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Information Sheet

Paper Title : Green Treatment of Marine Mud for Insitu Backfilling

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Green Treatment of Marine Mud for Insitu Backfilling

A common way of handling marine mud in local construction industry is disposing of it to either landfills in accordance with ETWB TC No 31/2004[1] *or marine dumping sites in accordance with ETWB TC No 34/2002*[2] *and Dumping at Sea Ordinance, Cap. 466 (DASO) Guidance Note No. 1/2006. However, recent public concerns are growing on the rapid depletion of landfill space in Hong Kong's three strategic landfills one after another at different stages by late 2010s, and also the high levels of cadmium and other heavy metal contents found in some common seafood species due to serious sea water pollution. In fact these environmental concerns have catalyzed the development of a Green Treatment process to convert the 12,000 m³ of marine mud sediment found in the Kai Tak Public Rental Housing Development Site 1A (the Site) into an inexpensive and sustainable earth filling material. This green initiative has extended successfully to other development sites.*

Keywords: *Green-Treatment, Cement-stabilization, Marine Mud, CSMM, Backfilling.*

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[1] Environment, Transport and Works Bureau Technical Circular (Works) No. 31/2004, "Trip Ticket System for Disposal of Construction & Demolition Materials", which is to be read in conjunction with "Buildings Department Practice Notes for Authorized Persons and Registered Structural Engineers No. 243" (re-issued as ADV-19).

[2] Environment, Transport and Works Bureau Technical Circular (Works) No. 34/2002, "Management of Dredged/Excavated Sediment", which is to be read in conjunction with "Buildings Department Practice Notes for Authorized Persons and Registered Structural Engineers No. 252" (re-issued as ADV-21)

Figure 1 – Aerial Photo of Kai Tak Development Area showing Site 1A

BACKGROUND

In the Kai Tak Planning Review, the Site (Figures 1 and 2) was zoned "Residential (Group A)2" under the Approved Kai Tak Outline Zoning Plan No. S/K22/2. It had an area of 3.47 hectares and was subject to a maximum domestic plot ratio of 6.3. The development mainly consisted of 5,204 public housing rental flats in six high-rise site-specific residential blocks ranging from 34 to 40 domestic storeys. Gammon Construction Limited was awarded the piling contract which was commenced in June 2009 and completed in June 2010. The contract valued at HK$179M.

Figure 2 – Bird's Eye View of Kai Tak Development Site 1A at piling stage

The Site was reclaimed from foreshore of Kowloon Bay in the early 1920s for construction of the ex-Kai Tak Airport. Ground investigations revealed that Fill of heterogeneous composition existed all over the Site. Among the different soil types in Fill was the marine mud, estimated at about 12,000 m^3 which would be excavated from construction activities as waste material. The marine mud waste material had little usage in construction indeed, and under normal circumstances it would be disposed of in landfills or marine dumping sites. However, as the disposal options were not sustainable from both environmental and technical perspectives, the Project Team of Housing Department (the Project Team) thus explored a green initiative to recycle and reuse the waste material without undue risks to human health or the environment or disproportionate costs instead of taking an easy way out on disposal decision.

DESCRIPTION OF MARINE MUD

Marine mud is described both in GEO (1994) [1] and the Hong Kong Housing Authority (HKHA) Earthwork Specification. It is broadly classified as fine soils of over 35% silts and clays of particle sizes up to 0.06mm, and of medium to high plasticity.

