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Displacement Filling at Lumut, Sg. Dinding, Malaysia

Abstract

This case study is on a design and build turnkey project using a displacement filling method whereby the design methodology and construction technique of displacement filling in Lumut will be discussed to highlight the steps undertaken to ensure the effectiveness of this method and its overall economic advantages.
A new method of extracting geotechnical parameters called Iternative Technique (IT) used to obtain critical parameters for slope stability analysis will be introduced. Some aspects and observations of rock bund construction on soft soil will also be explained. Apart from that, measures taken as part of the environmental management plan due to the usage of the displacement filling method will also be elaborated.

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Introduction

This paper overviews a case study on the reclamation in Sg. Dinging Lumut, Malaysia. The reclaimed land will be developed for shipbuilding operations and the general location of the project site is as shown in Figure 1.
The reclamation area that is located at the river mouth of Sg. Dinding is protected by Pangkor Island and located 170 km Northwest of Port Klang and 125 km Southeast of Penang Island. The approximate coordinate of Lumut, based on State Cassini Coordinate is W 23700, N 65100.

A reclamation technique that has long been used as the basis for reclamation on soft soil called the displacement filling as described by Terzaghi *et al*. (1995) and the mechanism involved in relation to reclamation using a Trailing Hopper Suction Dredger will be elaborated. Design techniques in terms of displacement filling considering possible heaved soft soil will also be highlighted.

Jasmin Ambrose (right) receiving the 2001 IADC Award from Mr Peter Hamburger, IADC Secretary General.

IADC Award 2001

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At the Sixteenth World Dredging Congress entitled "Dredging for Prosperity; Achieving Social and Economic Benefits", Jasmin Ambrose was presented with the annual IADC Award for young authors. Mr Ambrose is presently a Senior Design Engineer at Asbil Engineering & Construction in Klang Selangor, West Malaysia.
Each year at a selected conference, the International Association of Dredging Companies grants an award to a paper written by an author younger than 35 years of age. The Paper Committee of the conference is asked to recommend a prize-winner whose paper makes a significant contribution to the literature on dredging and related fields. The purpose of the award is "to stimulate the promotion of new ideas and encourage younger men and women in the dredging industry". The IADC Award consists of US$ 1000, a certificate of recognition and publication in *Terra et Aqua.*

Figure 1. General location of reclamation area in Sg. Dinding in Malaysia.

The general plan called for dredging of the softest of the clay, and dumping sand to build up the embankment. It was also necessary that side slopes be trimmed to optimise the overall fill volume. Using this method it would be difficult to predict the stability of the embankment owing to the endless uncertainties involved with the initial method of reclamation. Overall the decision to design the embankment for the construction stage using displacement filling and a safety factor (SF) near one was made based on economic considerations. Calculated risk taken by the engineers weighed costs of failure repairs against the cost of conservative design. This decision made in the early planning stage, contributed more than any other to the economic completion of the job.

Basic Concept of Displacement Filling

Displacement filling has always been understood in simple terms as removal of soft bearing material owing to heavier fill material. To elaborate further on this observable fact, the heavier fill material causes high stresses on the soft soil, therefore a general shear bearing capacity failure occurs in the soft soil and this causes displacement of the soft soil and penetration of the fill material into the soft soil. As shown in Figure 2, the active earth pressure of the fill material which is $K_a*\gamma*H$ (K_a + active earth pressure coefficient, γ = Bulk unit weight of fill material and H is the height of fill). The passive lateral resistance pressure of the soft soil that is fluid in behaviour will be $\gamma*H$.

Therefore the soft soil will be displaced laterally as long as the active pressure of the fill is larger than the soft soils passive pressure.

Both bearing capacity failure of soft soil and larger lateral pressure of fill should be satisfied to have an effective displacement of soft soil. Apart from this simplified description to determine lateral pressure of soil, there are various other computational methods that can yield better results using standard empirical formulae. However, detailed analyses are difficult as the properties of the soft soil changes throughout the process of reclamation (displacement filling).

Preliminary consideration for selection of displacement filling

Reclamation on soft soil may be unable to sustain the weight of a fill more that a metre or so in height. Basic bearing capacity formula such as $5.14*c_u$ may be used to determine the quality of fill material required for displacement. However owing to non-homogenous characteristics of soft soil beneath (increase in soil strength with depth), it was assumed that only the top most layer that is very soft (slime) will be effectively displaced. This assumption was adopted because there is no previously documented experiment on displacement filling that can be used to confirm the effectiveness of this method.

