Information Sheet

Paper Title: Towards A Sustainable Reclamation for Hong Kong

Authors:

a. Ir. Albert Cheng Ting Ning,

Highways Department HKSAR

4th Floor, Ho Man Tin Government Offices, 88 Chung Hau Street, Ho Man Tin, Kowloon

Tel: 27623400
pm.hzmb@hyd.gov.hk

b. Ir. Aaron Bok Kok Ming,

Highways Department HKSAR

4th Floor, Ho Man Tin Government Offices, 88 Chung Hau Street, Ho Man Tin, Kowloon

Tel: 27624986
cehkbcf.hzmb@hyd.gov.hk

c. Ir. Dr. Daman Lee

Ove Arup & Partners Hong Kong Limited

Festival Walk

80 Tat Chee Avenue, Kowloon Tong, Kowloon

Tel: 22683425
daman.lee@arup.com

d. Ir. Dr. K K Yin

Ove Arup & Partners Hong Kong Limited

Festival Walk

80 Tat Chee Avenue, Kowloon Tong, Kowloon

Tel: 22683471
kek-kiong.yin@arup.com

Towards A Sustainable Reclamation for Hong Kong

Albert Cheng Ting Ning, JP *Project Manager HKSAR Highways Department*

Aaron Bok Kwok Ming, *Chief Engineer HKSAR Highways Department*

Daman Lee, *Director Ove Arup & Partners Hong Kong Limited*

K K Yin, *Director Ove Arup & Partners Hong Kong Limited*

Synopsis

The call for sustainable development within the built environment has often been the lead priority amongst many of today's governments' agenda globally. Hong Kong is of no exception for this course, and has often led in many of its policies. The Hong Kong Zhuhai Macao Bridge (HZMB), being one of ten major infrastructure project announced by the Chief Executive's Policy Address, is poised to embrace the principle of sustainability for its reclamation.

The HZMB Hong Kong Boundary Crossing Facility (HKBCF) will be located on an artificial island of approximately 150 hectares to be reclaimed in a sustainable manner. The methodology for both the construction of the seawall and the main reclamation area will ensure that the marine soft compressible material remains intact during the process of land formation; i.e. a fully non-dredge reclamation - the first ever method adopted in Hong Kong. No dumping of marine sediments is thus required. With this design sandfill consumption, suspended particles and marine traffic during construction can be significantly reduced. The seawall will be made up of individual circular steel cellular units and physically connected with arc units to form the peripheral retaining structure for the main reclamation. To achieve stability, ground improvement technique using stone column shall be installed to render the subsoil's enhancement in strength parameters.

Over 60% of the main reclamation shall be filled with public fill material from various sources in Hong Kong. The rationale for this approach is to mitigate potential saturation of existing fill banks as well as re-exportation of public fill to the neighbouring Mainland areas. Liaison work between the various government agencies as well as statutory bodies is vital to achieve the balance.

The team's aim is to improvise a sustainable reclamation within the realms of Hong Kong statutory requirements and set the landmark methodology for future reclamation in the territory. This paper reflects the team's effort in introducing the methodology, driving the approach, solving the major constraints, and arriving unanimous consensus among the various government agencies to procure a fully sustainable reclamation for Hong Kong.

Introduction

A Brief Account

When the Hong Kong Zhuhai Macao Bridge (HZMB) officially opens in 2016, it will represent the culmination of engineering, economic policies and strategies of the three governments of Hong Kong, China and Macao. It is an explicit commitment to the attainment of high levels cooperation within the Pearl River Delta in the 21st century. Within it, an equally arduous task is to imagine the engineering challenges ahead to make the project a reality.

This essay reinforces the general approach, undertaken by the team, for a part of the HZMB which forms the first portion to be constructed in Hong Kong. Concerning issues included the need for development growth and the environment, for which the authors attempted to establish compatibility for material progress and respect for the physical environment. The first portion being the reclamation of an island to form approximately 150 hectares of land to house the boundary crossing facilities as well as infrastructure networks. In arriving this, the team looked into the various existing methodologies, both in and outside Hong Kong, before subscribing to an option that has least impact on the environment and in a sustainable manner. As this is the first of its kind in Hong Kong, the team's efforts included indistinguishable struggle to convince peer authorities in a professional manner. The achievements and benefits of such struggle will see the re-shaping of future reclamations within the Hong Kong Special Administrative Region (HKSAR).

One of the underlying principles for this paper is the idea that industry is dependent both on natural resources and on the capacity of the environment to accommodate the waste which it generates. The sustained development of industry is, therefore, dependent on the continued existence of the source and functions of the natural environment. This analysis was the starting point in the consideration of various strategies that could incorporate these concerns into its hitherto narrower focus for economic, industrial and development growth.

Global Reclamation

Land reclamation, usually known as reclamation, is the process to create new land from sea or riverbeds. The land reclaimed is known as reclamation ground. The creation of new land was for the need of human activities. This phenomenon is most explicit in Hong Kong due to land scarcity, figure 1. Over 68 square kilometres of our developable land came from reclamation.