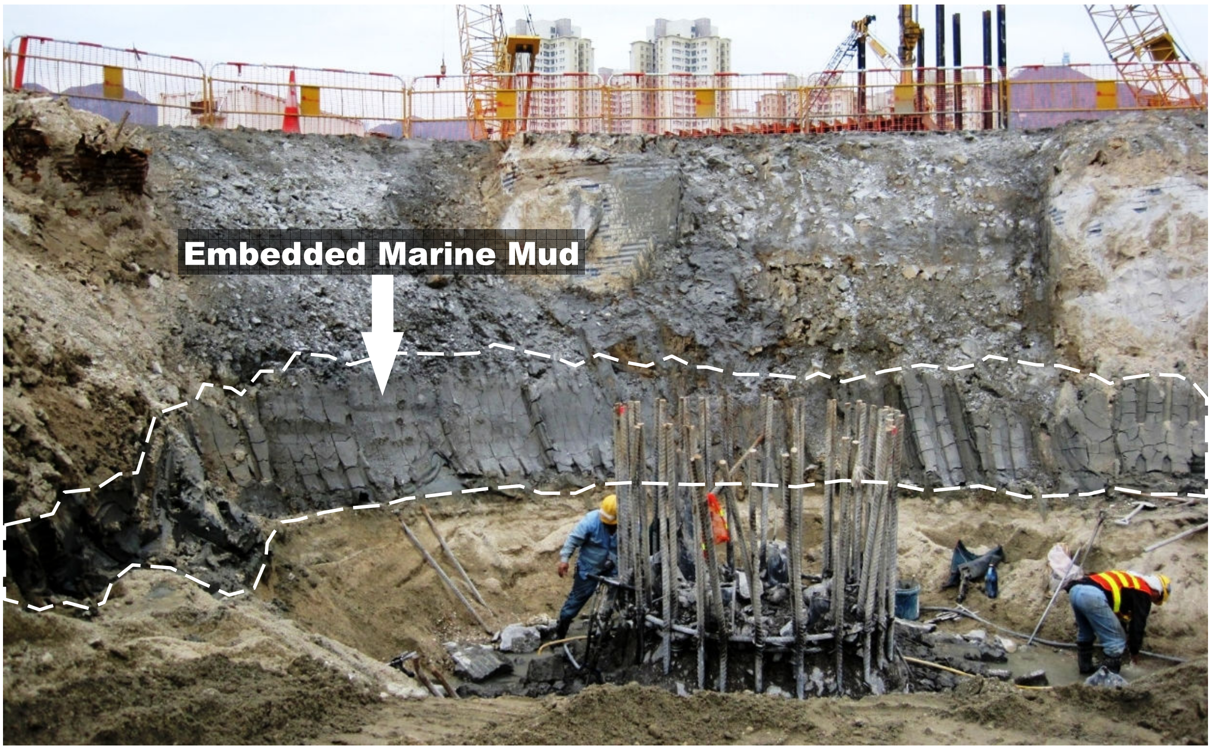


Figure 3 – Marine mud stratum being exposed in pile cap excavation

Descriptions for marine mud at the Kai Tak Site vary in different drillhole records and a summary of different descriptions used are provided below :-

- Very soft to firm, brown or greenish or bluish grey, silty CLAY…(FILL)
- Very soft to very stiff, dark or brownish grey, clayey SILT or silty CLAY... (FILL or Possibly FILL of Marine Deposit)
- Soft to stiff, dark or greenish or bluish grey, silty CLAY... (FILL / Reworked Marine Deposit)
- Soft to firm, greenish grey, silty CLAY... (FILL / Disturbed MARINE DEPOSIT)

- Soft to firm, grey to dark grey, silty CLAY or sandy SILT… (MARINE DEPOSIT)

Figure 4 – Marine mud being excavated

Laboratory index soil tests on undisturbed samples of marine mud carried out under Housing Department Ground Investigation Term Contracts indicated the following soil properties:

- Moisture content w_N : 0.22 to 0.76, with an average at 0.41
- Bulk unit weight γ_b : 14.4 to 20.2 kN/m^3, with an average at 17.7 kN/m^3
- Plasticity index I_P : 19 to 38
- Liquid limit w_L : 39 to 72

Plots of the particle size distribution (PSD) and plasticity index and liquid limit of the marine mud are shown in PSD curve and Plasticity Chart of Unified Soil Classification (Casagrande, 1948) [2] in Figures 5 and 6 respectively:

