
	Burleigh beach	B	Tallebudgera Crk estuary	E	80,000	CSD
1978 - 81	Burleigh beach	B	Tallebudgera Crk estuary	E	100,000	CSD
	Palm Beach	B	Currumbin Estuary	E	300,000	CSD
1981	Palm Beach	B	Currumbin Estuary	E	325,000	CSD
1985	Nth Kirra Beach	N	Offshore	O	100,000	TSHD
	Nth Kirra Beach	B	Offshore	O	215,000	TSHD
	Palm Beach	N	Offshore	O	100000	TSHD
	Burleigh Beach	N	Offshore	O	183000	TSHD
	Burleigh Beach	B	Offshore	O	200,000	TSHD
	Surfers Paradise	N	Offshore	O	142000	TSHD
	Narrowneck	B	Nerang Broadwater	R E	300,000	CSD
	Palm Beach	B	Currumbin Estuary	E	90,000	CSD
1988	Kirra - Bilinga	B	Offshore	O	1,500,000	TSHD
	Burleigh beach	B	Tallebudgera Crk estuary	E	100,000	CSD
1989	Kirra	N	Tweed R entrance	O	395,000	TSHD
	Kirra	B	Tweed R entrance	O	3,200,000	TSHD
1990	Burleigh beach	B	Tallebudgera Crk estuary	E	65,000	CSD
1991	Burleigh beach	B	Tallebudgera Crk estuary	E	56,400	CSD
1992	Burleigh beach	B	Tallebudgera Crk estuary	E	53,000	CSD
1994	Burleigh beach	B	Tallebudgera Crk estuary	E	60,500	CSD
1995	Burleigh beach	B	Tallebudgera Crk estuary	E	63,000	CSD
1996	Burleigh beach	B	Tallebudgera Crk estuary	E	63,000	CSD
1997	Palm Beach	B	Currumbin Estuary	E	50,000	CSD
	Burleigh beach	B	Tallebudgera Crk estuary	E	70,000	CSD
1998	Burleigh beach	B	Tallebudgera Crk estuary	E	50,000	CSD
	Palm Beach	B	Currumbin Estuary	E	40,000	CSD
1999	Burleigh beach	B	Tallebudgera Crk	E	92,000	CSD

			estuary			
1999 / 2000	Surfers Paradise / Narrowneck / Main Beach	B	Nerang R Broadwater	E	1,100,000	CSD
2000	Burleigh beach	B	Tallebudgera Crk estuary	E	44,000	CSD
2001	Burleigh beach	B	Tallebudgera Crk estuary	E	40,800	CSD
	Palm Beach	B	Currumbin Estuary	E	30,000	CSD
2002	Burleigh beach	B	Tallebudgera Crk estuary	E	38,000	CSD
2003	Burleigh beach	B	Tallebudgera Crk estuary	E	26,000	CSD
2004	Burleigh beach	B	Tallebudgera Crk estuary	E	16,000	CSD
	Palm Beach	N	Offshore	O	145,000	TSHD
	Palm Beach	B	Currumbin Estuary	E	30,000	CSD
2005	Burleigh beach	B	Tallebudgera Crk estuary	E	22,000	CSD
	Palm Beach	B	Currumbin Estuary	E	30,000	CSD
	Palm Beach	N	Offshore	O	124,000	TSHD
2006	Burleigh beach	B	Tallebudgera Crk estuary	E	29,000	CSD
	Palm Beach	B	Currumbin Estuary	E	37,000	CSD
	Palm Beach	N	Offshore	O	101,000	TSHD
2007	Burleigh beach	B	Tallebudgera Crk estuary	E	19,000	CSD
	Palm Beach	B	Currumbin Estuary	E	42,000	CSD
2008	Burleigh beach	B	Tallebudgera Crk estuary	E	31,000	CSD
2009	Burleigh beach	B	Tallebudgera Crk estuary	E	46,000	CSD
	Palm Beach	B	Currumbin Estuary	E	58,000	CSD
2010	Burleigh beach	B	Tallebudgera Crk estuary	E	28,000	CSD
	Palm Beach	B	Currumbin Estuary	E	60,000	CSD
2011	Burleigh beach	B	Tallebudgera Crk estuary	E	44,000	CSD
	Palm Beach	B	Currumbin Estuary	E	56,000	CSD
2012	Surfers Paradise	N	Nerang R estuary	E	127,000	TSHD
	Palm Beach	B	Currumbin Estuary	E	35,000	CSD
					13,091,700	
1970 - 2013	From building sites	B		BS	2,000,000	-
					15,091,700	

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沙灘養灘之剖面平衡方式：沙子放置後會發生什麼

5 位作者，包括：Kenneth Willson, Gordon Thomson, Tiffany Roberts Briggs, Nicole Elko, and Jon Miller

出自 *ASBPA Science & Technology Committee 期刊*

March 2017

沙灘養灘是一種沙灘受長期侵蝕的解決方案，可以提供棲息地並且減少對沿海地區被暴潮破壞之社區。在沙灘養灘期間項目，大量的沙子（與與原生沙子相似的屬性）從高地，離岸，海灘，或附近的入口來源運至一個已經設計好之高程或恢復被侵蝕之沙灘。在建造海灘期間養灘工程，沙子被通過疏浚方式或卡車運輸來擴大海灘。然後使用推土機將砂子分級為預定的施工模板。養灘項目的設計和建造利用自然力量如波浪和水流，移動沙子到近海。這個過程很自然沿海地區的傾斜海灘，和被稱為剖面平衡（或簡稱調整）剖面平衡過程，通常在發生沙子放置後 12 個月內，大大減少寬度。從非常寬闊的海灘乾燥的海灘，在養灘後觀察到海灘寬度立即減少（經過剖面平衡），經常被誤解一種失敗的沙灘養灘工程，因為他們看到“所有的沙子都被沖走了。”

本篇是介紹沙灘的剖面平衡過程，以非技術方式讓沿海社區知道，並增加公眾理解沙灘養灘如何運作。

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Beach nourishment profile equilibration: What to expect after sand is placed on a beach

By

Kenneth Willson, Gordon Thomson, Tiffany Roberts Briggs, Nicole Elko, and Jon Miller

ASBPA Science & Technology Committee
March 2017

Beach nourishment is a commonly implemented solution to mitigate long-term erosion, provide habitat, and reduce storm-damage to coastal communities. During a beach nourishment project, large volumes of sand (with similar properties as the native sand) are added to the beach from upland, offshore, or nearby inlet sources to establish a designed level of protection and/or restore sand that has eroded.

During the construction of a beach nourishment project, sand is brought to the beach by dredges or truck hauling to widen the beach. Bulldozers are then used to grade the sand into a pre-determined construction template. Nourishment projects are designed and constructed to take advantage of the natural forces, such as waves and currents, to move sand offshore. This process results in a natural sloping beach within the littoral zone, and is referred to as **profile equilibration** (or profile adjustment).

The process of profile equilibration, which typically occurs within 12 months following sand placement (depending on storms), dramatically decreases the width of dry beach from the very wide beach observed immediately after nourishment. This decrease in beach width (profile equilibration) is often misunderstood by some of the public as the failure of the beach nourishment project because they perceive "all the sand washed away." The objective of this paper is to explain the process of profile equilibration in a non-technical way to inform coastal communities and increase public understanding of how beach nourishment works.

BEACH BASICS

One of the first steps in understanding how beach nourishment works is to define "the beach profile." For purposes of this discussion, the **beach** (Figure 1)

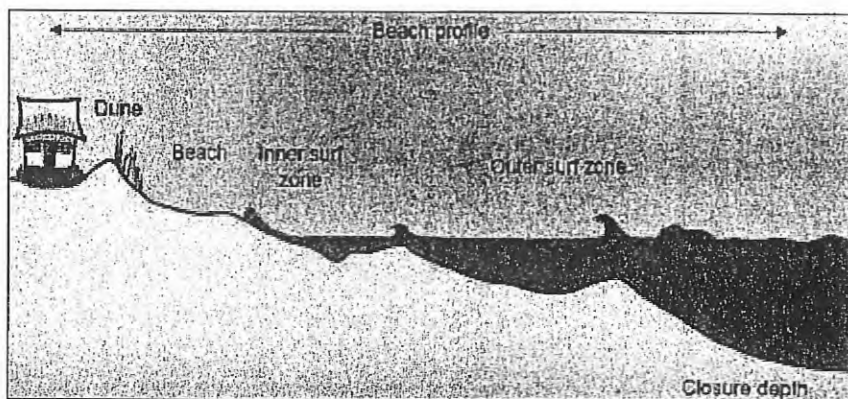


Figure 1. Diagram showing the basic features of a beach profile typical of many U.S. beaches.

refers to the typically dry area between the (high) water level and dune/upland region. Seaward of the beach is the **surf zone**, extending beyond the region where waves break. The dune, beach, and surf zone comprise the **beach profile** (Figure 1). The seaward boundary of the beach profile, just beyond where the largest waves break, is the closure depth. The closure depth depends on the local wave climate and the size of the sand, and represents the seaward-most point at which noticeable changes in the beach profile occur. Sand placed on the dry beach during nourishment is expected to be redistributed across the entire beach profile by the waves and currents, filling in the underwater portion of the beach profile as far offshore as the closure depth.

Beach nourishment involves placement of sand along the upper (dry) portion of the beach profile either by dump truck or dredge. Once the sand is placed, bulldozers redistribute the sand across the dry portion of the beach. Conventional construction equipment cannot physically place sand to a designed configuration 15-25 feet under water, which is the common range of the closure depth. It is for this reason that beach nourishment projects are designed to take advantage of

the natural processes by including a volume of sand intended to be transported offshore (Figure 2).

The constructed beach nourishment project includes a total volume of sand, "**constructed fill**," which consists of several components each with different functions. When engineers design a beach nourishment project, they determine how much sand is needed to meet the stated design goal. A typical goal may be to prevent waves overtopping the dune during a storm event. Since this is the basis of the design, it's called the "**design fill**" (Figure 2).