Notable examples in the West include large parts of the Netherlands; parts of New Orleans (which is partially built on land that was once swamp); much of San Francisco's waterfront has been reclaimed from the San Francisco Bay; Mexico City (which is situated at the former site of Lake Texcoco); Helsinki (of which the major part of the city center is built on reclaimed land); the Cape Town foreshore; the Chicago shoreline; the Manila Bay shoreline; Back Bay, Boston, Massachusetts; Battery Park City, Manhattan; Liberty State Park, Jersey City; the port of Zeebrugge in Belgium; the southwestern residential area in Brest, Belarus, the polders of the Netherlands; the Toronto Islands, Leslie Street Spit; and the waterfront in Toronto, just to name a few.

In the Far East, Japan, the southern Chinese cities of Hong Kong, Shenzhen and Macao, the Philippines capital Manila, and the city-state of Singapore, where land is in short supply, are also famous for their efforts on land reclamation. One of the earliest was the Praya Reclamation Scheme, which added 50 to 60 acres (240,000 m^2) of land in 1890 along Hong Kong's Central waterfront during the second phase of construction. It was one of the most ambitious projects ever taken during the then Colonial Hong Kong era, *ref 1*.

Figure 1 Reclamation in Hong Kong at a glance

Artificial islands are examples of land reclamation. Creating an artificial island is an expensive and risky undertaking. It is often considered in places that are densely populated and flat land is scarce. Kansai International Airport (in Osaka) and Hong Kong International Airport are examples where this process was deemed necessary. The Palm Islands, The World and hotel Burj al-Arab of Dubai in the United Arab Emirates are other examples of artificial islands.

Sustainable Reclamation

With so many examples of reclamation undertaken globally, there is a need to seek a holistic approach in this age of sustainable development. This paper seeks the various ways and means to fully encapsulate the principle of sustainability for a 21st century mega project undertaken by the HKSAR government. This collection represents the fruits of the team's research on industry and environment. It examines environmental issues from an industrial policy perspective. The paper combines the insights of a multidisciplinary team, committed to the twinning and intimately related imperatives of industrial development and environmental sustainability. Our efforts represent a beginning and an important objective to be addressed if this work is the catalyst for further research/methodologies.

Metamorphisms of Reclamation

Historically, reclamation in Hong Kong has been concentrated along the coastline of Kowloon and Hong Kong. The waterfront development in Hong Kong has a long history. Before 1984, thirty-three square kilometres had been added to Hong Kong by waterfront reclamation. Since that time the amount of reclamation is equal to all the reclamation done in the city from 1945. The need for more land of various kinds continues to grow steadily in both scale and diversity. Victoria Harbour, and Hong Kong itself, have experienced several distinct eras whereby forces and demands have changed the water/land edge, reshaping both the harbour and the city, figure 2. Hence, there is a need to subscribe to a holistic reclamation process and propose design principles and parameters to create a new basis for thinking about this edge definition over the next era of evolution.

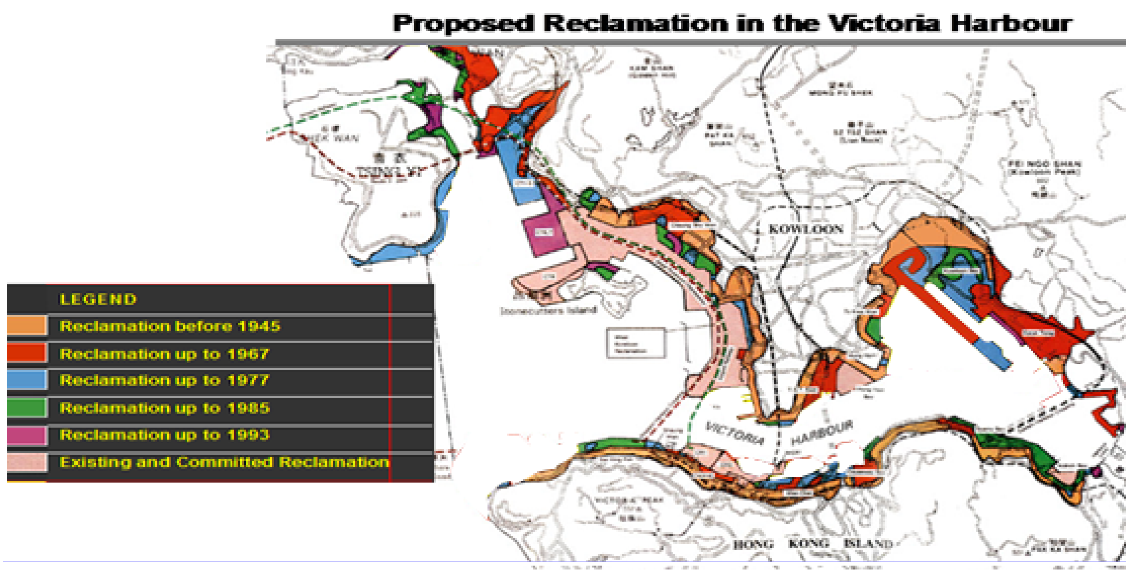


Figure 2 A brief account of reclamation

The metamorphosis of reclamation for Hong Kong, includes nominal dredging for seawall and undredge reclamation with no ground improvement to the fully dredge seawall and full dredge reclamation with ground improvement. In view of the depleting dump sites within the Hong Kong waters, and in view of the environmental requirements, reclamation in recent years often adopted the partially dredge method, that is, a fully dredge seawall with an undredge reclamation with ground improvement.