Figure 5 – Particle Size Distribution Curve for Marine Mud

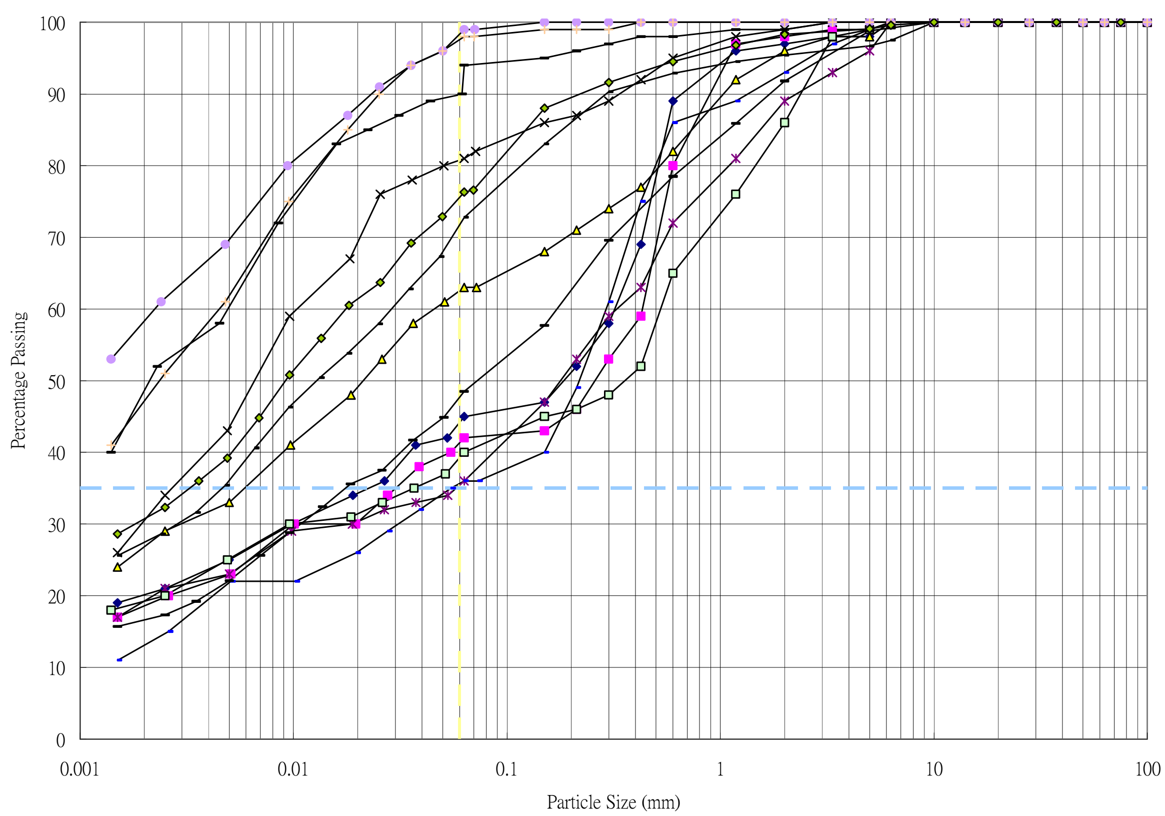
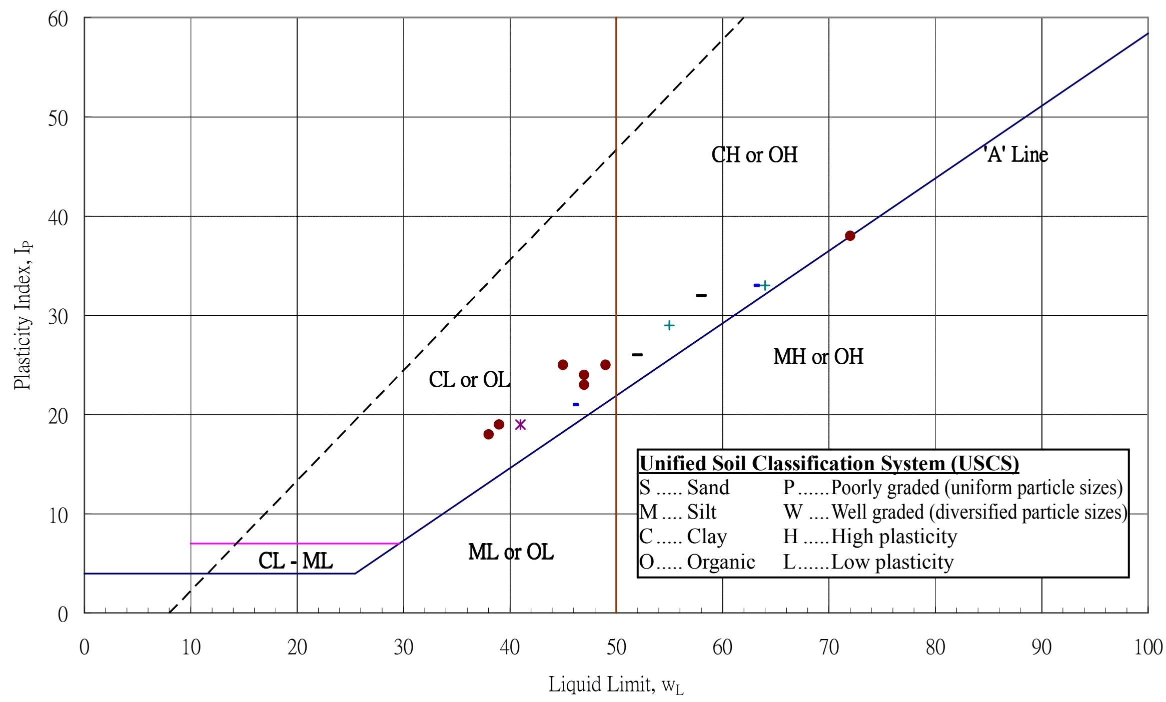


Figure 6 – Plasticity Chart for Marine Mud



From the charts in Figures 5 and 6, it can be observed that the marine mud is typically clay/silt of medium to high plasticity. The relative high plasticity index I_P also indicated the swell potential of the marine mud, and the need to reduce its swelling tendency from problematic levels (i.e. with high I_P) to non-problematic levels (i.e. with low I_P) if the marine mud is to remain on Site along with the development instead of disposal off site.

CONTAMINATION ASSESSMENT

A land contamination assessment for the housing development at Kai Tak Site 1A was conducted in 2002 to assess the extent of any land contamination and to recommend remedial actions where applicable. Initial desktop site appraisal was conducted and indicated that the underground fuel pipelines that ran within the adjacent Site 1B were considered as the most probable source of contamination. Further review indicated that no soil or groundwater contamination problems were found within the Site and contamination levels requiring remediation were not recommended.