Considering the above circumstances the engineer may choose between two alternatives which is to either displace the soft soil or to apply the fill at a certain rate that the soft soil does not fail but gains sufficient strength by consolidation to support the fill at its final height with acceptable settlement. Weighing the soil conditions, soft soil thickness, availability of fill material, construction period and feasibility, it was decided that the displacement method is the most suitable method for this project. Some advantages and disadvantages of displacement filling are shown in Table I.

In Lumut, usage of geotextile reinforcement was initially suggested. However stability analysis conducted showed that its application was not effective to stabilise the embankment and the construction period would be longer. It is also normal practice that reinforcing geotextile (woven geotextile) are used with a factor of safety as high as 3. This would cause the overall construction cost to increase tremendously. Apart from that settlement of soft soil beneath fill will cause unaccounted strain on reinforcing geotextile that causes rapid loss in strength of geotextile reinforcement which defeats the whole purpose of installing a geotextile reinforcement. Soil improvement using vertical drains which was planned for installation once fill is above high water level will cause propagating tensile failure on the reinforcing geotextile and a similar problem was addressed by Koerner (1995) whereby an increase in SF was recommended owing to the reduction in geotextile's strength.

Table I. Advantages and disadvantages of displacement filling.

Advantages	Disadvantages
a) Overall cost effective.	a) Larger fill volume due to direct discharge technique adopted.
b) Reduced settlement at location of displaced soft soil.	b) Removal of heaved slime causes cost and possible to slide if removed.
c) Shorter construction period since there is no need for controlled filling.	c) Possibility of excessive sliding due to reduction of soft soils shear strength to residual shear strength.
d) Does not need geotextile reinforcement during embankment construction.	d) Entrapment of clay layer that leads to invalid assumption of the final embankment gometry causing inaccuracies in stability analysis.
e) Cost saving on soil improvement since soft soil thickness is reduced.	e) Increased settlement at locations where soft soils are trapped.

Soil Parameters for Embankment Stability Analysis

To perform embankment stability analyses it is crucial that sufficient soil data are available. A method developed using IT will be utilised to obtain all parameters required to perform stability analysis. Using this unique IT, soil parameters such as γ and ϕ can be rationally determined for stability analyses.

The (IT) is a theoretical approach to utilise N-values and its correlation to derive soil parameters (Ab. Malik and Ambrose, 1999). Although the standard penetration test is an inexact method, it can be used advantageously for the study of soil properties and in most instances (depending on the scale of the project) N-values may even be sufficient for final design (Bazaraa, 1982). The IT using N-values allows the engineer who conducts the analyses to control the input and output information of the analyses in a systematic and organised fashion. IT is useful especially for soil properties prediction using N-values whereby important soil parameters have not been obtained in the soil investigation due to some unknown reason.

N-values and IT

The Standard Penetration Test (SPT), developed around 1927 (Bowles, 1988), is currently still one of the most popular and economical means to obtain subsurface information of soil (Moh, 1985). It has been used in correlation to determine unit weight, γ, relative density, D_r, angle of internal friction, ϕ', and the undrained compressive strength, q_u (Carter, 1983). It has also been used for estimating the stress strain modulus of soil, E, and the bearing capacity of foundations.

Iterations known previously in geotechnical engineering application for approximate determination of total stress values (Yu and Houlsby, 1991), while Christuolas (1985) have suggested N–ϕ, D_r–ϕ and N–D_r correlations for the determination of pile capacity in sand.

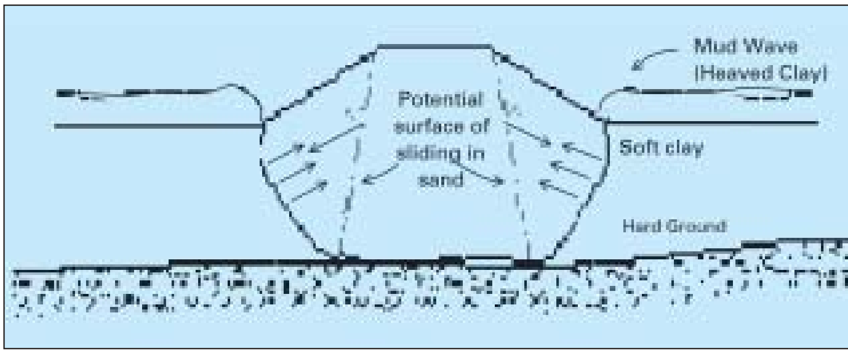


Figure 2. Forces that act on soil adjacent to buried part of a fill constructed by the displacement method (after Terzaghi et al. 1995).

However, this correlation does not relate N with overburden stress and unit weight of soil.