The HZMB HKBCF, in response to the government's call for sustainable development, has subscribed to a holistic approach in reclamation for Hong Kong. This new approach negates any form of dredging or disturbance in the seabed, thus maintaining the natural environment and ecosystems deep in the seabed. It also avoids the need to disposing the dredge materials which has a possibility of being a contaminated material and the need to infill for the seawall since the seabed is intact.

The Context of Choice

The factors limiting the choices in the move to promulgate a sustainable approach for reclamation is not without the pressure of the countervailing forces. The options available to the current methodologies in reclamation have never been greater, as reflected by the saturation in capacity of the fill banks in Hong Kong and the sourcing of designated dump pits for the 'storage' of dredge marine sediments. It begs the question of, "*would promoting expanded choices put the advocator in the driver's seat when, according to some opponents, that is exactly the position they need to abandon*?". One way to partially reconcile the dilemma between the norm and the emerging views of choice is to first acknowledge that prevailing sustainable approach is not an all or none phenomena.

A major obstacle to implement a chosen principle remains the limited support options available today within the community. Altering the situation requires moving the mind-set of stakeholders and market response to the new methodology. This is a process in which the team meticulously convinced the governing bodies, stakeholders and community, at large, over a period of the consultancy agreement prior to implementation.

Engineering Difficulties

Brief Geology of Site

The HKBCF lies to the east of the Chek Lap Kok Airport Island in an area of known complex ground conditions. The major superficial deposits include marine deposits and alluvial deposits with total thickness averaged at 45m.

The marine deposits generally comprise a relatively uniform layer of silty clay with thickness ranging between 7m to 30m, with the greatest thickness occurring towards the west side of the reclamation, figure 3. This layer includes both the Hang Hau Formation, typically present between sea bed level and approximately -20mPD, as well as localised deposits of the Pok Liu Formation. The latter is typically associated with eroded channels and areas of acoustic masking identified during geophysical surveys. The marine deposit layer is generally described as relatively homogenous very soft to soft, greenish grey silty clay and has a high void ratio averaged at approximately 2.1 and high water content ranging from 60% to 100%. Towards its base, occasional layers of sand and gravel have been identified in the cone penetration tests. Shell fragments are found throughout its sequence.

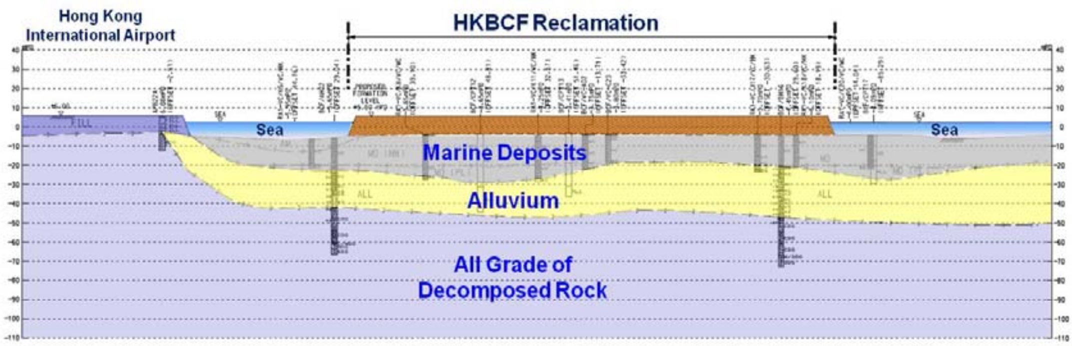


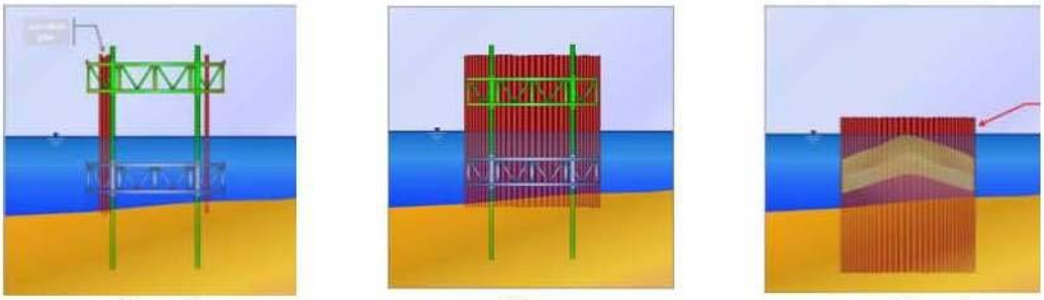
Figure 3 Cross sectional profile of geological stratification

The alluvial sediments beneath the marine deposits are more variable in terms of the composition and include inter-fingered layers of soft to firm sandy and/or silty clay, clayey silt and dense sand and gravels with cobbles. The presence of eroded and infilled channels within the alluvial deposits further adds to their complexity and variability. In general, the combined thickness of the various alluvial layers ranges between 12m to 30m and appears to thicken towards the east.