The anticipated storm event, and basis for determining the design fill, may occur several years after construction. In the time between construction and the major storm event, the beach will lose sand due to average waves and smaller storm events at a fairly predictable rate (long-term erosion rate). The design must account for this expected sand loss. To ensure that the design fill is always present and available to protect the upland infrastructure, additional sand is included in the construction fill called the "**advanced fill**." The advanced fill erodes at the long-term rate (e.g. x ft/yr). Ideally,

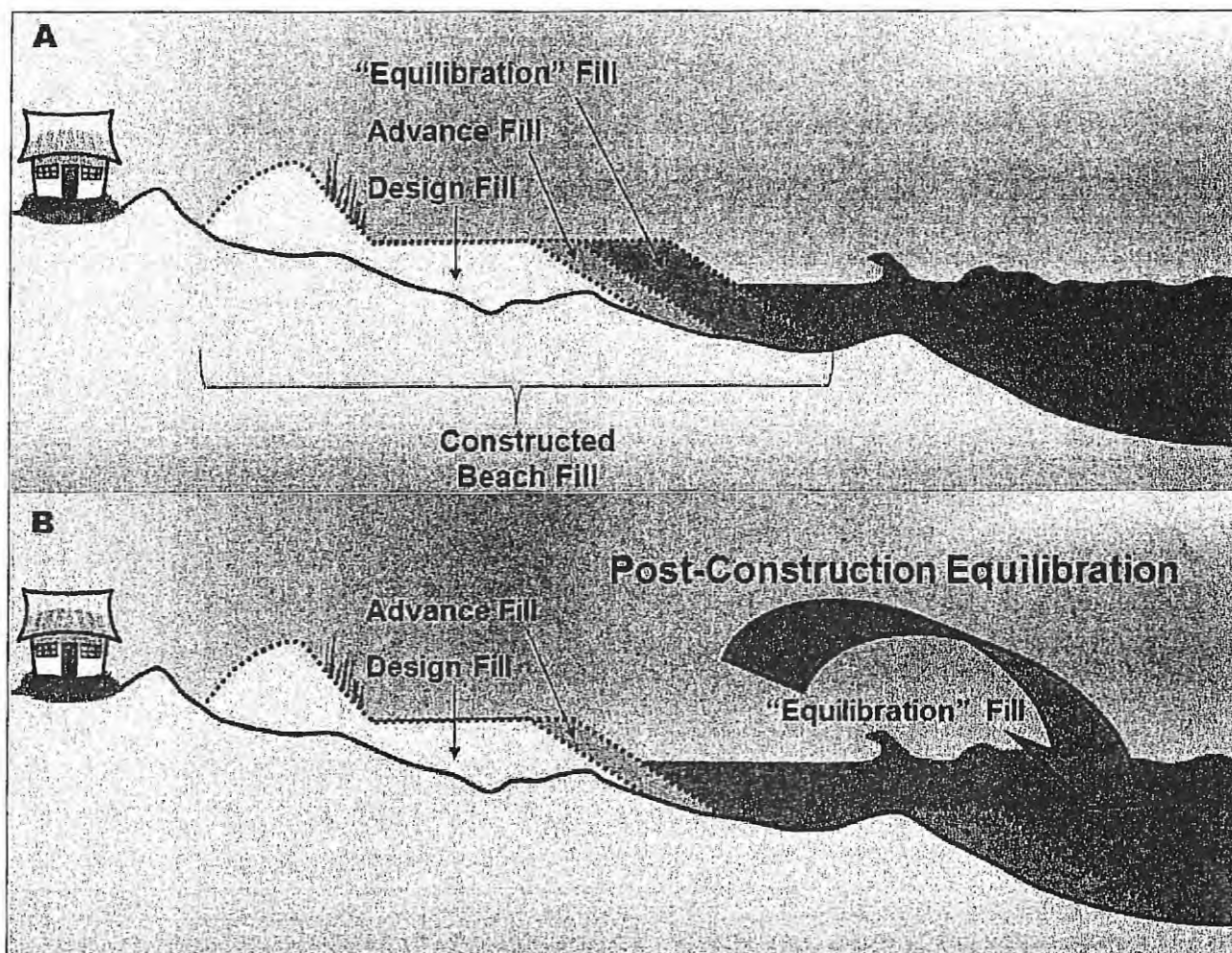


Figure 2. Beach nourishment projects are designed to allow sand movement across the profile, while maintaining a certain dry-beach width

once the advanced fill has dispersed and the design fill is beginning to erode, the next project (called a renourishment) will begin. The goal is to ensure that when a major storm occurs, at a minimum the design fill is present to reduce damage to the community.

A less intuitive volume of sediment included in beach nourishment design and construction is called the **"equilibration fill."** The equilibration fill is actually part of the advanced fill and design fill. During construction, the dredging contractor places sand at a slope steeper than the natural beach slope because it's cost prohibitive to shape the beach profile beyond the area where the waves are breaking. After construction, the waves and currents naturally soften the slope and move the sand offshore to fill the deeper parts of the beach profile. During this process, no sand has been lost from the beach profile; it has rather been redistributed to create a more stable beach shape, which is more

effective in breaking larger waves further offshore. The movement of the sand from the steep construction slope to this flatter, more stable shape typically occurs within 12 months after construction, depending on how many storms impact the area.

Although profile equilibration is factored into the design of beach nourishment projects, the public may negatively perceive this process. The immediate, rapid loss of newly placed (and often quite expensive) sand may discourage project stakeholders if the process of profile equilibration is not explained. It is critical that stakeholders understand that this loss of sand does not represent a failure. In fact, the offshore transport of equilibration fill (Figure 2) is part of the engineering design. Most often the beach profile hasn't lost any sand, the sand has just moved offshore as intended where it is performing an important role dissipating wave energy. After this initial equilibration process during which the

shoreline retreats rapidly, the shoreline retreat rate slows down as the profile approaches equilibrium.

REAL-WORLD EXAMPLE

The 2015 North Topsail Beach (NC) post-nourishment profile (constructed fill) and equilibration profile (equilibrated fill) provides a real-world example illustrating the equilibration process (Figure 3). The constructed fill (Figure 3A) equilibrated over a period of seven months transporting sediment to the surf zone (Figure 3B) and adjusting the overall beach profile (slope). As shown in the example beach profile, the equilibration fill is often deposited as a sandbar, which helps to trip the waves, and further reduce the amount of wave energy reaching the beach.

ENVIRONMENTAL CONSIDERATIONS

Understanding sediment transport pathways of the constructed fill is com-

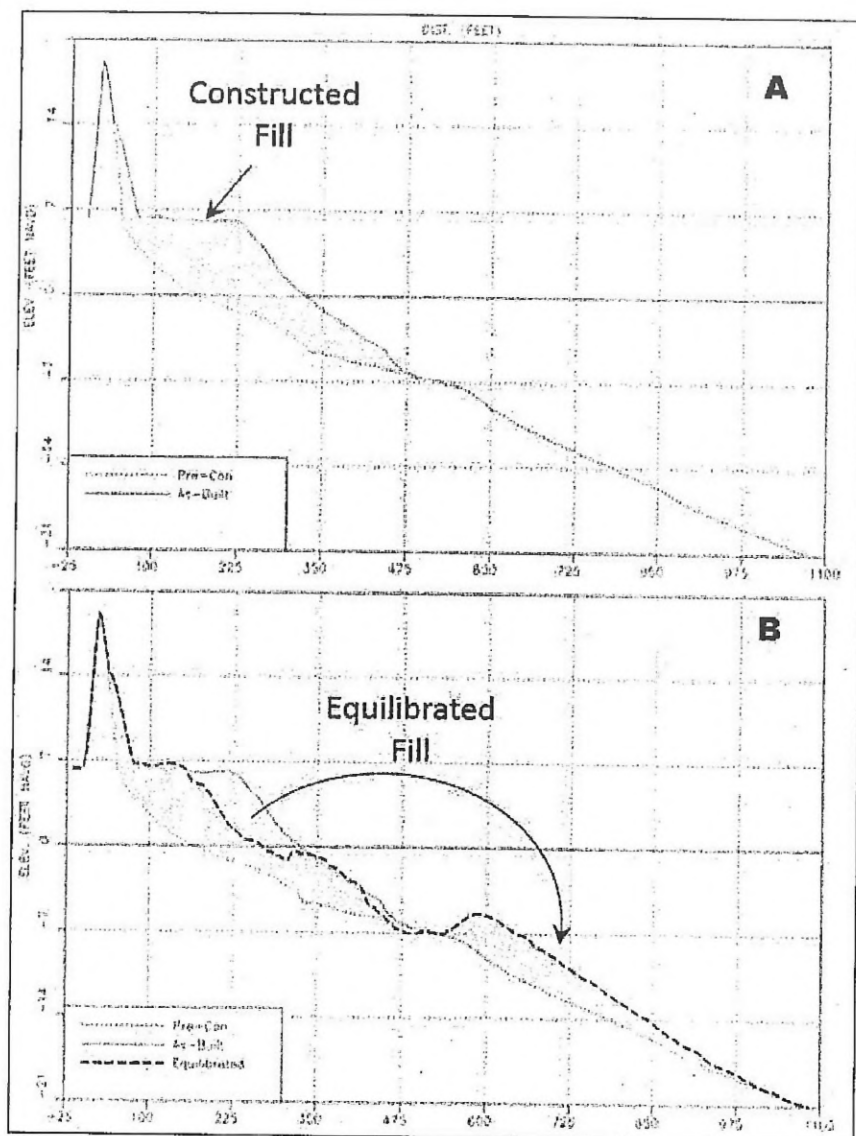


Figure 3. The North Topsall Beach (NC) beach profile immediately following nourishment construction (A), and seven months later once the profile equilibrated (B).

plex and is dependent on a number of factors. Therefore, when designing a beach nourishment project, careful consideration must be given to potential impacts of the equilibrating beach profile on adjacent resources. The movement of sand (equilibrated fill) from the constructed template seaward into the surf zone typically occurs over a period of months. Mobile benthic organisms are resilient in this highly dynamic setting and can adapt to frequent changes in the elevation of the seafloor. On the other hand, sessile organisms (that cannot move) may be more susceptible to impacts associated with sand transported offshore.

SUMMARY

The objective of this paper is to explain the process of profile equilibration to inform coastal communities and increase the public's understanding of beach nourishment. During beach nourishment projects, conventional construction equipment cannot physically place sand within the surf zone, and therefore projects are *designed* to include a volume of sand that the waves and currents will transport offshore to fill in the lower parts of the beach profile. During this process, the dry beach appears as though it has eroded, however this sand has moved offshore by design, where it is more effective at dampening the effects of the waves. ASBPA encourages coastal communities to share this white paper with coastal stakeholders before beach nourishment project construction begins.

香港填海造陸的歷史、現況與未來大計

若你正踏足全球最昂貴的土地上，何不乾脆讓這塊土地的面積繼續增加？我們追溯香港無休無止的填海造陸歷史

By Christopher DeWolf 2019 年 04 月 17 日

如果你能穿越時空，回到 100 年前的香港，最好帶備救生衣，因為你現時立足的地點，當時可能還是一片汪洋。早在香港開埠初期，地型就因填海造陸而不斷改變；同時亦全靠填海造陸這個重要的工具，香港這個海岸線崎嶇曲折、綿延 733 公里的彈丸之地，才能蛻變為人口達 750 萬的國際大都會。

「填海」一詞其實不是很恰當，更準確的說法應是「填海造陸」，因為過程中需開山闢洞，把挖出的泥石堆進海裡，藉此擴張海岸線或建造人工島。香港大部分地方都是藉這種方式得來，對不少香港人來說，年少時所看到的城市面貌跟現在已完全不同。

記者陳婉瑩憶述：「小時候，我會到一位朋友家中觀看龍舟比賽。房子位於灣仔告士打道，當時屬海傍地帶。」這已是 1950 年代的往事，現時這一帶有會展中心、中環廣場，以及多幢摩天大廈，同一地點已無法再見到海景。

住在油麻地渡船角的梁煥松說：「我懷念大海。」這個地方當時是一片伸出維多利亞港的土地，於 1970 年代開始發展。其後香港進行歷來最大規模的填海造陸計劃，將海岸線往西推進接近 600 米，令這裡面目全非。「那時我從家裡走到樓下，只需走幾步就來到海邊，如今卻幾乎看不見海了。」

不過，香港多處原有的海傍地段依然有跡可尋。在灣仔和中、上環，曲曲折折的皇后大道見證著昔日浪濤拍岸的風光。英國人於 1841 年踏足香港後不久，即開始填海造陸，到了 1857 年，已將海岸線推進至今天的德輔道。

接著，這個年輕城市推出迄今最宏大的填海造陸計劃。生於印度的亞美尼亞裔商人吉席·保羅·遮打滿懷雄心壯志，提出在中環填海 24 公頃的計劃。工程於 1900 年左右完成後，這片全新的土地成為城中的黃金地段，香港會、最高法院及皇后像廣場均選址這片新土地之上。

DISCOVERY

From the inflight magazines for Cathay Pacific and Cathay Dragon

HONG KONG'S LAND RECLAMATION: PAST, PRESENT AND FUTURE

If you're standing on the world's most expensive land, why not simply create some more? We examine Hong Kong's never-ending land grab

By Christopher DeWolf April 17, 2019

If you're a time traveller in Hong Kong, you'd better pack a lifejacket because chances are the land you're standing on wasn't there 100 years ago. Since its first days as a city, Hong Kong has been shaped and reshaped by land reclamation, which has been an indispensable tool in turning 733 kilometres of craggy shoreline into a global metropolis of 7.5 million people.

land reclamation is actually a bit of a misnomer; land creation would be more accurate. Mountains are levelled, holes excavated and the resulting soil and debris piled into the sea to extend shorelines or create artificial islands. Most of Hong Kong has been so thoroughly transformed through this process that, for many people, the city they remember from their youth no longer exists.