Iterative Technique is an approach that is used based on the assumption that the correlation used to relate N-values and the soil properties (ϕ', c_u, D_r, γ) are valid. A description of this technique will be presented here, covering the iteration process, and the suggested correlations. The IT process is presented in a stepwise manner to achieve better understanding of this method. For embankment stability ealuation N-values are used to derive ϕ', c_u and γ in soft soil and these parameters are the basic soil properties required for embankment stability analysis.

Stepwise procedures for IT

STAGE 1. N-Value is firstly corrected for the water table and to account for fine or silty sand below water (Coyle & Costello, 1981; Heydinger, 1984), as given in Eqn. 1. This correction factor is for the common form of error in performing the standard penetration test in sand or silt below ground water table (Bazaraa, 1982).
Water table correction on N-Values is just an example of one correction factor that can be applied on N-Values

for discrepancies occurring due to, e.g., differences in equipments' manufacturers, uncertainties in geotechnical parameters and drive hammer configuration. However corrections for all these parameters are site specific and differ from one manufacturer to another.

$$N' = \tfrac{1}{2}(N-15)+15 \qquad \text{Eqn. 1}$$

STAGE 2. The effective friction angle of sand, ϕ', can be correlated with the N'-values corrected for overburden-stress, N" (Norlund, 1963), using the relationship as presented by Peck et al., in 1974 (Wolff and Conroy, 1991; Ab. Malik, 1992), which can be approximated as:

$$\phi' = 26.7 + 0.36N'' - 0.0014(N'')^2 \qquad \text{Eqn. 2}$$

However, because N" is not available due to unavailable overburden stress data, σ_V, where N" is N-value corrected for overburden stress. In other words the unit weight, γ, is not available, therefore a preliminary assumption of N' = N" is presumed in Eqn. 2.
After the 1st iteration of the IT LOOP (1st IT LOOP), when N" is available, ϕ' can be calculated using N".
This step requires at least two complete iterations, i.e. 2nd iteration of IT LOOP (2nd IT LOOP).
This process is shown in Figure 3.

STAGE 3. The effective angle of shearing resistance ϕ' and the relative density, D_r, als in Eqn. 3 can be correlated as presented by Meyerhof in 1959 (Bowles, 1988). Equation 3 is rearranged to obtain D_r as a function ϕ' in Eqn. 4 whereby:

$$\phi' = 28 + 0.15{*}D_r \qquad \text{Eqn. 3}$$

$$D_r = \frac{\phi' - 28}{0.15} \qquad \text{Eqn. 4}$$

Even though Eqn. 4, can give a rough approximation of D_r, the expression in Eqn. 3 was not derived for the purpose of evaluation relative density from effective angle of internal friction, ϕ'. However, preliminary stability analysis utilising these data has provided satisfactory results.

STAGE 4. Now the relative density from Eqn. 4 can be applied into Eqn. 5 to find the unit weight, γ, of sand.

$$D_r = \frac{(\gamma' - \gamma'_{min})\gamma'_{max}}{(\gamma'_{max} - \gamma'_{min}) \times (\gamma\gamma)} \qquad \text{Eqn. 5}$$

Whereby γ_{max} and γ_{min} are arbitrarily chosen values considering medium and dense sand as a preset limit for normal sand conditions. Preset values chosen are γ_{max} = 20 kN/m^3 (D_r = 0.65) for dense sand and γ_{min} = 17 kN/m^3 (D_r = 0.35) for medium dense sand

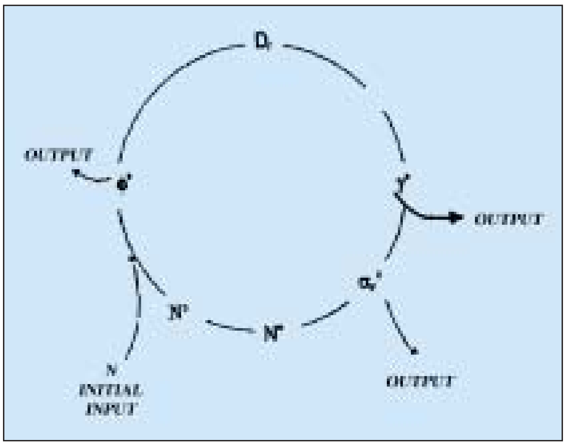


Figure 3. The IT loop for prediction of design parameters.