Non-dredge Seawall

The procurement of non-dredge seawall is not a novelty but this has not been attempted in Hong Kong in the past. Numerous attempts were made by different practitioners in Hong Kong to use ground improvement methods such as Deep Cement Mix (DCM), Sand Compaction Piles (SCP), Jet Grouting (JG) to name a few. However, all have failed to materialise because of the need for a major pilot trial scheme before getting the environmental approval.

As in any major project, there is a need to provide a feasible and viable option under the HKBCF whilst adhering to the principle of cost-effectiveness. The team looked into the various tangible issues that circumscribes both design and construction constraints. The final scheme adopted for the non-dredge seawall is a steel cofferdam of 31.5m in diameter and an average height of 34.0m. Each cofferdam is made up of approximately 200 numbers of 500mm by 12.7mm flat steel plate. The cofferdam can be made to be installed insitu or via the prefabrication, and installation is achieved via simultaneous vibration of individual plate into the seabed; and terminating 5m into the Alluvium for base stability, figure 4 (a) and (b).



Template Driving Finish

Figure 4 (a) Insitu installation

Lifting and towing Vibrating the cell

Figure 4 (b) Prefabrication Installation

Prior to installation of the steel cofferdam, stone columns were constructed to 'improve' the surrounding soft Marine Deposits, figure 5. The purpose of the stone columns is to render the surrounding soil a minimum strength during the eventual installation of the steel cofferdam

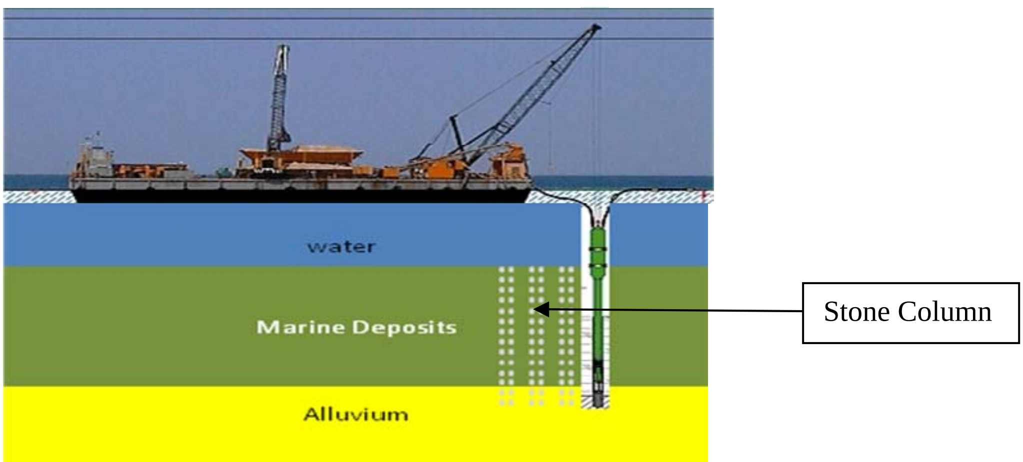


Figure 5 Stone Column as ground improvement technique

Design Principles

The design principles rely heavily on stability of the structure within the surrounding soft soil environment. Engineering judgements as well as first principles were sought in the wake of this unconventional approach.

The steel cellular structures are designed as gravity retaining structures to maintain their stability against forward sliding, overturning, bearing failure and global instability. As gravity structures embedded in soft ground, it is imperative to maintain ¨rigidity〃 of the cellular structures. To complement the non-dredge initiative for this seawall, stone columns will be installed inside the cellular structure to improve the properties of the existing ground material instead of excavation and replacement.

Seawall stability has to be maintained at all stages of construction, particularly when surcharge loading is in place behind the seawall. For conventional seawalls, stability is normally derived from the weight of the seawall. However, additional measures are required in this non-dredge seawall due to the nature and thickness of the soft marine clay which is still in place. Rock fill sloping berms with stone columns are proposed at the front of the cellular structures to provide additional weight and to improve soil properties on the passive side. Construction time rates and pause periods behind seawall have also been painstakingly reviewed to allow gain in shear strength within the soft clays.

Another interesting point in the design is that the weakest plane at the base of the cellular structure is not horizontal as normally found in conventional gravity wall. Instead the shear surface develops as a convex failure surface between the toes inside the cellular structures as manifested in the numerical results in PLAXIS, figure 6 (a) and (b). A 3-dimensional structural model using Oasys GSA was also set up to complement the numerical analysis and to determine the structural effects of the cellular structure, figure 6 (c).