Pump Park Vintage Photography / Alamy Stock Photo / Argusphoto

'When I was small, I used to go to a friend's flat to watch the dragon boat races,' recalls journalist Chan Yuen-ying. 'It was in a building on Gloucester Road in Wan Chai – which was the harbourfront then.' That was in the 1950s. Today, it would be hard to see the harbour from the same spot, blocked as it is by the Convention and Exhibition Centre, Central Plaza and a thicket of skyscrapers.

'I miss the sea,' says Christopher Leung, who grew up in the Yau Ma Tei enclave known as Ferry Point. When it was first developed in the 1970s, it jutted out into Victoria Harbour. That changed when Hong Kong's largest land reclamation project shifted the shoreline by nearly 600 metres to the west. 'I would go downstairs, just a few steps and I was at the water. Now I can hardly see it.'

It's still possible to trace the original waterfront in many parts of Hong Kong. In Wan Chai, Central and Sheung Wan, the twists and turns of Queen's Road mark the spot where waves once lapped against the

shore. Almost as soon as the British arrived in 1841, they began to push the shoreline outwards until it reached present-day Des Voeux Road in 1857.

The next stage of land reclamation was the young city's most ambitious to date. Indian-born Armenian businessman Catchick Paul Chater hatched a plan to reclaim 24 hectares of land in the middle of Central. When work finished around 1900, the new land became the city's most prized real estate, providing space for the Hong Kong Club, Supreme Court and Statue Square.



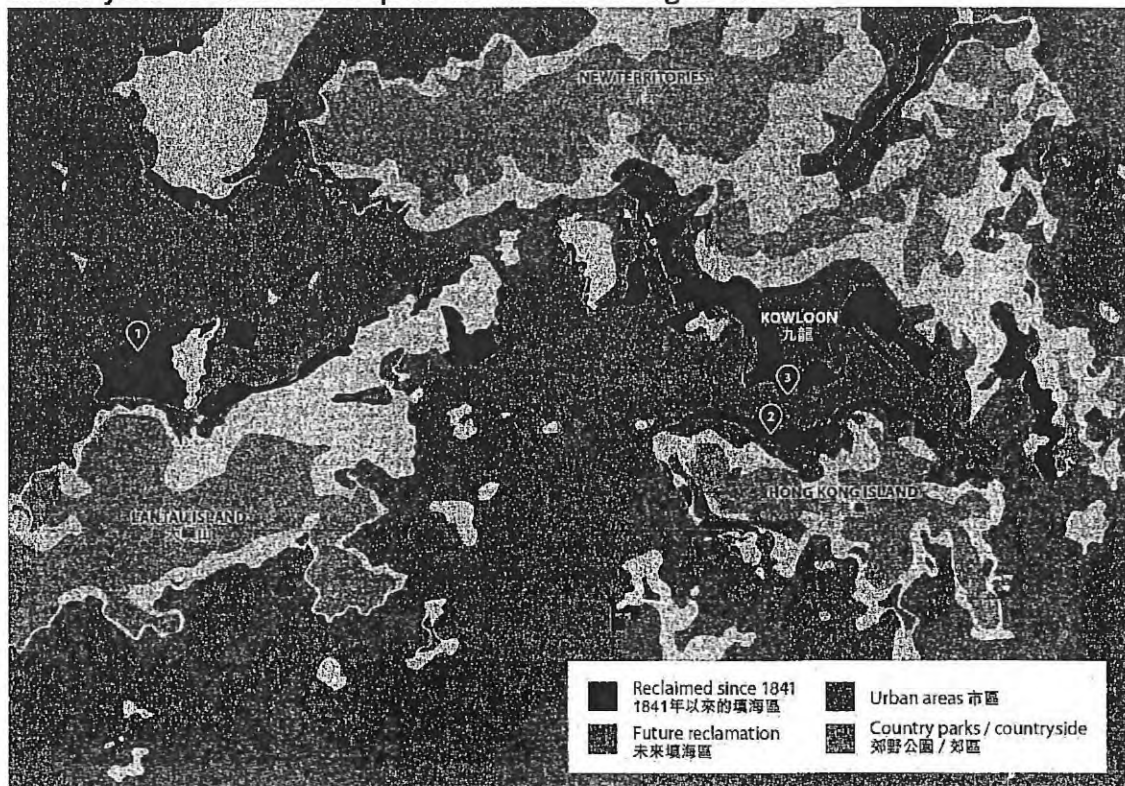
Pump Park Vintage Photography / Alamy Stock Photo / Argusphoto

Over the next century, land reclamation made room for airports at Kai Tak and Chek Lap Kok, along with business districts, container ports, factory zones and vast housing estates. But a turning point came in the 1990s, when 340 hectares of land were reclaimed off the west coast of Kowloon to make way for new roads, MTR lines and eventual mega-

projects like the Express Rail and West Kowloon Cultural District. Just as that project was being completed, plans were underway to fill in the harbourfront from Central to Causeway Bay. The idea of filling in the whole of Kowloon Bay was floated.

People genuinely worried the harbour would one day disappear, which sparked a backlash that's still felt today. In 1996, activist Winston Chu teamed up with legislator Christine Loh to pass the Protection of the Harbour Ordinance, which bans any future reclamation in Victoria Harbour unless there is an overriding public need. The land reclamation for the newly opened Central-Wan Chai bypass was approved just before the ordinance was passed.

But land reclamation is not off-limits outside the harbour. Government officials have proposed filling in parts of Tolo Harbour and Lung Kwu Tan to create more space for housing, and Chief Executive Carrie Lam recently unveiled plans for a massive artificial island that may be built off the tranquil south shore of Lantau Island. In Hong Kong, the ground under your feet is never quite as firm as it might seem.



1. Chek Lap Kok

About 900 hectares of reclaimed land tripled the size of the island for the new airport in 1998. The upcoming third runway will add a further 650 hectares.

2. Central

Waves lapped Des Voeux Road in the 1880s. Today, the new Central-Wan Chai bypass is the latest land reclamation project to alter the shape of the harbourfront.

3. Kowloon

In 1900, Tsim Sha Tsui's Clock Tower jutted into the sea. That changed in the 2000s when 340 hectares of land were added to the peninsula between Yau Ma Tei and Lai Chi Kok.

J.W.C. James

Reclamations and the Interpretation of Marine Geology in Hong Kong: A Comprehensive Approach

Abstract

Although reclamation of land from the sea has always been an aspect of Hong Kong's development, in the last decade the scale of reclamation has increased dramatically fueled by the initiation in 1989 of the Hong Kong Airport Core Programme. This included the construction of the 1248 ha airport platform at Chek Lap Kok and reclamations at West Kowloon, Central and elsewhere in Hong Kong.

These recent reclamations have stimulated a variety of site investigation techniques and methods. The extensive surveys undertaken for locating fill resources has benefitted the interpretation of the marine geology of Hong Kong by providing a widespread grid of reflection seismic lines with associated boreholes and CPTs. This has enabled the stratigraphy to be based on a regional scale appraisal and allowed the geological interpretations of relatively small reclamations to be set in the context of the surrounding geology. This is an important parameter for functions such as drainage pathways or sea wall design and construction whose effects impinge beyond the boundaries of a reclamation.

This paper is published with the permission of the Director of the British Geological Survey, the Director of Civil Engineering, Hong Kong SAR Government and the Airport Authority Hong Kong. Mr Niall Spencer of BGS Cartography produced the colour figures.

INTRODUCTION

Physically Hong Kong is characterised by hilly and mountainous terrain; flat land has always been at a premium, especially near the coast where the major centres of population have grown. The reclamation of land from the sea has therefore been an integral com-

Ceri James graduated in 1970 from Swansea University. He spent two years with the Ethiopian Geological Survey before joining the British Geological Survey in 1973. Since 1984 he has worked in the marine and coastal groups at BGS with particular interests in superficial deposits, bed-forms and seismic interpretation. He was the marine geologist with the Hong Kong Geological Survey from 1989 to 1991 and a consultant to the Airport Authority Hong Kong. He has recently co-authored a report on the effective development of marine aggregate in South East Asia for the UK Department for International Development.



Ceri James

ponent of Hong Kong's economic growth since the beginning of the century (Martin *et al.*, 1997). However in the last ten years the scale of reclamation has increased dramatically with the initiation in 1989 of the Hong Kong Airport Core Programme (Lam, 1998) which included the construction of the 1248 ha airport platform at Chek Lap Kok and reclamations at West Kowloon, Central and elsewhere in Hong Kong. By 1996 the total area reclaimed in Hong Kong was about 6000 ha and comprised around 5% of its land area. Reclamations are set to continue in the future with planned developments such as major container ports near Lantau Island.

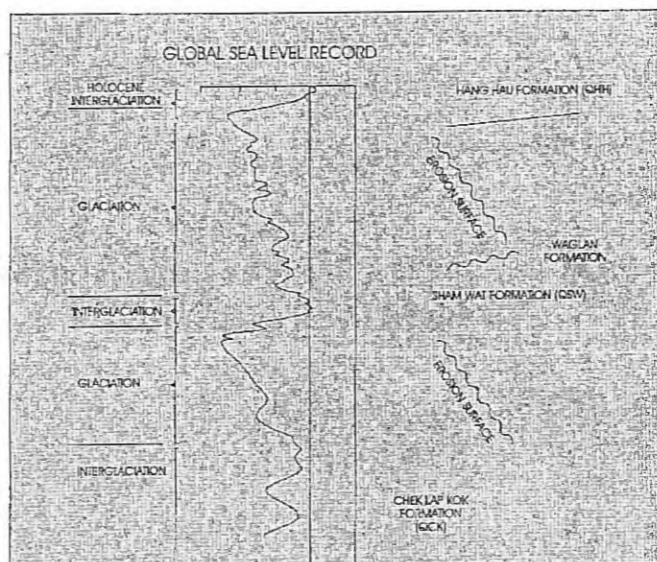


Figure 1. Quaternary sea levels (after James, 1993 and Fyfe et al., 1997).