Site investigation conducted in 2002 was mainly concerned with the potential contamination impacts in connection with excavation for foundation works. A total of 12 boreholes for soil sampling locations were sunk in even distribution over the Site 1A and Site 1B. Among them 5 were selected for groundwater sampling. Soil gas in terms of percentage methane and Lower Explosive Limit (LEL) was also monitored at all boreholes. A total of 52 soil samples and 5 groundwater samples were taken for laboratory analysis, and no biogas and Total Petroleum Hydrocarbons (TPH) exceedance was detected at all boreholes.

A risk-based assessment was carried out and the results showed that the TPH and molybdenum in groundwater did not exceed the risk-based criteria. As floating oil was also not observed during site investigation, groundwater remediation was thus considered not necessary.

The results showed that no exceedance in contamination criteria except 5 soil samples found to have concentrations of heavy metals (lead, copper and cobalt) exceeding the Dutch B criteria, where a 5 m soil sample only marginally exceeded the Dutch B value and the other 4 samples with exceedances were found within the alluvial layer which was below the marine sediment level. Therefore, the heavy metals found at these levels were considered natural occurrences and there would be negligible risk for any heavy metal at such depth to affect the future users of the Site. As such, no long-term or short-term health and safety concern was identified. Therefore soil remediation was considered not necessary.

Subsequently at construction stage in 2009, 10 marine mud samples were taken from seven additional boreholes on the Site for further testing on organic/chemical contaminants, and potential biogas issue due to backfill of marine mud on site with impervious paving on top. All analyses were conducted by HOKLAS laboratories in accordance with the requirements set by the United States Environmental Protection Agency (USEPA) and the EPD's Landfill Gas Hazard Guidance Note. The series of tests confirmed that the concentrations of all specified contaminants were well below USEPA's regulatory levels as shown in Table 1 [3]. Moreover, the estimated peak biogas generation was 6.39 L/m^2 per day which was less than standard of 10 L/m^2 per day; the peak concentration was about 0.64 % v/v which was also less than the EPD's standard of 1% v/v [4]. Therefore the marine mud did not have any significant biogas generation if it was left on the Site because the material did not contain large amount of organic matter. Thus it was confirmed that there would be insignificant biogas and odour impact if the marine mud was recycled and reused for backfilling on the Site. Monthly gas monitoring was carried out and reconfirmed the assessment findings.

Table 1 – Summary of Concentration of Contaminants for Toxicity Characteristic

Contaminant	Regulatory Level USEPA Std. (mg/L)	Range of Concentration from Samples Taken On Site (mg/L)
Arsenic	5	<1
Barium	100	<1 to 2
Benzene	0.5	<0.005
Cadmium	1	<0.2
Carbon tetrachloride	0.5	<0.005
Chlordane	0.03	<0.001
Chlorobenzene	100	<0.005
Chloroform	6	<0.005
Chromium	5	<1
o-Cresol	200	<2
m-Cresol	200	<4
p-Cresol	200	<4
Cresol	200	<4
2,4 – D	10	<0.0005
1,4 – Dichlorobenzene	7.5	<0.002
1,2 – Dichloroethane	0.5	<0.005
1,1 – Dichloroethylene	0.7	<0.005
2,4 – Dinitrotoluene	0.13	<0.004
Endrin	0.02	<0.0005
Heptachlor (and its hydroxide)	0.008	<0.0005
Hexachlorobenzene	0.13	<0.004
Hexachloro-1,3- butadiene	0.5	<0.005
Hexachloroethane	3	<0.002
Lead	5	<1
Lindane	0.4	<0.001
Mercury	0.2	<0.2
Methoxychlor	10	<0.002
Methyl ethyl ketone	200	<0.05
Nitrobenzene	2	<0.002
Pentachlorophenol	100	<0.01
Pyridine	5	N.D.
Selenium	1	<0.2
Silver	5	<1
Tetrachloroethylene	0.7	<0.005
Toxaphene	0.5	<0.02
Trichloroethylene	0.5	<0.005
2,4,5 – Trichlorophenol	400	<0.002
2,4,6 – Trichlorophenol	2	<0.002
2,4,5 – TP (Silvex)	1	<0.0005
Vinyl chloride	0.2	<0.05

GREEN INITIATIVE

At planning and design stages, site investigation and soil tests confirmed that there were approximately 12,000 m^3 of marine mud sediment on the Site, and they contained low concentration of hazardous contaminants as mentioned above, thus decontamination treatment was not required. Owing to the fact that this material was soft, high water absorbent but low permeability, and susceptible to volume change in wet and dry conditions, therefore it was not suitable for earth filling. The Structural Engineering Works Specification Library 2008 Edition of the Housing Department defines marine mud as "Unsuitable Material". Moreover, General Specification for Civil Engineering Works Volume 1, 2006 Edition, Clause 6.09 [5] stipulates that "Fill material shall not contain any material susceptible to volume change, including marine mud…". Thus it was of little value in construction and should be treated as waste.