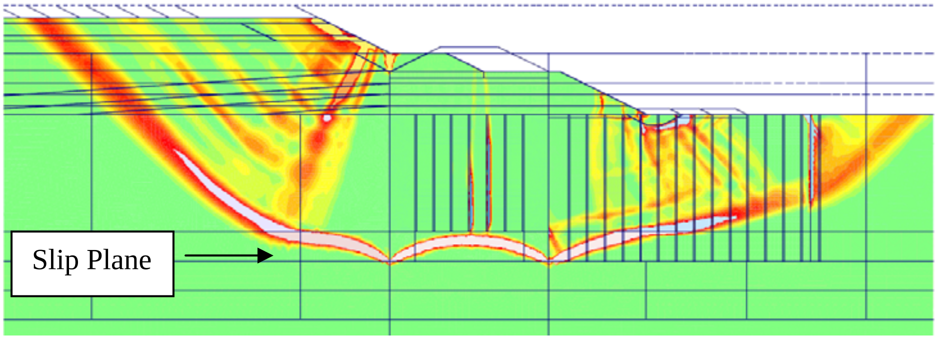


Figure 6 (a) Numerical Analysis by Plaxis

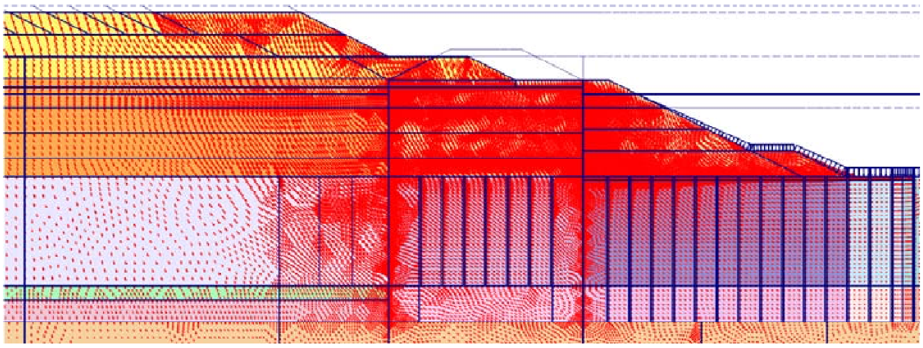


Figure 6 (b) Numerical Analysis by Plaxis, displacement vectors

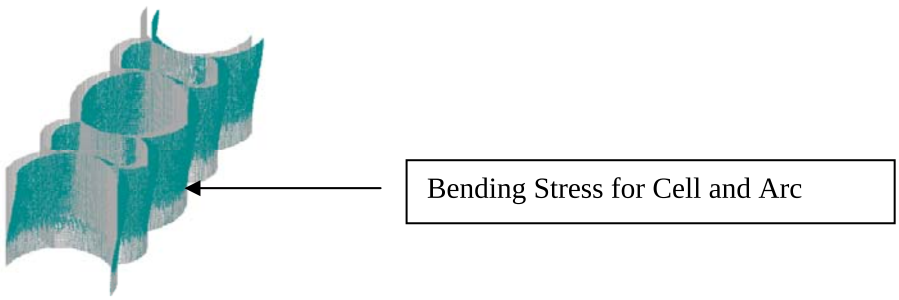


Figure 6 (c) 3D Structurtal modelling

Corrosion protection is a key consideration for steel structures in marine environment. Although there are a number of protective measures available, there is no track record of these measures being used in cellular structures in Hong Kong. Instead the cellular structures with sloping rockfill berm at the front have been carefully designed to ensure its robustness in the long term when the steel structures corrode, i.e. without relying on the steel structures. However, the team at the frontier of engineering development wholeheartedly believes that local knowledge of using corrosion protection on this type of steel marine structure should be widened to facilitate future application. Corrosion protection(anodic) is therefore proposed for a 100m-long section of seawall for long term monitoring, inspection and testing.

Construction Principles

The construction method is perhaps the most challenging aspect in this undredge methodology. The engineers have provided the envisaged construction techniques, with due compliance to the site constraints, in particular, the Airport Height Restriction by Civil Aviation Department and the Terminal Doppler Weather Radar from Hong Kong Observatory. In addition, the marine operation is also weather dependent. Hence, it is a combination of a tight construction programme and needs to coordinate each operation with the various stakeholders in the vicinity of the site.

To ensure aeronautical and marine safety, the engineers have introduced two installation techniques for the undredge seawall. The steel cofferdams can be either prefabricated or installed insitu, figure 7 (a) and (b). Given the prevalent weather dependency, it is envisaged that most of the cofferdam can be prefabricated whereas some may need to be installed insitu.