The enormous scale of these recent reclamations in terms of infrastructure design and construction has stimulated a variety of site investigation techniques and methods which have been imaginatively deployed. The wealth of new site investigation data available, not only from localised reclamation sites, but also from the extensive surveys undertaken for locating fill resources has benefitted the interpretation of the marine geology of Hong Kong by providing a widespread grid of reflection seismic lines with associated boreholes and CPTs. This has enabled the stratigraphy to be based on a regional scale appraisal and allowed the geological interpretations of relatively small reclamations to be set in the context of the surrounding geology. This is a very important parameter for functions such as drainage pathways or sea wall design and construction whose effects impinge beyond the boundaries of a reclamation.

RECLAMATION DESIGN AND CONSTRUCTION

The need to design and assess the behaviour of reclamation platforms both during and after construction has long been acknowledged in Hong Kong.

To model this behaviour geotechnically requires a comprehensive analysis and understanding of the geology at reclamation sites. A framework based on geological interpretation of the site investigation data, which should be as extensive as possible, has to be developed for each reclamation, built up of the various formations and units of sediment and rock which underlie the platform.

Such an interpretative framework can indicate the spatial distribution, both vertical and lateral, of all the geological formations. It is a fundamental building block which should underpin all reclamation design and construction and provide critical information and data including:

- distribution of soft compressible sediment;
- base levels for dredging soft sediment from platform sites;
- distribution of over-consolidated sediment such as palaeosols, which may influence ground movement and control the magnitude and rate of settlement;
- identification of drainage pathways below the reclamation through sand and gravel horizons;
- identification of platform areas which may need ground treatment such as surcharge or dynamic compaction;
- identification of potential problem areas for settlement and stability at seawalls and within the reclamation platform;
- identification of platform areas which should be subject to monitoring by instrumentation such as inclinometers, extensometers and piezometers;
- level of top of decomposed rock and its thickness; this level may also equate with the base of superficial deposits in most reclamations; and
- level of top of Grade III – moderately decomposed rock.

The geological interpretation therefore provides a basis for the assessment of platform performance in terms of total and differential settlement. With regard to dredging and fill requirements it is important in the calculation of material volume, both for any soft sediment dredged from reclamation sites and fill material, to create a platform.

DEVELOPING GEOLOGICAL INTERPRETATIONS

In developing a geological interpretation for a reclamation platform, the aim is to produce a model of the three-dimensional geometry and lithology of the superficial deposits which underlie a site, and the form of the rockhead surface on which they sit. Superficial deposits in this context comprise unlithified, transported material of sedimentary origin deposited within the Quaternary Period, a time span covering the last two million years. Superficial deposits do not include "rock" which may locally have weathered in situ to unlithified deposits.

A number of factors influence the processes of sedimentary deposition and therefore have to be reconciled within a geological interpretation. These are:

- climatic changes during the Quaternary Period;
- global sea level oscillations reflecting these climatic changes;
- morphology of rock outcrops in the reclamation area;

- alluvial, estuarine and marine erosion and deposition; and
- hydrodynamic conditions.

On a regional and global scale the most important factor determining the disposition of the superficial deposits is Quaternary climate change. During the Quaternary, the climate fluctuated between glacial and interglacial cycles. Major oscillations in sea level were associated with these climatic changes. Figure 1 shows the climatic state and global sea level curve for the Late Quaternary.

In Hong Kong these changes in sea level and climate had a profound influence on the geological development of nearshore coastal areas in which reclamations are constructed. During glacial periods, all areas of Hong Kong which are presently beneath the sea became emergent. Exhumed landscapes were formed in superficial deposits, crossed by rivers and streams eroding and depositing sediment. Vegetation covered the landscape, underlain by extensive soil profile development. With subsequent rises in sea level during interglacial periods, landscapes became inundated and modified by the sea. However, soil profiles may remain as palaeosols beneath younger superficial deposits. With rising sea levels upstanding parts of old land surfaces formed of unconsolidated material could be eroded by wave action, cutting the surface on which subsequent estuarine and marine sediments were deposited.

The sequence of events which mark the depositional and erosional history of the superficial deposits of Hong Kong would therefore appear to be complex and

difficult to interpret. However, with a comprehensive site investigation programme and knowledge of the history of sedimentation during the Quaternary in Hong Kong derived from a regional perspective, an interpretation can be constructed to produce a geological framework for reclamation design and construction.

METHODS OF INVESTIGATION AND DATA

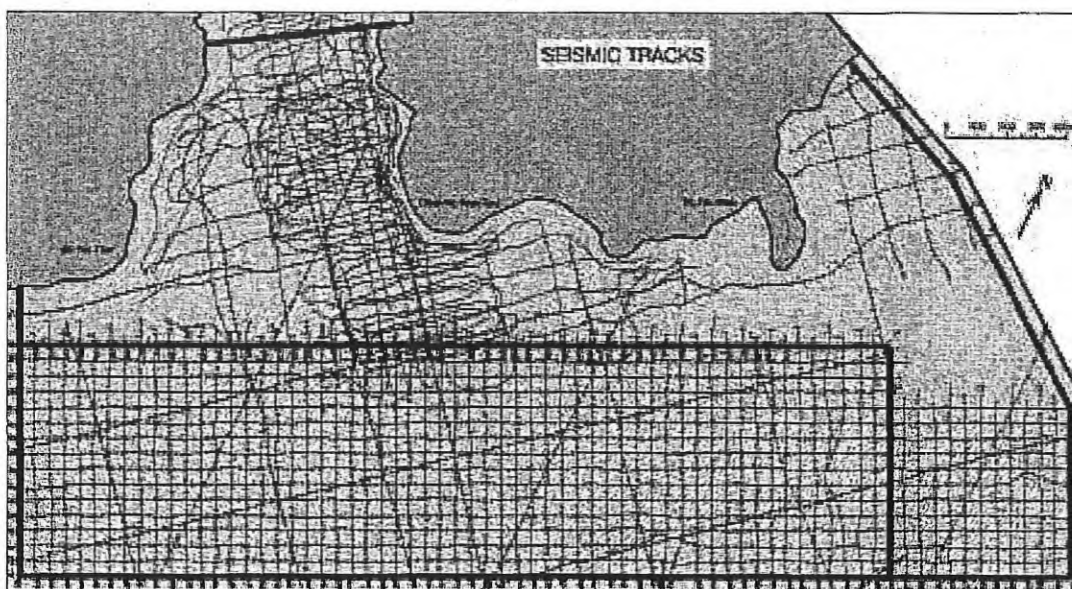
An important element in the quality of a geological interpretation for any reclamation is the quality and extent of site investigation undertaken.

Survey grid

The first imperative is a survey grid of high resolution reflection seismic records, generally at a maximum spacing of 50 to 100 m. The grid should be rectangular with one axis aligned along a principal feature of the reclamation such as a sea wall or runway. Additional seismic lines should be run along the alignment of any major structures including those which deviate from the grid plan. Figure 2 includes the tracks of seismic surveys undertaken in the Penny's Bay area of Lantau Island and the proposed site of Container Terminals 10 and 11 (James, 1994). It illustrates the difference between a modern survey, undertaken in 1994, with a rectangular grid at 50 m spacing and an older, 1981 survey within Penny's Bay itself, which has an irregular, spaghetti-like plan with no clearly defined individual lines and are therefore more difficult to interpret.

Reflection seismic surveys of Hong Kong reclamations principally employ a boomer acoustic source (Ridley

Figure 2. Seismic surveys at Penny's Bay (James, 1994).



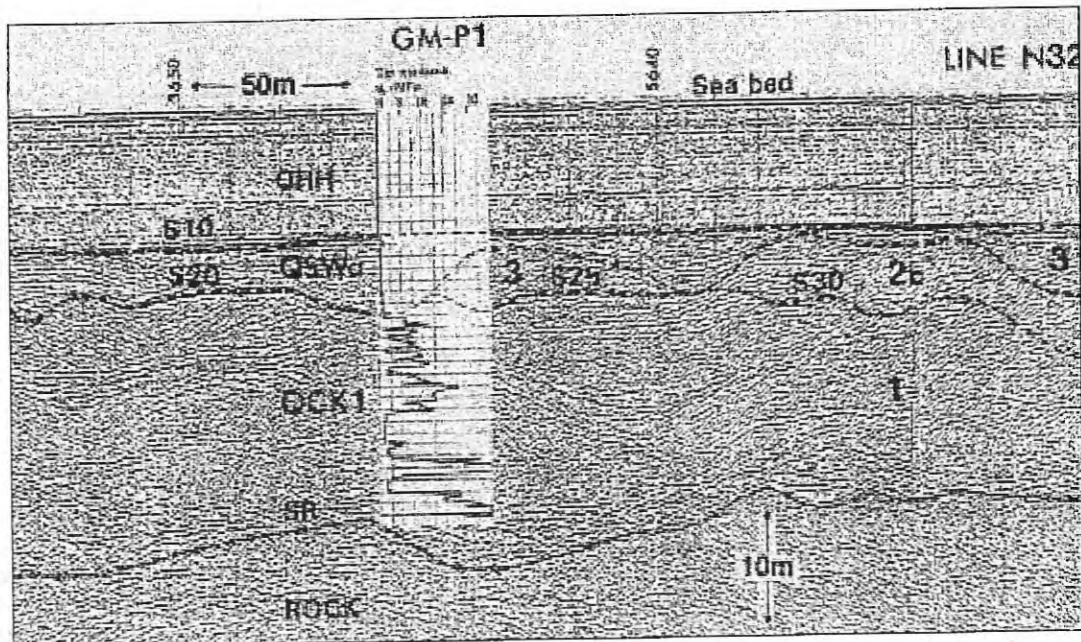


Figure 3. Interpreted seismic record and CPT trace (James *et al.*, 1994).

Thomas *et al.*, 1988). Depth of penetration beneath the sea surface is normally about 100 m, an adequate depth to reach the base of superficial deposits at most coastal reclamation sites. The boomer normally gives excellent resolution within superficial deposits allowing detailed interpretations to be undertaken. Because of the nature of the predominant solid rocks in Hong Kong, mainly granites and volcanics in various states of decomposition, acoustic impedance contrasts are very low and this leads to poor penetration and resolution within these solid rocks, in marked contrast to the normally well resolved superficial deposits.

Boreholes and CPTs

A thorough interpretation will produce seismic records annotated with picked reflectors (Figure 3) delineating the formations and units which have been interpreted. In an ideal site investigation the seismic interpretation should precede any borehole or CPT (cone penetrometer test) survey undertaken to produce lithological and geotechnical data. To calibrate and confirm the seismic interpretation, boreholes and CPTs should be sited to give the optimum amount of data for all formations. They should always be located directly on seismic lines, preferably at the crossover of two lines, allowing the borehole or CPT data to be traced in four directions away from the location.

The number of boreholes and CPTs undertaken for a site investigation will depend on the area covered by the reclamation, the complexity of the geology and the structures to be built on the reclamation, as well as the

finance available. For example, the marine geological interpretation for the new airport at Chek Lap Kok (James *et al.* 1994), which covered an area of about 938 ha, utilised 236 boreholes and 404 deep CPTs.

The vast majority of these were sited for engineering and construction criteria rather than geological and only a minority are located exactly on seismic lines.

Calibration of the geophysical data

The final part of any investigation is the calibration of the geophysical data from seismic and CPT sources. The physical and lithological results from borehole logging and any specialist input from palaeontologists, petrologists, geotechnical engineers and other specialists is used to produce a comprehensive geological interpretation with delineated formations and units described in detail and illustrated with isopach and base level maps, and cross sections along the major structures such as sea walls and runways.