(relative density for most soil is in between 0.35 – 0.65). The simplification of this formula is as shown in Eqn. 6.

$$\gamma' = \frac{340}{20 - 3D_r} \qquad \text{Eqn. 6}$$

Equations 4, 5 and 6 are applied to find D_r and γ'.
To obtain effective unit weight, γ', γ_W is subtracted from the bulk unit weight as in Eqn. 7 (for submerged cases).

$$\gamma' = \gamma - \gamma_w \qquad \text{Eqn. 7}$$

STAGE 5. It is known from soil mechanics theory that the effective overburden stress, σ_V', can be determined as long as the unit weight and the depth of the soil element can be determined accurately. Therefore overburden stress, σ_V', dan be represented as:

$$Q_v' = \sum_{i=0}^{n} \left[\gamma_n' z\right]_i \qquad \text{Eqn. 8}$$

STAGE 6. The final link for this procedure is completed using a correction factor for overburden stress similarly used by Coyle and Costello (1981) (Heydinger, 1984) will be used in this study. This correlation is as presented in Eqn. 9, and this will be used in all the analyses using IT.

$$N'' = N'{*}0.77{*}\log\left(\frac{1915.2}{Q_v'}\right);(Q_v' \text{ is in kPa}) \qquad \text{Eqn. 9}$$

STAGE 7. Now a loop has been created where the corrected SPT-N value, N", can be used to obtain ϕ', D_r, γ' and c_u (N–c_u correlation) by continuous iteration. This loop as shown in Figure 3 need only a single input, N-value, however input and output can be at any level of iteration in the loop.

Abbreviations

ϕ' – Drained angle of friction
γ – Bulk unit weight of soil
D_r – Relative density of soil
K_a – Active earth pressure coefficient
H – Thickness of soil
SF – Safety factor
P_a – Active earth pressure
IT – Iterative technique
q_u – Unconfirmed compressive strength of soft soil
N-values – SPT-N values derived from standard penetration test
SPT – Standard penetration test
E – Stress strain modulus of soil
σ'_v – Effective overburden stress
z – Depth in soil from ground level
c_u – Undrained shear strength of soft soil
c' – Drained shear strength of soft soil
MLWS – Mean low water spring level
MHWS – Mean high water spring level
σ_{cu} – Standard deviation of undrained shear strength values around mean strength value

The method described in Stages 1 to 7 can now be used to determine γ, ϕ' and c_u to conduct embankment stability analyses.

Method of Embankment Stability Analysis

This paper was not intended to elaborate on detailed numerical stability analysis because of space limitations and there are many other references and publications with detailed explanations on slope stability analysis (e.g. Nash {1987}, Fredlund and Krahn {1977}, Lafleur and Lefebvre {1980}, Charles and Soares {1984} and many others). However the different stages of analysis considering displacement filling as the adopted methodology are highlighted to elaborate on the various possibilities considered before arriving at the intended solution. Soil data extrapolated using IT was used for the stability analysis.

Analysis was carefully separated into Pre-Construction, During Construction and Post-Construction conditions. This is important because the geometry and soil property of the embankment change during the different construction stages described. In terms of slope stability it is usually related to the changes in sub soil strength, which in this case is the controlling factor (for deep seated failure check). Relating to the different construction stages, the slope stability analysis on soft soil will be for the different construction stages, the slope stability on soft soil will be for undrained shear strength, c_u (During construction) and drained shear strength c' (Post-construction).

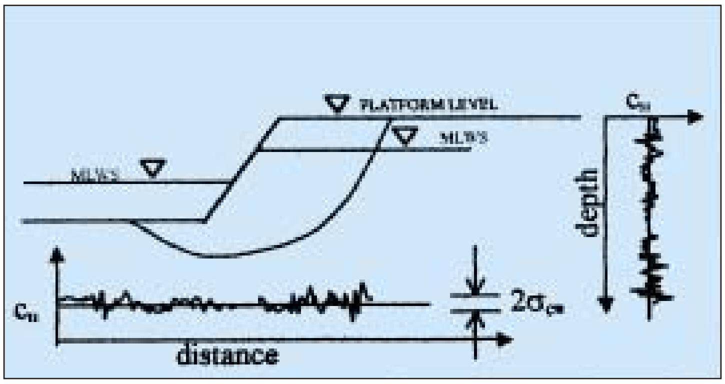


Figure 4. Variation of soil properties with varying depth and distance to embankment profile.

Delineation of the soil profile (soil properties) as shown in Figure 4 and different methods for computation of SF have to be considered. Any method of analysis may be adopted and all are generally accepted and in this case the critical condition that needs to be checked would be for a deep-seated failure. One logical approach for taking a systematic conservative shear strength value would be $c_u - \sigma_{cu}$, whereby c_u is the average shear strength of soft soil in a particular layer while σ_{cu} is the standard deviation of the soft soil's shear strength value in a particular soft soil layer.

This is as shown in the c_u *vs* distance graph in Figure 4. The c_u *vs* depth graph is only used for cases of homogeneous soil condition which almost never exist. This is consistent with the input data that are usually required by most slope stability analysis software.