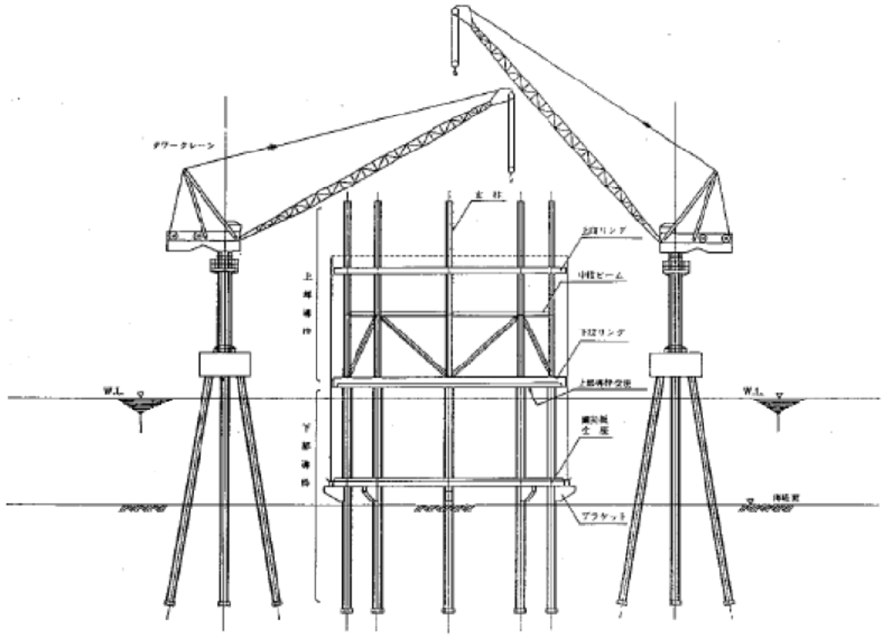


Figure 7 (a) A Schematic prefabrication yard

It is anticipated that the prefabrication yard to be stationed within the site to avoid the long haulage distance. The average cofferdam is approximately 450 tonnes once in full fabrication, and manoeuvring it requires careful control. Longer routes are not favoured in the view of the marine risks. The maximum haulage distance is approximately 1 nautical mile, with an average speed of 2 knots. Once the cofferdam is lifted to the exact location, it will be 'pitched' via optical theodolite and GPS to fix the position. The cofferdam will then be vibrated simultaneously into the seabed before terminated in a stable stratum. Filling of the void portion of the cofferdam shall be carried out immediately upon the completion of installation, to ensure the gravity structure is stable from the sea currents.

For insitu installation, the operation will be carried out if the AHR imposes the height restriction. The conventional installation of steel sheetpile is envisaged except in a marine environment. The difficulty for this manoeuvre is the splicing and welding of the sheetpile to provide the necessary length.

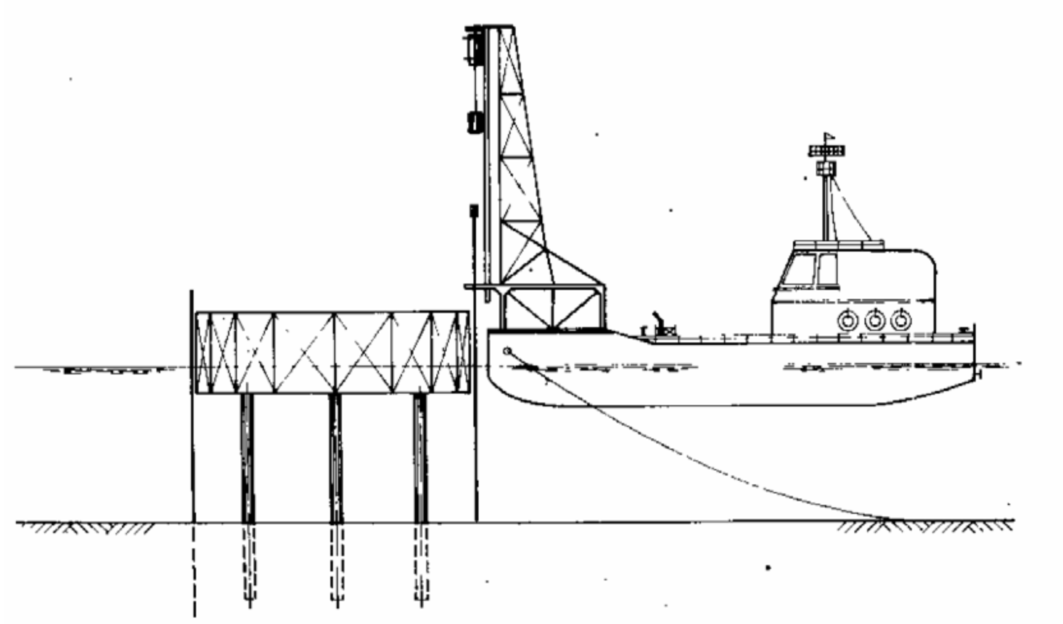


Figure 7 (b) A schematic insitu installation

Sustainable Approach

It is the unquestioned desire of man that the sea be allowed to remain in its natural state, clean and unpolluted. However, pollution in one form or another has continued for many years, making in necessary for many countries to introduce legislation to protect the sea. Hong Kong is no exception, and restrictions with regard to marine works and waste disposal have been tightened.

The sitting of the current HKBCF has undergone numerous studies since its inception. The final site selection study was undertaken since 2008, with the HKBCF to be located to the eastern shore of the Hong Kong International Airport. The location is governed by a series of consideration, namely the connectivity, environmental and ecological, economic benefits, social etc. Culminating from study is a man-made island, some 150 hectares, to accommodate modern day boundary crossing facilities as well as adequate provision of traffic stoppage and circulation. Acknowledging the need to dredge millions cubic metres of sediments, replacing them with marine sandfill, the Highways Department initiated the need, and echoed the government's call, to subscribe to the principle of sustainable developments.

The evolution of sustainable reclamation for the HKBCF metamorphosed from the early fully dredge (positive waste) to non-dredge (zero waste). The team took an additional positive measure by utilising the public fills from the fill banks as well as current rail projects. Potentially a total of 21 million cubic metres of public fill will be generated from the various rail projects over next 5 years. Close liaison work with CEDD, Mass Transit Railway Corporation Limited and the team has resulted in maximum utilisation of the fill generated in the reclamation project. This inherently resulted in the negative waste solution, and has often been complimented as crowning jewel of the reclamation for the HKBCF.