Currently the three strategic landfills in Hong Kong are located in the New Territories – Nim Wan in the west, Tseung Kwan O in the southeast, and Ta Kwu Ling in the northeast (Ta Kwu Ling was assigned by EPD for disposal of non-inert construction and demolition material from the Site). They are the key disposal sites for Hong Kong handling more than 9,000 tonnes solid waste every day, and will be filled up progressively in this decade [6]. In the event that they were to absorb the 12,000 m^3 of marine mud sediment from Kai Tak Site 1A, which is almost equal to the total capacity of five standard Olympic swimming pools, it would become a heavy burden to their landfill capacities. Moreover, high fuel consumption in the transportation of the sediment from Kai Tak to Ta Kwu Ling back-and-forth would be inevitable. On the other hand, two open sea floor marine disposal sites at South Cheung Chau and East Ninepin are designated for disposal of uncontaminated mud, whereas another one at

East Sha Chau is designated for disposal of contaminated mud in Hong Kong. However dumping of large amount of marine mud will unavoidably release significant amount of heavy metals and organic pollutants to the sea, and posts potential threat to the marine environment. It will arouse health concern if people, in particular children, pregnant women and the elderly, have consumed seafood or shellfish which are toxins carriers. In view of these considerations, and also as an effort to promoting green construction laid down in the prevalent Hong Kong Housing Authority Corporate Plan, the Project Team did not consider the disposal options but conceived an innovative idea of Green Treatment of the marine mud for insitu backfilling the excavation around the sides of pile caps in the Site (Figure 7). The implementation of this initiative will convert the waste into a green opportunity that helps minimizing environmental burden and handling cost, and also save the need of importing conventional suitable earth filling material for use in the Site.

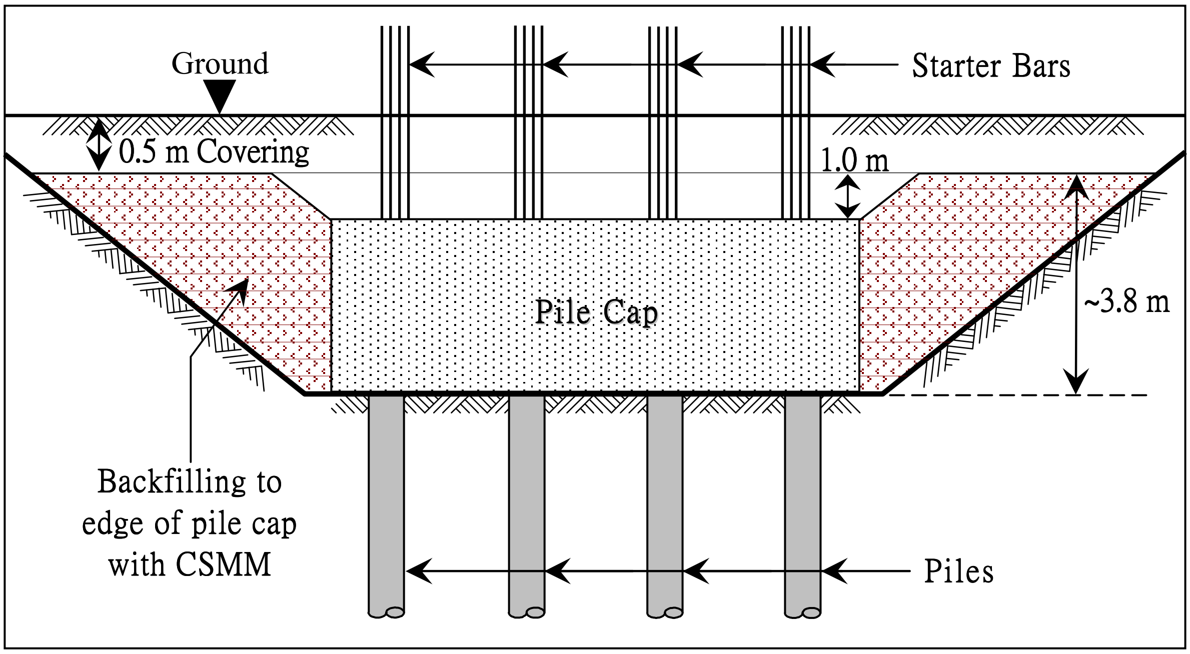


Figure 7 – Typical Profile for Use of CSMM in Backfilling around Pile Caps

GREEN TREATMENT OF MARINE MUD

Conversion of soft marine mud into a material suitable for earth filling has to go through Green Treatment – the cement-stabilization process. It is aimed at obtaining a green recycled earth filling material which is safe to the environment and can be compacted by normal compaction machinery to achieve normal engineering properties similar to the parent ground, such that it can provide similar lateral resistance to the foundation. It is designed as a mixture comprising mainly marine mud, granular material and Portland cement.

Portland cement is a hydraulic binding agent that can provide rapid strength gain, with the chemical composition and typical constitutes of Portland Cement clinker minerals, such as tricalcium silicate (C_3S), dicalcium silicate (S_2S), tricalium aluminate (C_3A) and tetracalcium aluminate ferrite C_4AF). Stabilization of marine mud can be achieved by the following chemical reactions:

(1) The reaction of cement with the water in the marine mud;

(2) Pozzolanic reactions between calcium hydroxide in cement and pozzolanic minerals in the soil;

(3) Ion exchange between calcium ions in cement and ions in the marine mud.