Some considerations during analyses
Some factors to be considered in the design of reclaimed embankment on soft soil (approximately 10 m thick) with embankment fill height of approximately 13 m high (from toe to crest) include:

a) Embankment construction is in water (reclamation), therefore increased stability due to water frontage whereby sea water level taken as MLWS and water level in soil as MHWS to consider water logged condition which would be the most critical condition.
b) The angle of the slope is directly related to the stability of the slope, but there is limitation due to the allowable boundary of reclamation and gentler slope means higher sand volume and increased cost of reclamation.
c) Changed soft soil geometry due to displacement filling (original soft soil strength approximately

10 Kpa) whereby geometry of slope is crucial in any stability analysis.
d) Properties of soft soil at the seabed changes throughout the process of reclamation.
e) Embankment failure need not be defined as slight movement of embankment, but as large slips which can be identified by very low SF, whereby SF is the ratio of resisting moment over acting moment of the embankment mass.
f) Varying slope geometry involving different soils underneath causes a certain level of uncertainty in the analysis conducted.

Pre-construction analysis
At this stage the analysis includes extraction of parameters obtained from the soil investigation. The soil investigation should be conducted in an alignment perpendicular to the direction of the embankment to ease modelling of embankment geometry and its respective soil properties. The engineer may conduct simple statistical data treatment at this stage whereby the average shear strength values c_u minus σ_{cu} will give conservative shear strength values. A more rigorous method of analysis includes using Reliability theory to determine cost of variation, Mean Factor of Safety, Reliability index, Safety Measure and probability of failure.

Well known techniques include Monte Carlo technique and Bayesian theorem whereby the latter is more widely accepted. The simpler statistical method using c_u minus σ_{cu} described earlier, was the method adopted for the final design while the more vigorous analysis may be used in the final analysis of Intermediate and Post-Construction stages but will not be elaborated in this paper.

Intermediate construction analysis
This stage of analysis is important to check the stability of the embankment during construction and would determine the method of construction to be adopted. To further elaborate, it was understood that a construction period of three months was allocated for construction of the embankment and another three months for installation of shore protection works. The three months allocated for the construction stage was chosen because this would give time for increase in soil strength and the duration must be compatible with the dredger's capacity chosen for reclamation.

Based on the construction schedule, a trailing hopper suction dredger was chosen. As a design and build turnkey contractor, the analysis was to include the effect of the dredger chosen for the embankment construction. The main concern was the high rate of filling that could cause embankment failure. Here the definition "failure" should be related to the extent of failure or better described as to what extent it would affect the overall project. Different embankment geometry throughout reclamation area was analysed using undrained soil strength values (short term stability) using a simple assumption that there is no increase in soil strength values owing to increase in overburden stress (filling).

This assumption was necessary as release in excess pore water pressure in soft soil resulting in gain in shear strength will require longer time and this assumption obviously will give conservative results to the overall design. Adopting displacement filling for embankment construction with SF less than unity shows that there will be some movement of the embankment, and this should not be understood as a failure whereby filled slope construction (reclamation) in water using displacement filling will definitely have high localised movement. After construction, the embankment movement must be minimal to ensure that the superstructure and infrastructure constructed on this reclaimed land will be stable and safe. This will be checked in the long term stability analysis.

The movement of the embankment's mass will gradually stop once the acting moment (acting slope mass) equals the resisting moment (resistance from shear strength of soil), but this movement will also reduce the undrained shear strength of the soft soil (along with the slip circle) to residual shear strength values. Another fact also considered is that slips that occur will cause displacement of the subsoil and heaving at toe stabilizes the embankment.

The embankment construction using reclamation technique was analysed and it was decided that for all cases the embankment shall be overfilled by 10 m beyond the limit of reclamation. This is important to ensure the heaved soft soil at the toe of the slope is separated from the main embankment toe and allowing for further extent of prefabricated vertical drain (PVD) installation. This is also important to ensure that any future dredging around this area that can cause movement of the soft soil at the toe does not affect the main embankment. From the slope stability analysis is was determined that the short term stability (Undrained analysis) without any soft soil heaved at the toe is with a SF = 1.067 – 1.4. The lower range of these values is slightly below the adopted value of SF = 1.2 for short term stability, showing that some slips are bound to occur at some of these locations.

Post-construction analysis
Post-construction analysis refers to long term stability of the embankment taking into account creep, chemical weathering, or removal of soluble binder from soil mass. Other factors not related to the geotechnical properties of the embankment but affecting the selection of SF includes the possibility of a slide that might endanger life or property. Long term stability analysis (drained analysis using ϕ' values extracted from plasticity

index (PI) *vs* sin ϕ′correlation) without any clay formation at the slope toe was carried out and a SF = 1.54 was obtained. However, the critical slip circle obtained showed that these failures are owing to surface slips in the fill material which are not critical.