MARINE GEOLOGY AND STRATIGRAPHY

The offshore superficial deposits of Hong Kong mapped by the Hong Kong Geological Survey have previously been subdivided into two formations, the Hang Hau Formation and the Chek Lap Kok Formation, based on lithological and palaeontological evidence from boreholes and on interpretations of seismic character (Strange and Shaw, 1986; Langford *et al.*, 1989). The subdivision has a chronological element,

with the Hang Hau Formation being younger than the Chek Lap Kok Formation.

A two-fold subdivision of the offshore superficial deposits has long been recognised in geological and geotechnical investigations in Hong Kong, with the terms "alluvium" and "marine deposits" given to sediments which could nominally be ascribed to the Chek Lap Kok and Hang Hau formations respectively.

From the interpretation of seismic records across the whole offshore area of Hong Kong a more complex series of units than a simple twofold subdivision has emerged. Two new formations, the Waglan Formation and the Sham Wat Formation have been recognised (Fyfe *et al.* 1997) which sit between the Chek Lap Kok Formation and the Hang Hau Formation (Table I).

Waglan Formation

The Waglan Formation is confined to the south-eastern waters of Hong Kong and therefore is likely to be of no consequence in coastal reclamations.

Hang Hau Formation

The Hang Hau Formation (QHH) consists of relatively homogenous very soft to soft, greenish grey silty clay. Undrained shear strengths range from <3 kPa to 20 kPa and SPT N values are generally zero. Moisture content is high, around 100%. It is the most widely developed of the superficial deposits in Hong Kong and generally forms a blanket of sediment over all the underlying superficial deposits and rock and has a well-developed unconformity at its base. In many coastal areas the base of the formation is deeply channelled with sediment up to 29 m thick (Figure 7). The delineation of these soft sediment channels is important to the design of a reclamation. The form of this basal surface would be crucial as a base level for dredging in dredged reclamations and also in estimating settlement rates and areas of ground treatment for drained reclamations. A tight grid of seismic lines enables the thickness and geometry of the soft mud to be delineated for a reliable reclamation design.

The Sham Wat Formation (James, 1993) is of limited extent in western and southern waters, but was identified beneath the platform of the new airport at Chek Lap Kok (James *et al.*, 1994) (Figure 6). It comprises a generally firm grey silty clay and is firmer, <40 to 60 kPa, and has a lower moisture content, <80%, than the overlying Hang Hau Formation.

Chek Lap Kok Formation

The Chek Lap Kok Formation is the most lithologically, seismically and geotechnically variable of the formations within the superficial deposits of Hong Kong. In many areas the formation can exhibit abrupt variation in sediment type both laterally and vertically and this is corroborated by an absence of distinctive seismic

Table I. Offshore Quaternary stratigraphy of Hong Kong.

Formation	Age
Hang Hau	Holocene
Waglan	Late Pleistocene
Sham Wat	Late Pleistocene
Chek Lap Kok	Pleistocene

reflectors and sequences which can be traced extensively on a regional scale. Where seismic lines are greater than 500 m apart it is difficult to produce continuity and interpret distinctive sequences and units within the Chek Lap Kok Formation. However, at some reclamation sites, such as the new airport, where the seismic grid is at a spacing of 100 m or less, characteristic seismic reflectors and sequences can be deduced from the interpretation of seismic records which allows the Chek Lap Kok Formation to be subdivided into units (Figure 4).

RECLAMATION GEOLOGY

The regional stratigraphy outlined above has been used as the basis for the detailed interpretation of the geology of two reclamation sites in Hong Kong. Firstly, at the site of the Hong Kong International Airport at Chek Lap Kok (James *et al.*, 1994) and secondly, in the area of Penny's Bay and the proposed sites of Container Terminal 10 and 11 (James, 1994).

Hong Kong International Airport

The James *et al.* (1994) interpretation at Chek Lap Kok was commissioned by the Airport Authority in July 1993. The purpose of the study was primarily the same criteria as those outlined above in the reclamation design and construction section with an emphasis on providing the Airport Authority with a geological framework as a backbone to the design, construction and monitoring of the platform. Although the interpretation was not used in the original design exercise for dredging at the reclamation, it was intended to be used by the Airport Authority to clarify dredge levels and highlight particular areas which might require modifications to the proposed dredging operations (Plant *et al.*, 1998).

The soft mud of the Hang Hau Formation (marine mud) is highly compressible and traditional practice up to the late 1980s in Hong Kong had been to reclaim over the soft marine mud (Martin *et al.*, 1997) with ground treatment, usually by vertical drains, to accelerate consolidation of the mud. This "drained" alternative was considered in the design options at Chek Lap Kok but the disadvantages included the relatively large amount

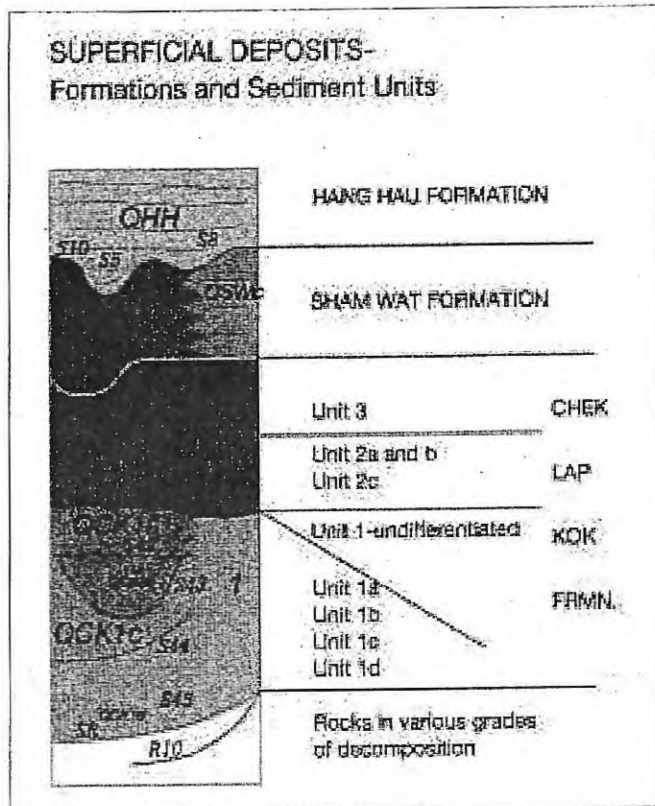
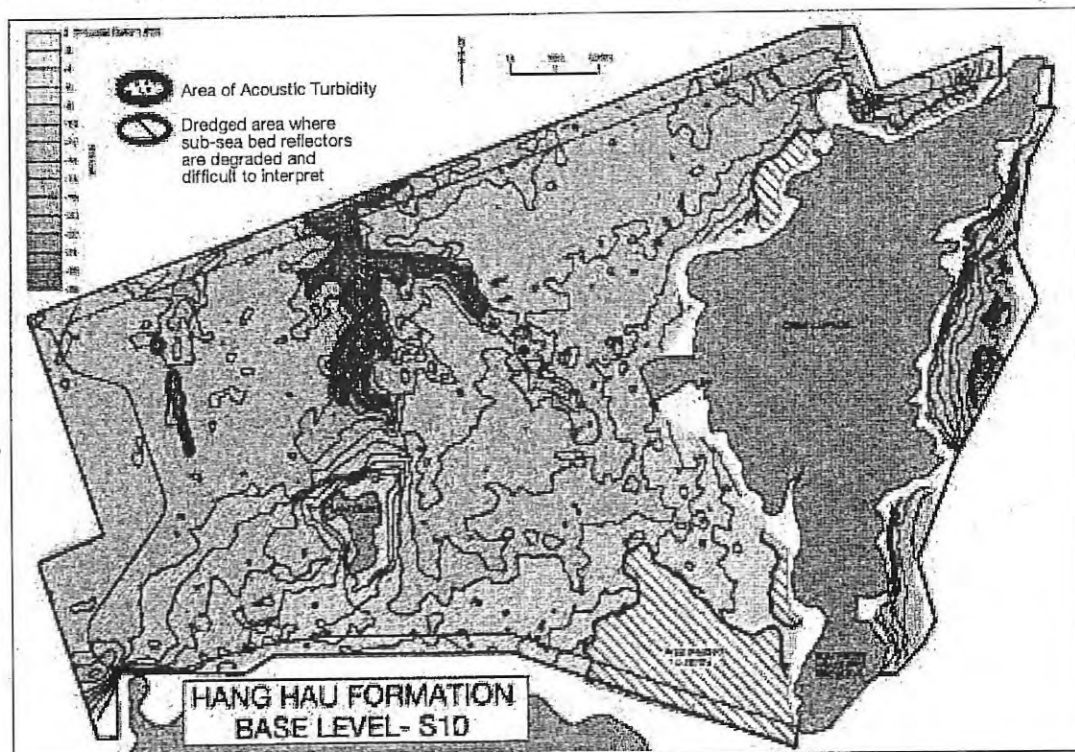


Figure 4. Stratigraphy at Hong Kong International Airport (James et al., 1994).

Figure 5. Hang Hau Formation base level at Hong Kong International Airport (James et al., 1994).



of settlement and the fact that it would have occurred too slowly, plus the assumption of a degree of uncertainty about the length and rate of consolidation and the practicality of surcharging. Although the "dredged" option meant a larger volume of reclamation fill was required compared to the "drained" option to replace the dredged soft mud, it was chosen because of the short time available for construction before the airport was to open (Plant *et al.*, 1998).

The Hang Hau Formation forms a blanket of sediment beneath the sea bed over most of the airport site. It covers all the underlying older superficial deposits and its base is a well developed erosion surface or unconformity. Although much of the basal surface is almost planar there is a small network of channels which vary in amplitude from less than 3 m to about 10 m. A few of these channels (Figure 5) are also marked by acoustic turbidity on seismic records formed by the presence of gas within the mud. Elsewhere on seismic records the base of the formation is marked by a distinctive, well-developed, high amplitude, continuous reflector (Figure 3).