Portland cement in the stabilization process serves several purposes [7] :-

- It acts as a binding agent to limit the spread, via leaching, of contaminated material to water courses or the underground.
- It reduces toxicity of heavy metals by inducing changes in valence state, though the contents of heavy metals in the marine mud were insignificant.
- It increases the mechanical strengths (shear/compression) of the recycled material to facilitate compaction and prevention of undue ground settlement afterwards.

Granular fill material is a natural and inert raw material readily available on the Site. It was chosen as a filler material to improve packing of particles in the soil mixture and to reduce the amount of cement in the mixture without loss of strength. It can partially replace a portion of the cement and at the same time improve the properties and the microstructure of the cement-stabilized marine mud (CSMM) with enhanced mechanical properties.

SPECIFIC TECHNICAL SPECIFICATION FOR QUALITY CONTROL

The recycled marine mud was an innovative product which had never been applied in Hong Kong. The multi-disciplinary Project Team, which mainly comprised project structural engineer, geotechnical engineer and civil engineer, had jointly worked out a set of brand-new specific performance criteria for quality control at both the cement-stabilization stage and the backfilling/compaction stage. Some major technical requirements are given below :-

1. After mixing – achieve a minimum 7-day undrained shear strength (s_u) of 50 kN/m^2, or a minimum 7-day unconfined compressive strength (UCS) of 100 kN/m^2, for assuring the effectiveness of the cement-stabilization process.
2. After compaction – obtain a relative compaction of at least 95% of the maximum dry density (similar to normal earth filling), and a minimum 7-day Standard Penetration Test (SPT) N-value of 10, for assuring the effectiveness of the backfilling and compaction processes. The testing frequency was one for $100m^3$ of the backfilling or part thereof at each backfilled area on each operation day.

The technical requirements for the stabilization process were designed based upon an objective that the marine mud would be improved to a state comparable to that of the compacted general fill, that is, either medium dense granular soils or stiff cohesive soils.

Some of these tests were to be carried out after the hydration process of cement had taken place for 7 days. It ensured that certain strength had been developed in the cement in the stabilization process. Therefore it relied on the Contractor to carry out sufficient number of pilot trials on mixing and field operations on the Site and quality control tests to demonstrate the suitability of the cement-stabilization and backfilling/compaction processes.

For conserving transportation costs and environmental concerns, it was also specified in the Contract document that pilot trials and the subsequent mass production were to be carried out on the Site.

PILOT TRIALS ON SITE

The Project Team and the Contractor firmly believed that partnering spirit enabled them to collaborate to achieve a common objective, deliver quality products and services to meet the needs of the Contract. By working as a team, they succeeded to overcome a number of challenges in the development of the innovative Green Treatment process for the marine mud on the Site.

At construction stage, pilot trials on mixing, field operations and quality tests on materials and workmanship with different mix proportions and different mixing procedures were carried out prior to mass production (Figure 8). The trials served to determine an optimum mix proportion that could fulfill all acceptance criteria specified in the specification. Through those trials, changes of physical and mechanical properties of the marine mud mixes with different mix proportions of ingredients were experienced by the Project Team and the Contractor. Successful pilot trials with different mix proportions by weight are listed in Table 2.

Figure 8 – Pilot Trails

Table 2 – Mix Proportions Adopted in Pilot Trial

Trial Mix	Portland Cement	Granular Material	Marine Mud
#1	10%	20%	70%
#2	10%	15%	75%
#3	5%	20%	75%
#4	5%	15%	80%

To maximize cost benefit and environmental value, the optimum mix should contain minimum content of Portland cement, maximum content of marine mud and adequate content of granular material. Subsequently an optimum mix proportion accompanied with successful cement-stabilization process was developed; it involved a thorough mix of 80% of wet marine mud with premixed 5% Portland cement and 15% insitu granular material (Mix #4 in Table 2). Strength and stiffness of the stabilized material were substantially improved, and conventional mechanical compaction could be executed easily on it for insitu backfilling around substructures in 300 mm layers as normal. The final product achieved the specified quality requirements on both UCS test and SPT test.

Furthermore, it was found that the compacted material remained dense and intact even soaking in water.

SITE OPERATION FOR MASS PRODUCTION

In mass production on the Site, initial screening of the excavated marine mud first took place at the excavation area to remove large rock pieces and to break up soil clumps as necessary. It was then transported to a designated storage area on Site.

Batching and Mixing of Ingredients

The mixing plants for the Green Treatment process basically included two metal tanks and a conventional backhoe (Figure 9). The required proportions of cement and granular material were thoroughly pre-mixed inside the first metal tank using the backhoe for about 5 minutes. In the second tank, marine mud was placed in three layers of 500 mm thick each; trace amount of water would mix with marine mud to enhance workability. On top of each layer, an adequate proportion of the pre-mixed cement/granular material compound was evenly placed. After the batching was completed, all the materials inside the second tank were thoroughly mixed for another 20-30 minutes by the backhoe until a uniform compound with no distinguished marine mud lumps inside the mix was obtained (Figure 10).