This analysis is not usually preferred because ideally drained shear strength values should be obtained from laboratory tests (which models actual behaviour of the soft soil under controlled load due to its site specific behaviour) instead of standard correlations.

However, in the absence of sufficient test data these standard correlations may be applied. A deep seated failure analysis which is the most important aspect of slope stability in relation to reclamation on soft soil was carried out and the drained ϕ′ values were obtained using the above chart for long term stability analysis and the lowest SF of 1,85 was obtained. This value is larger than the usual long term SF of 1.5 indicating long term stability of embankment is satisfied.

ADOPTED DESIGN

During reclamation activity, two methods of filling were adopted in stages. In the initial stage (1st stage) of reclamation the dredger's central discharge system was used whereby this technique will displace very soft material (slime) on the surface layer of the seabed. An illustration of the explained concept is as shown in Figure 5. As for the second stage of filling (2nd stage), land based equipments were used to complete the displacement filling exercise and these are detailed in the section below.

Referring to the concept highlighted in Figure 5, there are limitations to this method and one of this limitation includes the minimum factor of slope stability, as explained by Eqn. 10. Safety factor with respect to sliding of fill material may be expressed as follows:

$$SF = \frac{\tan\phi'}{\tan\beta} \qquad \text{Eqn. 10}$$

Therefore clean dry sand, with internal angle of friction of ϕ′, can be heaped with a slope angle lesser than ß, irrespective of its height and keeping in mind that free falling sand (heaped sand in Quarry as an analogy) will be stable with a slope angle lesser than its own angle of internal friction. However this is not possible during pumping of sand (during reclamation using direct discharge) because of the high water to sand ratio pumped and therefore water pressure from the high mix ratio that is required to assist in sand particle transportation causes a temporary reduction in the effective angle of friction of sand and resulting in a gentler slope (1:6 to 1:8). This discourages displacement filling and

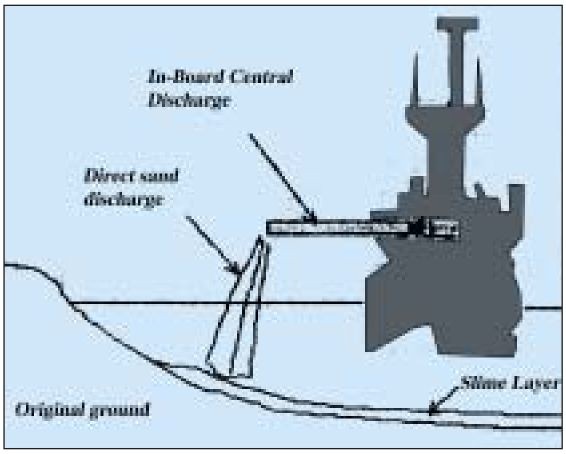


Figure 5. Direct discharge from in board central discharge system.

causes an increase in sand volume required to form the final embankment. The gentle slope causes another problem, that is, the dredger has lesser draft thus reducing its reach to discharge directly to the dry embankment to reduce sand loss.

In relation to reclamation in Lumut, the trailing hopper suction dredger was initially used as a direct discharge method (without using pipeline to displace soft soil) as shown in Figure 5. The reclaimed embankment not only resulted in higher sand volume, it also increased the cost of slope protection because the slope face (distance between crest and toe) length increased.

Definitely one way adopted to reduce this problem was by using a pipeline after displacement of the soft soil, and this was the second stage of embankment construction. This proved that sand pumped on permeable ground (sand) allows the fill material to gain strength once the water is drained out from the fill material. This drained sand was used to construct the embankment and it is important to provide slope protection as soon as possible to reduce sand loss.

Another approach used to recollect the excessive sand on the slope was by using small size pontoons with lesser draft requirement to pump the excessiv material at the slope face onto the dry embankment resulting in a steeper slope angle. Other options explored include using Clamshell and Long Arm Excavators.
However both of these equipments have insufficient reach on the long slope face that needs to be trimmed to its final profile.