The base of the Hang Hau Formation is generally well seen and distinguishable as a good basal reflector on seismic records and over much of the reclamation this should equate with the dredge level. An area where seismics cannot be used to determine the base of the Hang Hau Formation is where the reflectors are obscured on seismic records by acoustic turbidity; these

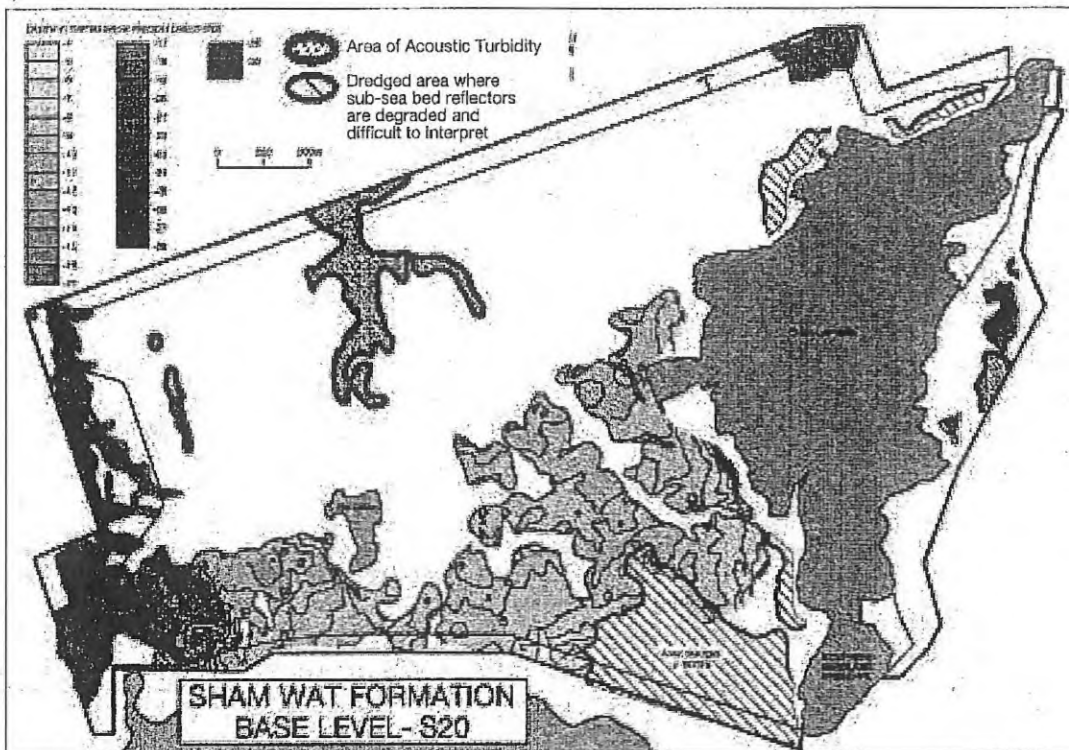
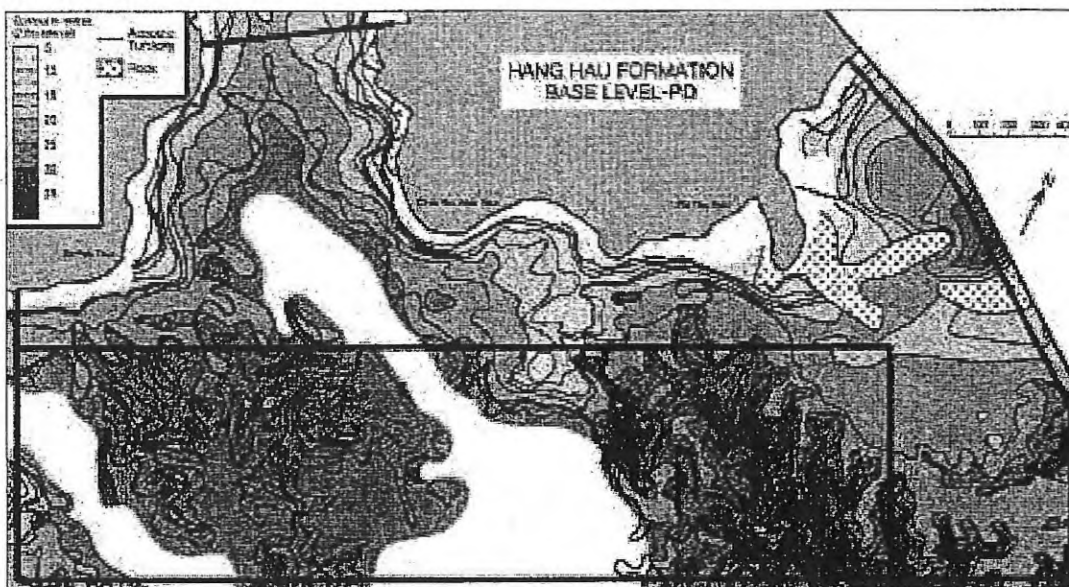


Figure 6. Sham Wat Formation base level at Hong Kong International Airport (James et al., 1994).

areas are not extensive at Chek Lap Kok. To resolve the dredge levels, a suite of 3202 dredge level CPTs were undertaken across the site and the "Base of Unsuitable Material" (BUM), i.e. the material to be dredged, was determined by the designers for each CPT location (Plant et al., 1998). Typically the marine mud of the Hang Hau Formation has a net CPT tip resistance (q_{net})

of less than 500 kPa and this was taken as a representative value for the soft mud. In addition, to avoid interpreting thin sands within the muds as the BUM, which would have $q_{\text{net}} > 500$ kPa, the criterion that net tip resistance should exceed 500 kPa for a depth of at least 500 mm below the BUM was added. The BUM interpretation from the CPTs was also corroborated by

Figure 7. Hang Hau Formation base level at Penny's Bay (James, 1994).



reference to the seismic records and any disparities were resolved within the design process.

During offshore regional mapping by the Hong Kong Geological Survey around Lantau Island a distinctive sequence was recognised on seismic records beneath the Hang Hau Formation. Borehole and CPT evidence confirmed the sequence had distinctive physical as well as geophysical characteristics and it was formally recognised as the Sham Wat Formation (James, 1993).

To the unfamiliar it is easy in borehole cores to misinterpret the Sham Wat Formation as the Hang Hau Formation. They are both predominantly grey silty clay, although the Sham Wat Formation is generally firmer, <40 to 60 kPa, and has a lower moisture content, <80%, than the overlying Hang Hau Formation. However, the Sham Wat Formation does have a distinctive character on seismic records with a strong reflector at its base and contains continuous, sub-parallel, undulating reflectors which drape over channel interfluvies and down into channel deeps.

West of the airport site at Chek Lap Kok, the Sham Wat Formation infills a major channel system which encroaches beneath the platform from the south-west (Figure 6). Its base in the deepest channel is at -29 mPD with a thickness of sediment up to 18 m, and its tributaries branch north-west along the western margin of the platform.

In this area of the platform the Sham Wat Formation also has a characteristic CPT signal compared to the overlying Hang Hau Formation. At the interface between the two formations there is generally an increase of 200 to 300 kPa in the value of net tip resistance (q_{net}) at the top of the Sham Wat Formation. Typical values for q_{net} are 500 to 800 kPa increasing gradually with depth to 1000 kPa at the base of the formation. The higher values of tip resistance, pore pressure and skin friction for the Sham Wat Formation compared to the overlying Hang Hau Formation indicates a greater degree of consolidation has occurred within the sediments of the Sham Wat Formation. Across most of this area there is a good correlation between the CPT response for the Sham Wat Formation and its interpreted sequence on the seismic records.

The recognition and delineation of the form and extent of the Sham Wat Formation was an important factor in aiding the design and construction of the western area of the platform beyond Lam Chau.

The sea wall at the western end of the southern runway overlies a Sham Wat Formation infilled channel and the initial design dredge levels for the sea wall in this area were the deepest for the site at -29 mPD and entailed dredging the Hang Hau Formation and the Sham Wat Formation. Calculations were undertaken to

evaluate a higher dredge level within the Sham Wat Formation and although settlement would be higher, a change to a base level of -22 mPD was considered acceptable and adopted as the deepest dredging limit (Plant *et al.*, 1998).

In total almost 69 Mm³ was dredged from the platform area, predominantly soft mud of the Hang Hau Formation and some soft to firm mud of the Sham Wat Formation and minor sediment from the Chek Lap Kok Formation. The average thickness of the dredged mud was 7.5 m with the thickest sequence dredged, at 21 m, within the major gas filled channel of the Hang Hau Formation which ran across the northern runway and northern sea walls (Figure 5) (Plant *et al.*, 1998).

The extensive seismic, borehole and CPT data set enabled an extensive appraisal to be undertaken of the Chek Lap Kok Formation and produced a comprehensive stratigraphy for the formation, and in greater detail than had previously been produced in Hong Kong reclamations. The Chek Lap Kok Formation has been subdivided into three units (James *et al.*, 1994), numbered QCK Unit 3, QCK Unit 2, QCK Unit 1 (Figure 4). Two of the units (QCK Unit 1 and QCK Unit 2) have been further divided. The subdivision has been based on lithological and seismic criteria, such as continuity of reflectors marking erosional events, and units with distinctive seismic signatures. The formation includes firm to stiff palaeosols, channel sands, and soft to firm estuarine clays. It is this formation that provides the platform on which the reclamation fill has been placed.

The mapping of the various units within the formation was a significant contribution to the design and construction of the reclamation as it proceeded and continues to be relevant to the monitoring of platform performance.

Penny's Bay and the site of Container Terminals 10 and 11

Penny's Bay lies at the south-eastern end of Lantau Island at the opposite end of the island to the site of the airport at Chek Lap Kok. The geological interpretation (James, 1994) was undertaken during the design stage of the reclamation prior to any planned construction.

The interpretation is based on a 50 m grid of modern boomer seismic reflection lines over the site of the container terminals and older records of poorer quality in Penny's Bay. The site investigation also included 109 boreholes, 41 vibrocores and 22 CPTs. The stratigraphy at the site is primarily a two-fold succession of soft mud of the Hang Hau Formation overlying a complex mixture of firm to stiff silty clay with some sand and silt which forms the Chek Lap Kok Formation. The Sham Wat Formation was not recognised at the site.

In terms of reclamation design the form of the soft mud of the Hang Hau Formation is important in terms of settlement considerations. It is constrained in extensive channel systems (Figure 7) with two major channels in the west infilled with up to 29 m of soft mud and a narrower dendritic set in the east infilled to a maximum thickness of 27 m.

The two major channels and the area in Penny's Bay contain a large accumulation of gas within the sediment which forms areas of acoustic turbidity on the seismic records. These obliterate seismic reflectors which trace features such as the base of the Hang Hau Formation. In these areas of acoustic turbidity the interpretation has to rely on point source information such as boreholes and CPTs and any surfaces such as the base of the soft mud has to be extrapolated between them. The upper ten metres of the Hang Hau Formation is generally not obliterated by acoustic turbidity and the form of the reflectors can be used to map out channels within the zone with acoustic turbidity and therefore provide a basis for planning a CPT survey programme to delineate the base of the soft mud.

Conclusions

The comprehensive approach to the interpretation of the marine geology of any reclamation site is based on excellent site investigation provided by a tight grid of seismic reflection profiles calibrated with borehole and CPT surveys. These should be analysed with a knowledge of the regional geology to provide a context for the reclamation and a detailed stratigraphy. The geological framework and information obtained from such an approach is crucial in enabling the planning, design and construction to proceed on schedule and to budget, without any unforeseen ground conditions delaying progress.

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SPEECHES

THE LAND RECLAMATION CASE:
THOUGHTS AND REFLECTIONS*by* TOMMY KOH* and JOLENE LIN**†

A geographically small country, with a shortage of land, Singapore has traditionally relied on land reclamation as a means of providing additional physical space to accommodate its housing, industrial and economic needs. Singapore has been reclaiming land since its early colonial days without attracting much attention from its neighbours. However, in 2002, Singapore's land reclamation works in Pulau Tekong and Tuas View Extension attracted complaints from Malaysia. Malaysia alleged that the reclamation works, *inter alia*, impinged on Malaysia's territorial waters, caused pollution and other adverse harm to the marine environment in the Straits of Johor. This culminated in Malaysia invoking the provisions of the 1982 UN Convention on the Law of the Sea and referring the dispute to arbitration, under Annex VII of the Convention. Subsequently, Malaysia applied to the International Tribunal for the Law of the Sea (ITLOS) for provisional measures to stop Singapore's land reclamation works pending the outcome of the arbitration. This article briefly describes the chain of events leading to the two countries appearing before the ITLOS arbitral tribunal and the final peaceful settlement of the dispute. The authors then go on to reflect on the important lessons gained from this episode, in the hope that future differences may continue to be amicably resolved.