Positive Waste

This is the conventional construction in Hong Kong, where the soft sediments are excavated and replaced with marine/river sand, figure 8. For the HKBCF, this would involve dredging of approximately 17 million cubic metres of soft sediments (equivalent to bulk volume of 22 million cubic metres on disposal) and replacing the exact volume of marine sand.

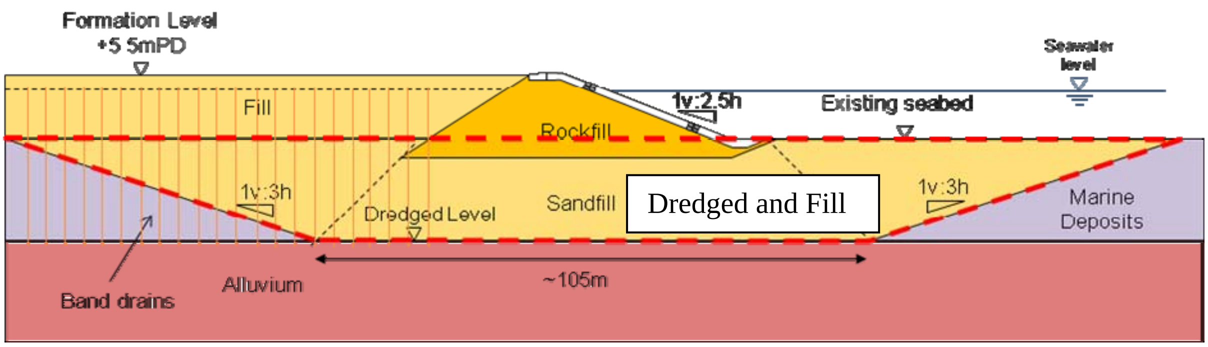


Figure 8 Conventional Dredged Seawall

The mud to be disposed of can fill up about 17,600 Olympic size swimming pools. In addition, there is also the need to procure rockfill and armours to create the seawall.

Zero Waste

Acknowledging the procurement of large amount of sandfill to replace the soft sediment is environmentally unfriendly as well as unsustainable, the team looked into the non-dredge option. The result is the provision of cellular cofferdam in lieu of the rockfill seawall, figure 9.

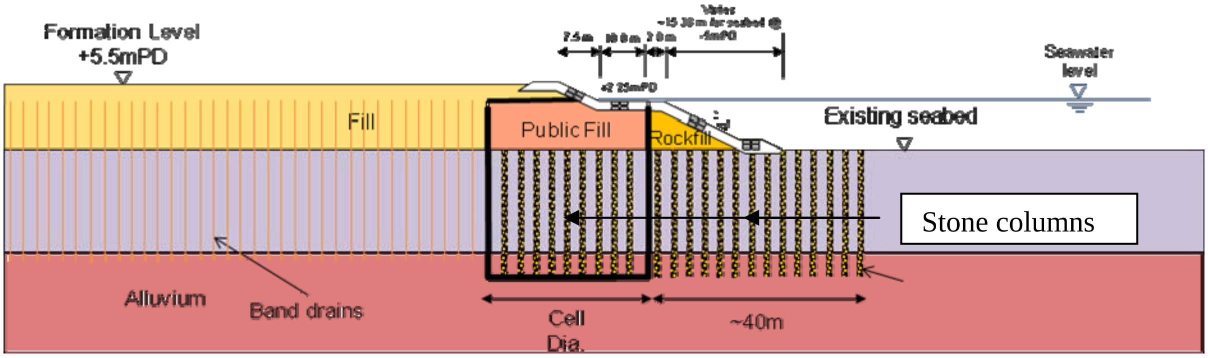


Figure 9 Undredged Seawall for HKBCF

The advantages of this method are three folds: minimise dredging the existing seabed; mitigate the burden on existing or new dump pits; reduce consumption of marine sandfill. Translating these set of advantages to core values: no dredging renders the seabed and its ecology intact and hence better water quality; lesser consumption of the natural resources in Pearl River Delta or other regions, hence preserving the natural banks of the deltaic area; lesser marine traffic trips, meaning lesser demands/pollution from fossil fuels; and most importantly lesser disturbance to the Chinese White Dolphins community.

Negative Waste

The use of public fill from the government's fill banks as bulk fill material for large scale reclamation has yet to be implemented in Hong Kong. The governing serviceable criterion to limit the settlement over the design period has yet to achieve a common consensus. For this particular project, the team has looked into, apart from the primary and secondary consolidation, the behaviour of public fill material to achieve the 'acceptable' serviceable limit. Deformation behaviour includes the creep behaviour of the public fill which consist primarily of man-made fill, alluvium and CDG. The result is a sorted public fill material with a maximum size of 250mm and a minimum of 60 microns, to limit the settlement no larger than 500 mm over a period of 50 years.

In total, the usage of public fill from a fill bank in Tseung Kwan O Area 137 and MTRCL Express Rail Line project, accounted for approximately 60% of the total reclamation fill material. Effectively, the adoption of public fill material is essentially the re-use of materials through consumption of construction waste (excavated spoil) generated from on-going projects, thereby reducing the pressure to source for fill banks in land scarce Hong Kong.