Control of fill drection to assist displacement
Controlled filling of sand transported onto embankment using pipelines was carried out using land based equipment and this is identified as the 2nd stage of reclamation. This technique is somewhat new as it is undocumented in terms of its effectiveness. The usual problem faced in displacement filling is the entrapment

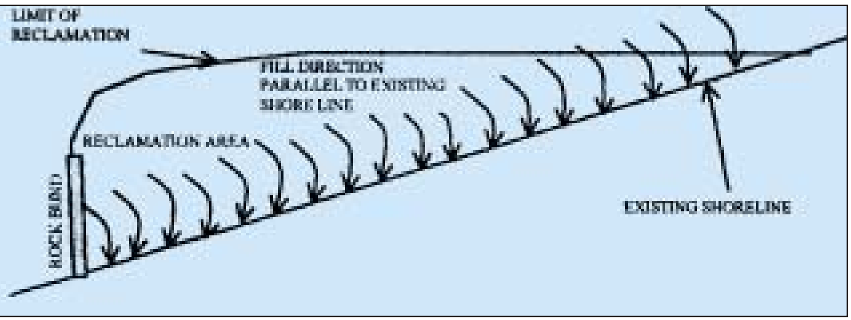


Figure 6. Controlled fill direction to reduce entrapment of soft soil as practiced in Lumut, Malaysia.

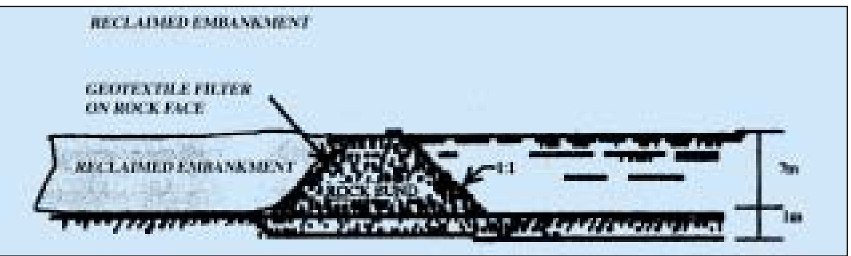
of the soft heaved slime causing reduced stability of the embankment and excessive settlement after construction. To assume that these pockets of heaved slime layer entrapped are to be taken as the controlling factor for soil improvement, will cause a significant increase in soil improvement cost. Therefore controlled direction of discharge parallel to the slope as shown in Figure 5 was adopted to continuously push the heaved soft soil away from the embankment.

Using displacement filling technique, it was also important to ensure that the direction of filling is in a manner that there are no horizontal entrapments (parallel to existing and new shoreline) occurring. The method adopted is as shown in Figure 6, whereby the fill direction was always maintained parallel to the existing shoreline and as the embankment construction progresses away from the existing shoreline, fill direction was maintained parallel to the final embankment shoreline.

Rock Fill on Soft Soil

A rock bund was constructed at a location as shown on Figure 7 to increase the stability of the steep slope. This rock filled embankment was constructed to protect the main discharge drains from being clogged. As anticipated the rock filled embankment settled 1.2 m immediately after its construction. This however cannot be defined as settlement due to consolidation of soft soil underneath, but as a localised bearing capacity failure. A total embankment failure causing excessive settlement was avoided using a sand layer beneath the rock bund. This method was used to avoid direct contact between the rock face and soft soil that will cause high concentration of local stresses that causes punching failure in soft soil. Total settlement after construction is approximately 1.6 m.

Figure 7. Rock Bund constructed on soft soil to create a steep slope face in Lumut, Malaysia.



Instead of placing a sand layer on the rock placement area, direct discharge technique using displacement filling was used as described earlier. Settlement curves of the rock bund shown in Figure 8 indicated that the local bearing failure of the rock bund occurred within days while the local bearing failure of the sand filled embankment (collapsed to displace the bearing soft soil) occurred 1 to 2 weeks after construction. This is due to the higher density of the rock fill compared to sand filled embankment.

No excessively heaved clay was recorded at site during construction or 6 months after construction. However continuous observation is necessary to determine the final results. Barbesis 1935 explains that similar techniques have been successfully used in construction of breakwater in the harbours of Valparaiso, Chile and Kobe, Japan (Terzaghi *et al*. 1995).

Silt Screen as a Control for Displacement Filling

The environmental aspects of dredging and reclamation cycle can be described by the different processes involved in a dredging operation. In Lumut, the process involved dislodging of the in-situ material during reclamation, raising of the dredged material, horizontal transport of dredged material and placement of dredged material. Of the four phases described, only placement of material (reclamation) is of relevance to this project.

During construction of the embankment using central discharge system to accommodate displacement filling, fine sediments were dispersed causing heavy pollution to the surrounding waters. The water quality in this area had to be controlled to avoid adverse impacts on marine life, especially in Lumut as this area is known for its fishery and tourism activities. As part of the environmental management plan, a silt screen and water quality monitoring programme were introduced to reduce the adverse affect owing to displacement of soft seabed sediments. To maintain water quality of the reclaimed area, a silt screen was designed and constructed at site.