I. LAND RECLAMATION IN SINGAPORE

Singapore is a small island republic in Southeast Asia situated just off the tip of the Malayan peninsula. Since the beginning of its independent existence, Singapore's physical constraints have made it a challenge to balance its competing needs and to optimise the use of its scarce land area.

Therefore, Singapore has been reclaiming land from the sea since the beginning of colonial Singapore. Recent reclamation projects include the Kallang River in the 1960s for industrial and housing purposes, Marine Parade in the 1970s for housing purposes, Changi Airport in the 1980s for infrastructure purposes, Jurong Island (joining seven islands in south-western part of Singapore) in the 1990s for industrial purposes, and Changi East in 1994-2002 for the expansion of Changi Airport, development of infrastructure and industrial purposes.¹ The reclamation works carried out over the last thirty years have enabled Singapore to increase its land area from 580 to 680 square kilometres (58,000 ha to 68,000 ha).²

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† This article is based on a talk given by Ambassador Koh to students at the Faculty of Law, the National University of Singapore, on 14 April 2005.

¹ See Para. 29 of *Response of Singapore, 20 September 2003, International Tribunal of the Law of the Sea, Malaysia v. Singapore* ["Response of Singapore"], online: International Tribunal for the Law of the Sea <http://www.itlos.org/start2_en.html>.

Land reclamation is also an important activity in several other small countries, such as Belgium, the Netherlands, Dubai and some of the other Gulf States.³ It has also become an industry and a fine art. The best practices, which Singapore adopts, enables it to embark on some quite massive land reclamation projects, in Pulau Tekong and in Tuas, without causing significant impacts on the marine environment, for example, pollution.

II. MALAYSIA'S RESPONSE TO THE LAND RECLAMATION WORKS IN PULAU TEKONG AND TUAS

In 2002, Malaysia began to voice its displeasure at Singapore's land reclamation works in Tuas and Pulau Tekong.⁴ As can be seen from the map below, Pulau Tekong is situated in the north-eastern part of Singapore. Tuas is in the Western part of Singapore.



Map of the main island of Singapore, showing the Tuas View Extension and Pulau Tekong reclamation areas⁵

Malaysia alleged that Singapore's land reclamation works in Pulau Tekong and Tuas impinged on Malaysian territory, caused pollution and other harm to the marine environment in the Straits of Johor, damaged the jetties, reduced the catch of the fishermen who made their living in the Straits of Johor, etc. Singapore repeatedly asked for details of Malaysia's concerns so that proper investigations could be made. However, although Malaysia promised to do so each time, at both levels of the Prime Ministers and Foreign Ministers, no such information was provided.

² Para. 30, Response of Singapore.

³ Examples of well-known reclamation projects include Kansai International Airport in Osaka, Japan, the Shannon Estuary in Ireland, the Palm in the United Arab Emirates and the IJburg Project in Amsterdam, the Netherlands.

⁴ More specifically, Malaysia did not protest against the reclamation in Tuas until January 2002, and then only in respect of the alleged encroachment into its territorial waters. At that point in time, the Tuas reclamation project had already been in progress for more than one and a half years. It was only in April 2002 that Malaysia raised the issue of any geophysical and hydrographical impacts arising from the Tuas reclamation project. On 30 April 2002, Malaysia raised objections for the first time concerning the alleged environmental impact and narrowing of the waterway in Kuala Johor as a result of the Pulau Tekong reclamation works. See Para 57, Response of Singapore.

⁵ This map was reproduced in Para. 24, Response of Singapore.

III. REFERRING THE DISPUTE TO INTERNATIONAL ARBITRATION

Finally, more than a year later, Malaysia provided Singapore with the details of her technical studies on 4 July 2003. However, at the same time, Malaysia invoked Article 286 of the 1982 *UN Convention on the Law of the Sea* (UNCLOS), and initiated arbitration under Annex VII of the UNCLOS.

Article 286 of the UNCLOS states:

Subject to section 3, any dispute concerning the interpretation or application of this Convention shall, where no settlement has been reached by recourse to section 1, be submitted at the request of any party to the dispute to the court or tribunal having jurisdiction under this section.

Singapore reminded Malaysia that under Article 283, parties to a dispute are under an obligation to exchange views and to attempt to settle the dispute through negotiations.

Article 283 (Obligation to exchange views) states:

1. When a dispute arises between States Parties concerning the interpretation or application of this Convention, the parties to the dispute shall proceed expeditiously to an exchange of views regarding its settlement by negotiation or other peaceful means.
2. The parties shall also proceed expeditiously to an exchange of views where a procedure for the settlement of such a dispute has been terminated without a settlement or where a settlement has been reached and the circumstances require consultation regarding the manner of implementing the settlement.

Singapore therefore invited Malaysia to come to the negotiating table. On 13 and 14 August 2003, meetings were held in Singapore. Both parties began to identify the issues at hand. Singapore gave detailed presentations on the Tuas and Pulau Tekong reclamation projects as well as oral and written responses to Malaysia. Both parties agreed that the talks were useful and both the Agents for Singapore and Malaysia agreed to continue them. Singapore then proposed that a second meeting be held and that the parties consider the formation of technical working groups to discuss the technical information. However, Malaysia imposed a pre-condition for the continuation of the talks, that is, that Singapore should stop all reclamation works in the meantime. Singapore could not accept this condition. Instead, Singapore replied that its studies and reports had demonstrated that the ongoing and planned reclamation works had not caused and would not cause any significant impact on Malaysia's concerns. Further, Singapore reassured Malaysia that it had always ensured that its reclamation works would not impede navigation through the Straits of Johor. Singapore also gave an undertaking that it would notify and consult Malaysia before it proceeded to construct transport links between Pulau Tekong, Pulau Ubin and the main island of Singapore if such links would have any effect on Malaysia's passage rights. Malaysia responded on 4 September 2003 by applying to the ITLOS for provisional measures under Article 290(5) of the UNCLOS.⁶

⁶ See *In the Dispute Concerning Land Reclamation Activities by Singapore Impinging Upon Malaysia's Rights In and Around the Straits of Johor Inclusive of the Areas around Point 20, Malaysia v. Singapore, Request for Provisional Measures*, 4 September 2003 ["Request for Provisional Measures"], online: International Tribunal for the Law of the Sea <http://www.itlos.org/start2_en.html>. Article 290(5) states: "Pending the constitution of an arbitral tribunal to which a dispute is being submitted under this section, any court or tribunal agreed upon by the parties or, failing such agreement within two weeks from the date of the request for provisional measures, the International Tribunal for the Law of the Sea or, with respect to activities in the Area, the Seabed Disputes Chamber, may prescribe, modify or revoke provisional measures in accordance with this article if it considers that prima facie the tribunal which is to be constituted would have jurisdiction and that the urgency of the situation so requires. Once constituted, the tribunal to which the dispute has been submitted may modify, revoke or affirm those provisional measures, acting in conformity with paragraphs 1 to 4".

The provisional measures that Malaysia sought were:⁷

- (a) that Singapore shall, pending the decision of the Arbitral Tribunal, suspend all current land reclamation activities in the vicinity of the maritime boundary between the two States or of areas claimed as territorial waters by Malaysia (and specifically around Pulau Tekong and Tuas);
- (b) to the extent it has not already done so, provide Malaysia with full information as to the current and projected works, including in particular their proposed extent, their method of construction, the origin and kind of materials used, and designs for coastal protection and remediation (if any);
- (c) afford Malaysia a full opportunity to comment upon the works and their potential impacts having regard, *inter alia*, to the information provided; and
- (d) agree to negotiate with Malaysia concerning any remaining unresolved issues.

Malaysia appointed Dr. Kamal Hossain of Bangladesh as its ad hoc Judge. Singapore appointed Prof. Bernard Oxman of the USA as its ad hoc Judge. On 20 September 2003, Singapore submitted its response to Malaysia's Request. Oral hearings were then held at five public sittings on 25-27 September 2003.⁸

While the two Agents were in Hamburg, Germany, the President of the ITLOS, Judge Dolliver Nelson, consulted with them about the composition of the Arbitral Tribunal. Article 3 of Annex VII of the UNCLOS prescribes a tribunal of five members. The two ad hoc Judges, Dr. Hossain and Prof. Oxman, were appointed by the Parties. Since the two Parties could not agree on the remaining three arbitrators, the President of the ITLOS could exercise his power under Article 3(e) of Annex VII to make the appointments and is, in fact, required to do so within thirty days of receiving a request from either party to the dispute. Singapore made such a request on 9 September 2003, which meant that the appointments of the arbitrators had to be made by 9 October 2003. Consultations in Hamburg between Judge Dolliver Nelson and the two Agents resulted in the appointment by Judge Nelson of Dr. Christopher Pinto of Sri Lanka as the President of the Tribunal. Prof. Ivan Shearer of Australia and Sir Arthur Watts of the UK were appointed as the two other members.

On 8 October 2003, the ITLOS delivered its unanimous judgement.⁹ A notable feature of the judgement is that the two ad hoc Judges filed a Joint Declaration.¹⁰ This is a rare occurrence. The court did not accede to Malaysia's request for provisional measures against Singapore. In that sense, the outcome was a victory for Singapore. Instead, the court required the two Parties to establish a group of independent experts, with the mandate to conduct a study on terms of reference to be agreed between Malaysia and Singapore. The group of experts was tasked to determine, within a year, the effects of Singapore's land reclamation works and to propose appropriate measures to deal with any adverse effects. This was a brilliant move by the court because it compelled the two Parties to return to a co-operative mode and to resolve their differences on the basis of an objective study by independent experts.

IV. SUBSEQUENT TO THE DELIVERY OF THE ITLOS JUDGEMENT

Malaysia appointed Professor Roger Falconer and Professor Christopher Fleming of the United Kingdom as its two experts. Singapore appointed Professor Kees d'Angremond of the Netherlands and Professor William Kamphuis of Canada as its experts. Professor

⁷ Para. 13, Request for Provisional Measures.

⁸ Verbatim records of the oral proceedings can be found on the ITLOS website at <http://www.itlos.org/start2_en.html>.

⁹ The judgement can be found on the ITLOS website at <http://www.itlos.org/start2_en.html>.

¹⁰ See "Joint declaration of Judges *ad hoc* Hossain and Oxman" on the ITLOS website at <http://www.itlos.org/start2_en.html>.

Falconer and Professor d'Angremond co-chaired the Group of Experts (GOE). Several rounds of negotiations were held before both Parties reached agreement on the GOE's terms of reference. The two governments also agreed to appoint an official each to act as its liaison with the GOE. DHI-Water and Environment, an international consulting and research organisation, was appointed by both governments to assist the GOE in its work.