The proposed non-dredge method for both the seawall construction and reclamation would offer significant water quality benefits in terms of reduction in sediment release during the construction phase as compared to the conventional fully dredge method. The conventional fully dredge method would have the seawall dredging / filling and the reclamation dredging / filling happening simultaneously although they may be at some distance apart as determined by the length of the leading seawall. An earlier Investigation Stage design estimated the sediment release rate to be 49,000 to 688,000 kg/day even after implementing the practicable mitigation measures such as cage-typed silt curtain for dredging. With the proposed non-dredge method, the sediment release due to sediment dredging would be totally removed. In addition, since the seawall filling would be conducted totally within the casing, there would be virtually no sediment release as well. The only component for sediment release would be the filling activities for the reclamation. The sediment release from the reclamation filling could be further controlled by adopting an appropriate mix of public fill and sand fill.

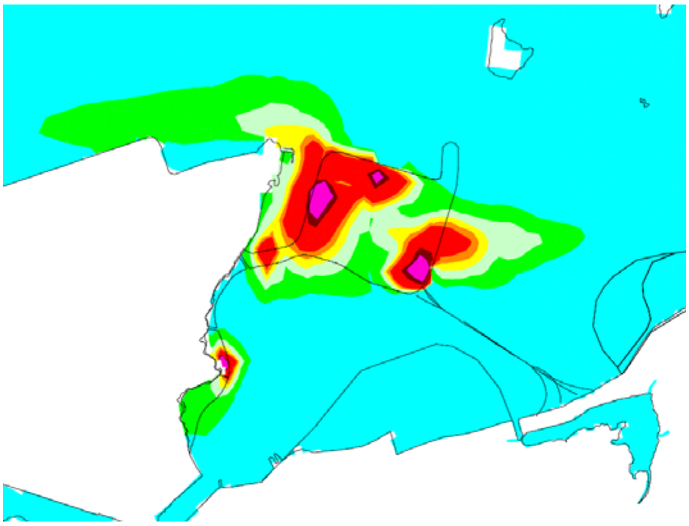


Figure 10 Water quality model

For the current non-dredge design for HKBCF, the sediment release rate shall be significantly reduced when compared to that in fully dredge design for the majority of the construction time, figure10. The peak sediment release rate would be 12% less than that of the fully dredge method and the construction time is 5 months shorter; thereby the total release would be 70% less. This huge reduction in sediment release would significantly further improve the water quality impacts on the neighbouring water quality sensitive receivers during the construction phase.

The Future Trend

The Government of Hong Kong SAR has always been an advocate of sustainable development and has capitalised on the opportunity to steer forward with some of the policies on this landmark project. The success of implementing innovative and safe design under the realm of sustainability will set the guiding framework for all reclamations, in particular, the environmental impact, the depleting dump pits and diminishing borrow pits within and outside the territory.

Conclusion

In arriving at the final methodology for the sustainable reclamation, the team has meticulously looked into every design and construction aspects, including stability, durability, procurement of primary materials, supply of 'fill' materials, disposal of soft sediments, marine activities, ground improvement, environmental etc. For Hong Kong, the methodology is new and untested wherein the performance is concerned. However, the methodology has undergone rigorous assessments, inter-departmental challenges from various government agencies, fine tuning to circumscribe and incorporate the various tangibles. A further step undertaken by the team to ensure the robustness of the scheme is to seek third party's view. On this front, Highways Department has invited Professor John Burland from Imperial College to conduct an independent check on the design.

The final analysis of this methodology showed the following benefits for the sustainable reclamation albeit with only marginal increase in construction cost. They are as follows:

- Reduce dredging and dumping of soft sediments by 97% (by 17Mm^3);
- Reduce suspended particles in water by 70%;
- Reduce the sandfill consumption by 60% (by 14 Mm^3);
- Increase public fill consumption by 25% (by 4 Mm^3);
- Reduce marine traffic by 64% (by 100 day trips); and
- Shorten construction period by 3 months.

The durability of the steel cofferdam over the design life is an issue wherein marine environment are concerned, but the team explored exhaustively the associated risks and mitigating measures. The final analysis showed, over time, the underlying subsoil would have gained the necessary strength against potential slips with satisfactory Factor of Safety.

The team has also allowed a strip of 100m of cofferdam to be reserved/monitored for research of durability of steel in the marine environment through the design life.

Subscribing to the undredge methodology has a lesser impact on the water quality during the construction period, as the seabed is virtually untouched.

The challenges ahead rely on the workmanship of the construction team to procure suitable techniques befitting for the installation of the steel cofferdam within:

- A tight construction programme
- Site constraints, eg, Sky Pier, Marine Cargo Terminal etc
- Low headrooms due to Aviation Height Restriction (though the project team has applied for relaxation in advance)

Notwithstanding the aforementioned benefits, the methodology for sustainable reclamation is likely to set a trend for all future land formation works in Hong Kong. There is much work that remains to be done in this area. Policymakers, clients, engineers and contractors all need to factor these key variables into their decision-making. The team has taken the important first step in providing the basis for informed approach to the vital and complex sustainable development. Our struggle today with the question of choice may mark the dawn of that coming day.

Reference

Bard, Solomon. [2002] (2002). Voices from the Past: Hong Kong 1842-1918. HK University press. ISBN 9622095747