A maximum 22 m^3 of CSMM could be produced with the plants at a time in about 40 minutes, achieving a maximum daily production rate of about 363 m^3.

Figure 9 – Site Mixing Plant Setup

Figure 10 - Mixing of Ingredients with a Backhoe

Backfilling and Testing of CSMM

At completion of the mixing process, CSMM was produced. For quality control of the cement-stabilized filling material, one sample per 100 m^3 of the material was taken for making test cubes for analysis of 7-day UCS. The fresh CSMM was immediately transported by internal dump trucks to the foundation area where backfilling was to be taken place. It was deposited and compacted in 300 mm thick layers by means of conventional vibratory rollers to achieve the required compaction standard. For quality control of the workmanship of compaction, after compaction, the fill material was tested for relative density in a sampling rate of 3 nos. per 100 m^2 similar to conventional backfilling. Seven days afterwards, the compacted material was then tested for 7-day SPT. One drill hole per 100 m^3 of backfilled materials was sunk and tests were conducted at 1.5 m deep interval inside the backfilled material (Figure 11).

Backfilling with CSMM | Compaction with a vibrating roller | Field Testing

Figure 11 – Site Operation

Test results were all 'Passed' and it was indicated that the material and the workmanships had all fulfilled the specification requirements. The following is a summary of the test results obtained; it reflects the general properties of a ground filled with the innovative CSMM :-

- Average SPT N-value — 14.28 (Acceptance is 10)
- UCS (soaking in water) — 1330 kN/m^2 (Acceptance is 100 kN/m^2)
- UCS (curing in natural air) — 2520 kN/m^2 (Acceptance is 100 kN/m^2)
- Relative compaction — Over 95%

ENVIRONMENTAL AND SAFETY MANAGEMENT

Marine mud was not allowed to be delivered off site. Before cement-stabilization, the marine mud generated from piling work and pile cap excavation was stockpiled at a specific levelled storage area on the Site with concrete paving and proper drainage system. It served to separate the material from other construction and demolition wastes for prevention of spillage of contaminants. The storage area was labeled with warning sign and covered entirely on top and all sides by impermeable sheeting to prevent contaminants from moving by rain causing leaching into groundwater.

All surface runoff from the storage area was collected by on-site drainage system and diverted to wastewater treatment facilities. The effluent was then treated to meet the standards stipulated in the Water Discharge License prior to discharge into public drains.

Only competent and well-trained workers were allowed to execute the cement-stabilization process and backfilling operation with marine mud. Workers who would be in contact with marine mud were required to wear protective clothing, chemical-proof gloves and impermeable safety boots to prevent their bodies from direct contact with the contaminants in the material.

Figure 12 – Temporary Dust Screens

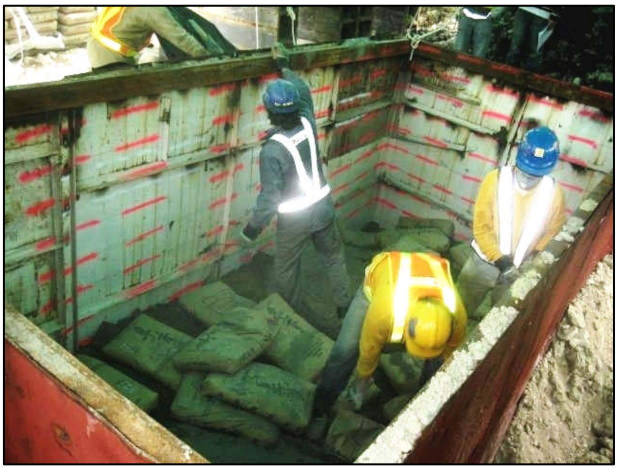


Figure 13 – Workers operating safely in a mixing tank

Temporary dust screens were erected around the mixing plant to prevent spread of dust in the mixing process with cement (Figure 12). Workers operating in the mixing plant were all equipped with additional protective equipments, such as reflecting clothing, protective goggles and dust respirators to protect their bodies, eyes and respiratory systems (Figure 13).

COST EFFICIENCY

The conventional disposal methods of marine mud to strategic landfills and designated marine dumping sites basically involve transportation of marine mud from the Site to a discharge point by means of dump trucks, and a government charge for operation and maintenance of the dumping areas. Subsequently, cost of import of suitable fill material and then backing should also be considered. For the Green Treatment process of marine mud, it involves mainly the cement-stabilization process and backfilling; backfilling cost in this method is higher than conventional backfilling because of inclusion of other ingredients in the mix. According to the cost comparison of different disposal/treatment methods of the marine mud illustrated in Table 3, the cement-stabilization and insitu backfilling option resulted in cost savings of \$3.54M and \$4.62M respectively in comparison with the landfill option and the marine dumping option.