The whole process worked out very well. The four experts were able to work in a collegial, professional and independent manner. The two liaison officers, Hajjah Rosnani and Mrs. Cheong Koon Hean, developed a good working relationship. The relationship of mutual respect between the two liaison officers also greatly eased the process. Working under tremendous pressure of time, DHI-Water and Environment succeeded in presenting a rigorous (and voluminous) study to the GOE.¹¹ This report was carefully studied by the GOE which then submitted a unanimous report to the two governments on 5 November 2004. The fact that the report was unanimous made it difficult for either Malaysia or Singapore not to accept the report as a basis for their subsequent negotiations to resolve the dispute. Thus, the two governments agreed to the use of the recommendations of the GOE as a basis for seeking a settlement. The study found that Singapore's reclamation works had not caused any serious impact. Of the fifty-seven impacts identified by the experts, they found that forty of them could be detected only in the computer model, but were not likely to be detectable in the field. Of the remaining seventeen impacts, mitigating measures to eliminate them were recommended.

Two rounds of negotiations were held on 22-23 December 2004 in Singapore and 7-9 January 2005 at the Malaysian Embassy in The Hague, the Netherlands. On 9 January 2005, both parties reached an *ad referendum* agreement to settle the dispute.¹² At Malaysia's request, a third round of negotiations was held in Singapore on 8-9 February 2005.

On 10 January 2005, the Agents for the respective governments appeared before the Arbitral Tribunal at the Peace Palace in The Hague. The agreement to meet on 8 and 9 January was useful as it put pressure on the two delegations to settle before they appeared before the tribunal. Before the tribunal, the two Agents took turns to read a joint statement informing the tribunal that the two governments had reached an *ad referendum* agreement to settle the dispute. They promised to inform the tribunal as soon as the agreement had been approved and signed by both governments. The tribunal will then be able to make an order terminating the case.

On 26 April 2005, both governments signed the Settlement Agreement, marking an amicable resolution of the dispute.

V. LESSONS LEARNT

First, the national interests of Singapore are best served by its strict adherence to international law. The importance of international law to Singapore has been reinforced by this land reclamation case and the case of Pedra Branca which is before the International Court of Justice.¹³

¹¹ The report, "Report of the Group of Independent Experts (GOE) in the matter of the ITLOS Order of 8 October 2003, 5 November 2004", is available online at <http://www.mfa.gov.sg/internet/press/land/GOE-Final_Report.PDF>.

¹² A joint press statement was issued by both countries on 9 January 2005; "Case Concerning Land Reclamation by Singapore in and around the Straits of Johor — Joint Press Statement" online: SPRINTER <<http://app.sprinter.gov.sg/data/pr/2005011402.htm>>.

¹³ On 24 July 2003, Malaysia and Singapore jointly submitted to the International Court of Justice a dispute concerning sovereignty over Pedra Branca/Pulau Batu Puteh, Middle Rocks and South Ledge. They did so by notifying the Court of a Special Agreement between them which was signed on 6 February 2003 at Putrajaya and entered into force on 9 May 2003. For a succinct account of this dispute, see Simon S.C. Tay, "Singapore: Review of Major Policy Statement" (2004) 8 S.Y.B.I.L. 219 at 222-3. Also see *Sovereignty over Pedra Branca/Pulau Batu Puteh, Middle Rocks and South Ledge (Malaysia/Singapore)*, online: International Court of Justice <www.icj-cij.org>.

Second, there is no basis for the fear that the ITLOS would be more easily swayed by pro-developing country or pro-environment arguments than, say, the ICJ. The ITLOS has demonstrated competence and integrity which inspires confidence.¹⁴ Third, an important determinant or influence on the state of Singapore-Malaysia bilateral ties is the personality and preferences of the Malaysian Prime Minister. It is not certain that the land reclamation case would have been settled amicably if Dr. Mahathir were still the Prime Minister of Malaysia.¹⁵

Fourth, third-party processes, whether of a legal (eg., submitting a dispute to the ITLOS under the provisions of the UNCLOS) or a technical (eg., the GOE report) nature, are very useful tools to break impasses and to bring disputes to an amicable resolution. Often, the parties themselves would have politicised the dispute to the extent that it is difficult for either party to step back or compromise without third-party intervention.¹⁶ Third-party intervention also permits the application of objective criteria in the search for acceptable solutions. A good example is the employment of the technical expertise of the GOE in this case. This confidence in the effectiveness of third-party intervention explains Singapore's willingness to submit the dispute with Malaysia over Pedra Branca to the ICJ and why Singapore has also suggested the use of third-party resolution methods to resolve other seemingly intractable disputes with Malaysia, such as the Malayan Railway and the price that Singapore pays Malaysia for water supplied.

Fifth, as a maritime nation and State Party to the UNCLOS, Singapore should actively cultivate a keen awareness of its rights and responsibilities under the Convention. Its provisions touch on a broad range of activities in and affecting the oceans and their resources. It is also important that Singapore takes an active interest and, when needed, an active role, in the formulation of these agreements and international legal norms because, as a small country, Singapore relies on them.

Sixth, the ITLOS hearing in Hamburg underlined the importance of meticulous preparation and an intimate familiarity with every point of one's case. Nothing can substitute the need for hard work and careful preparation before one appears before an arbitral tribunal or

¹⁴ The ITLOS has heard thirteen cases since its formation. The case of *Malaysia v Singapore* was the third request for provisional measures to come before the ITLOS. For an overview of the jurisprudence of the ITLOS thus far, see Christoph Schwarte, "Environmental Concerns in the Adjudication of the International Tribunal for the Law of the Sea" (2004) 16 Geo. Int'l Envtl. L. Rev. 421.

¹⁵ See Assif Shameen, "Commentary: Malaysia and Singapore: A New Détente", BusinessWeek Online, 6 September 2004, online at <http://www.businessweek.com/magazine/content/04_36/b3898081.htm> where the author describes how tensions in Malaysia-Singapore relations eased when Mahathir Mohamad stepped down and Abdullah Badawi became the Prime Minister of Malaysia. Similar sentiments were expressed in an article that appeared in the Washington Times; see Sonia Kolesnikov-Jessop, "Singapore Improving Ties with Malaysia", 26 August 2005, online: Washington Times <<http://washingtontimes.com/upi-breaking/20040825-095111-2962r.htm>>.

¹⁶ For an interesting discussion of how this dispute was "securitised" (i.e., made into a security issue) and why such securitisation or politicisation should be avoided, see Kog Yue-Choong, "Environmental Management and Conflict in Southeast Asia — Land Reclamation and its Political Impact", Project on Non-Traditional Security in Asia, Institute of Defence and Strategic Studies (IDSS), Nanyang Technological University, online: IDSS <<http://www.idss-nts.org/environment.htm>>. For an alternative view of how conciliation and inquiry procedures may present viable and attractive alternatives to traditional third-party dispute resolution methods such as adjudication and arbitration in the management of Singapore-Malaysia relations, see C.L. Lim, "The Uses of Pacific Settlement Techniques in Malaysia-Singapore Relations", (2005) 6(2) Melbourne Journal of International Law 313. Also see Simon S.C. Tay, "The 17th Singapore Law Review Lecture: The Singapore-Malaysia Relationship and the Future Roles of International Law", (2004) 24 Sing.L.Rev. 78-92; the author argues that "legal approaches and international law clearly are emergent factors in Singapore-Malaysia relations" (at 92). He also suggests that Singapore and Malaysia establish a joint committee for the study, consultation and conciliation of bilateral issues. However, unlike the committee established in the land reclamation dispute, the proposed joint committee should be given a broad mandate to discuss the spectrum of issues that remain outstanding between both countries. The author believes that this joint committee "...can usefully search for ways in which legitimate concerns from both sides can be addressed. Such a joint working committee would be a useful counter-point to the friction of litigation" (at 91).

in a court of law. A lawyer will not be able to effectively present her case without thorough knowledge of the case.

Seventh, Singapore benefited from the fact that the various agencies involved in the land reclamation process and the settlement of the dispute arising from the reclamation activities were united by a common objective. This engendered close and smooth coordination and cooperation which allowed the Singapore delegation to respond quickly and effectively to developments.

Eighth, an effective negotiator is one who is able to understand the mindset of the other party. To negotiate successfully with Malaysia, a Singapore negotiator should understand the content of the Malay "cultural box" and behave in a manner that is not offensive to a Malay. The way to approach such negotiations would be to adopt a "halus" manner, combining the "hard power" of solid facts and legal arguments with the "soft power" of courtesy, friendship and warmth. Therefore, a good negotiator must possess I.Q., E.Q. (emotional intelligence) and C.Q. (cultural intelligence).

Ninth, it is unrealistic and counter-productive for Singapore negotiators to enter discussions with their counterparts with the expectation that they will behave like Singaporeans. Singapore negotiators cannot expect others to be equally efficiency-driven and must cultivate the virtue of patience.

Finally, key to the resolution of disputes is good inter-personal dynamics between players at all levels. As mentioned earlier, the GOE members interacted very well amongst themselves even though each of them was appointed by one of the parties to the dispute. The good working relationship certainly contributed to the unanimity of the findings of the report, which in turn, provided an excellent basis upon which the two governments could find an amicable solution to the dispute. At the level of the liaison officials, both the Singapore and Malaysia liaison officers got on very well and this personal rapport was crucial to the successful joint administration of the consultancy contract with DHI-Water and Environment. This in turn facilitated the successful conclusion of the study. Finally, at the level of the Agents of the two governments, the very good personal relations between the two Agents developed over many years helped them to bridge the differences in arriving at the Settlement Agreement acceptable to both governments. It is clear that such good personal relations must continue to be fostered between officials of both governments at all levels. As neighbours, disagreements from time to time are inevitable. Good inter-personal dynamics, however, will help significantly in enabling both parties to have at least frank and friendly discussions of those differences, and optimally, the amicable resolution of them.

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Analysis of the Benefit of Land Reclamation and its Application

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Abstract:



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在維基裡 Land reclamation 定義為

Land reclamation

From Wikipedia, the free encyclopedia

Land reclamation, usually known as **reclamation**, and also known as **land fill** (not to be confused with a **landfill**), is the process of creating new land from oceans, riverbeds, or lake beds. The land reclaimed is known as **reclamation ground** or **land fill**.

In a number of other jurisdictions, including parts of the United States,^[1] the term "reclamation" can refer to returning disturbed lands to an improved state. In Alberta, Canada, for example, reclamation is defined by the provincial government as "The process of reconvertng disturbed land to its former or other productive uses."^[2] In Oceania it is frequently referred to as land rehabilitation.

Methods^[edit]

Land reclamation can be achieved with a number of different methods. The most simple method involves filling the area with large amounts of heavy rock and/or cement, then filling with clay and dirt until the desired height is reached. The process is called "infilling"^[3] and the material used to fill the space is generally called "infill".^{[4][5]} Draining of submerged wetlands is often used to reclaim land for agricultural use. Deep cement mixing is used typically in situations in which the material displaced by either dredging or draining may be contaminated and hence needs to be contained. Land dredging is also another method of land reclamation. It is the removal of sediments and debris from the bottom of a body of water. It is commonly used for maintaining reclaimed land masses as sedimentation, a natural process, fills channels and harbors naturally.^[6]

填海造陸，通常稱為**填海**，也稱為**造陸**（不與垃圾填埋場混淆），是從海洋，河床或湖床創造新土地的過程。開墾的土地被稱為**填海場**或**填埋場**。在許多其他司法管轄區，包括美國的部分地區，[1]“填海”一詞可以指將受干擾的土地歸還為改善狀態。例如，在加拿大艾伯塔省，填海工程被省政府定義為“將受干擾的土地重新轉變為其原有或其他生產用途的過程”。[2]在大洋洲，它經常被稱為**填海造陸**。