In the design stage of the silt screen some of the factors considered were wave action, wire rope strength, type of connections, distance between floaters, materials to be used for sediment screening, counter weights, tide fluctuations and anchors. Initially a 70 m test silt screen was constructed to verify

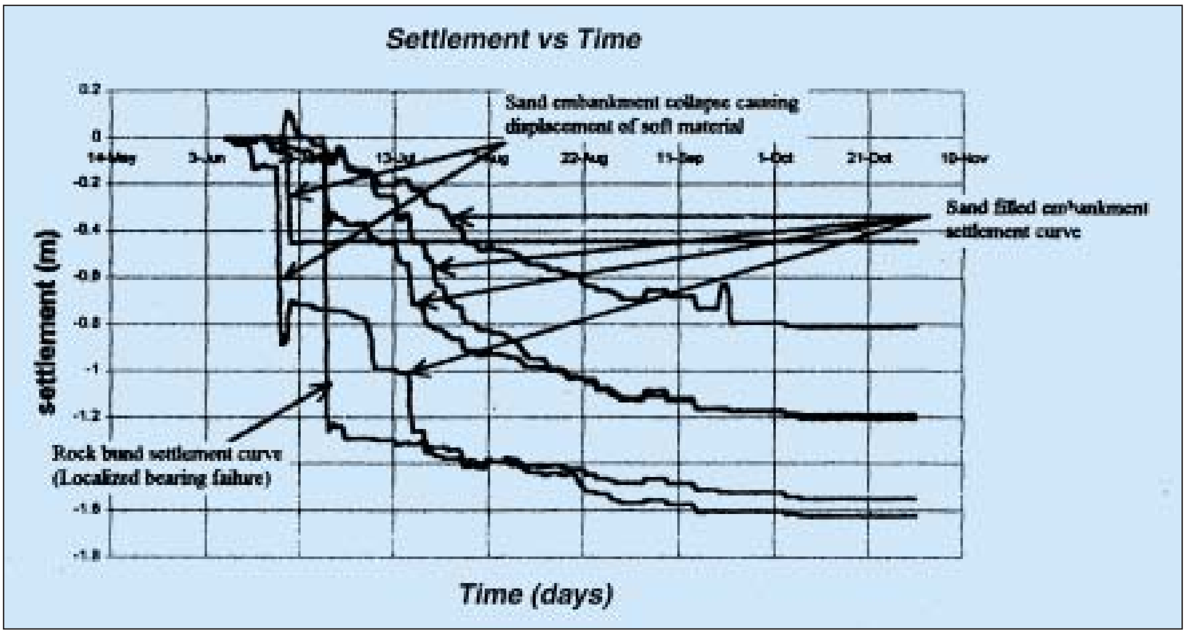


Figure 8. Settlement curves for rock bund and sand embankment showing immediate collapse as proof of displacement filling.

its performance especially against the wave action and strong current in Sg. Dinding, and it was concluded that the designed counterweights were inadequate to maintain the silt screen in its location. Therefore additional anchorage to seabed was provided using anchors fabricated from high tensile steel bars.

These anchors were installed after the silt screen was suitably placed without causing any distraction to the dredger's path, notably because the silt screen with anchors is not easily relocated as may be required from time to time. The silt screen functions mainly to diffuse fine particles movement safely using the physical method. Another advantage of this method is that it does not chemically pollute the environment. The biggest advantage would be that the silt screen can be fabricated at site and launched using minimum labour.

Conclusion

At the moment very little is understood about the behaviour of soft soil in relation to displacement filling. There is a need to model the interaction between soft soil material filled with denser fill material. This modelling will help to predict the extent or effectiveness of displacement filling. With better predictions derived from laboratory and site observations. it is also easier to justify the cost and explain the economic advantages of displacement filling in comparison to other methods of reclamation.

Despite the fact that the described methodology is widely used (even though not widely discussed), this case study serves as an outstanding model for future large scale reclamation on soft soil. This case study also serves as an excellent example on the factors to be considered when choosing a design SF with an eye towards the costs and risks associated with a project.

"Risks are inherent in any project that the existence of such risks should be recognized, and steps representing a balance between economy and safety should be systematically taken to deal with these risks. Two ways of defining calculated risk are:

a) The use of imperfect knowledge, guided by judgement and experience, to estimate the probable ranges for all pertinent quantities that enter into the solution of the problem.

b) The decision on an appropriate margin of safety, or degree of risk, taking in to consideration economic factors and the magnitude of losses that would result from failure."

From Arthur Cassagrande's Terzaghi Lecture of 1964 (Whitman 1984)

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