Table 3 – Cost Comparison for Three Different Treatment Options of Marine Mud

Item	Landfill	Marine Dumping	Cement-Stabilization and Insitu Backfilling
1. Transportation	\$1,440,000 (\$120/m³)	\$2,520,000 (\$210 /m³)	Not Applicable
2. Government charge/operation fee	\$3,000,000 (\$250 /m³)	\$3,000,000 #1 (\$250 /m³)	Not Applicable
3. Cement-stabilization	Not Applicable	Not Applicable	\$1,056,000 (\$88/m³)
4. Purchase of suitable filling material	\$300,000 (\$25/m³)	\$300,000 (\$25/m³)	Not Applicable
5. Backfilling	\$564,000 (\$47/m³)	\$564,000 (\$47/m³)	\$708,000 (\$59/m³)
Total Cost	\$5,304,000 (\$442/m³)	\$6,384,000 (\$532/m³)	\$1,764,000 #2 (\$147/m³)

#1 Free-of-charge for government project; however an operation fee as that for the landfill is assumed and it is to be borne by Civil Engineering and Development Department.

#2 The Cement-stabilization and Insitu Backfilling option resulted in cost savings of \$3.54M and \$4.62M respectively in comparison with the Landfill option and the Marine Dumping option.

LIMITATIONS AND DIFFICULTEIS

The stabilization effect of cement in the CSMM was largely depending on the strength of calcium silicate hydrated gel. When the clinkers, such as calcium silicates, of cement reacted with water, a layer of calcium silicate hydrate would form on the surface of calcium silicates particles and create a barrier hindering further reaction of the un-hydrated calcium silicates with water. To ensure that the strength of the stabilized marine mud was consistent, the cement had to be mixed with marine mud in such a way that the cement particles would be distributed as evenly as possible. Therefore, mixer was recommended to be used for the mixing process instead of backhoe. However, the production rate would be lower. Moreover, premix of Portland cement with dry granular material in a separate tank prior to mixing with wet marine mud in another tank would help mixing and producing a relatively uniformed mix.

Organic substances had a negative effect on stabilization effectiveness. Humic acids and other acid groups reacted with calcium hydroxide forming insoluble products. The pH value would be decreased and made the strength gain slower. Other than organic substances, similar chemical reaction would be resulted when marine mud was rich in ammonium and magnesium salts, they would react with hydroxide ions and lowered the pH value.

Finally, marine mud containing heavy content of organic wastes and volatile organic compounds is generally not suitable for cement-stabilization since the organic compounds would not be easily bound by cement.

FURTHER DEVELOPMENT ON CSMM

As a summary for the achievement of the Green Treatment of marine mud for insitu backing in Kai Tak Site 1A, over 12,000 m^3 of CSMM were produced with a mix proportion of 5% cement, 15% granular fill and 80% marine mud within a mass production period of 3 months. From the aspect of cost conservative, cost savings of $3.54M and $4.62M respectively were achieved in comparison with the landfill option and the marine dumping option. In addition to these benefits, the original waste marine mud was completely recycled and converted into a usable, economical and environmental-friendly earth filling material; the process has avoided impacts to the environment and hence human life since zero disposal of the excavated marine mud was necessary.

Further research and development on the Green Treatment process of marine mud is recommended with a view of enhancing the effectiveness on environmental protection, improving cost efficiency and also extension of its applications. For example fine-tuning of mix proportion ratio, introducing other green additives like PFFA to improve workability of the mix, and reviewing the mixing method and procedure.

CONCLUSION AND WAY FORWARD

The innovative approach for Green Treatment of marine mud is a self-developed technique and has been applied successfully to a construction site in Hong Kong for the first time. It has been proved to be effective, inexpensive and environmental friendly for converting the construction waste into a useful earth filling material for construction. Following its success, it has become the blueprint of other public housing development projects, namely, Kai Tak

Site 1A building contract, Kai Tak Site 1B integrated contract, and Tseung Kwan O Area 65B foundation contract.

In fact, the benefits brought by the innovative Green Treatment of marine mud could be extended to non-HA development sites as well. In Hong Kong, several major development areas and marine activities will generate huge volumes of marine mud as described below :-

(1) In Hong Kong, a lot of lands are obtained from reclamation; the development and redevelopment of these lands will inevitably generate certain amount of marine mud excavated from the ground, like the Kai Tak Site 1A project.

(2) According to Kai Tak Development Environmental Impact Assessment Report approved by EPD on 4 March 2009, the development of the cruise terminal in Kai Tak will generate more than a million cubic metres of dredged marine sediment from dredging the seabed to provide a manoeuvring basin [8].

(3) CEDD carries out regular maintenance dredging of fairways, anchorage areas and major river outlets to ensure navigation safety; the dredging works generate millions of cubic metres of dredged marine sediment every year [9].

In view of these potential applications, the Project Team had shared the Green Treatment process with other relevant Government Departments and Contractor Association, and received positive response. It is expected that these applications will help preventing adverse environmental impacts for the enjoyment of the public in a green living environment.

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