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Paper Title : Sustainability Solution Unlimited – Housing Department's Reforming Marine Mud Waste to Building Materials

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THE HONG KONG INSTITUTION OF ENGINEERS
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Sustainability Solution Unlimited – Housing Department's Reforming Marine Mud Waste to Building Materials

ABSTRACT

Housing Authority (HA) commenced the construction works of the public rental housing projects in the area of former Kai Tak Airport in 2009. The site was reclaimed from foreshore of Kowloon Bay in the early 1920s that the marine mud on the seabed was not dredged away during the reclamation works in those years. Approximately 15,000 cubic meters of marine mud waste are generated in the excavations for the construction works. The normal practice in the construction industry of disposing the marine mud to either landfills or marine dumping sites is very harmful to the environment. Housing Department (HD) has developed a practical and cost-effective green treatment technology to make use of the "original" waste and reform it to useful building materials – namely Marine Mud Made Materials (MMMM). The technology is well received by the industry as another sustainable solution that resolves the marine mud waste issue in building works yet enables the industry to make another step forward on environmental protection for a sustainable community.

1. BACKGROUND

In the development of Kai Tak Development Site 1A Project (KT1A) in the former Kai Tak Airport premises, huge amount of marine mud is encountered in the construction of the foundations and superstructural works of the Project, which was the marine mud at the seabed not dredged away in the reclamation works in those years for the former Kai Tak Airport. Instead of adopting the conventional practice practiced by the construction industry of disposing marine mud to either landfills or marine dumping sites that greatly harm our environment, HD has developed an innovative "green treatments of marine mud"; which is a new technology used for the first time in Hong Kong to reform the waste (also found in many other construction sites) to useful building products of Marine Mud Made Materials (MMMM), namely MM Paving Blocks, MM Planter Kerbs, MM Protection Blocks and MM Roof Tiles. To further enhance sustainability of the KT1A project, the MMMM are all used back in the KT1A project. The new technology is well-received by the industry.

2 THE PROJECT

After the relocation of the Kai Tak Airport to Chek Lap Kok in 1998, HA is the first to commence two public housing developments in the area – the Public Rental Housing Development at Kai Tak Site 1A and the Public Rental Housing Development at Kai Tak Site 1B (KT1B) (see Fig. 1 for location of KT1A Site).

Fig. 1 Kai Tak Development Showing Location of Public Rental Housing Development at Kai Tak Site 1A

The KT1A occupies a total site area of 3.47 hectares and will provide 5,204 flats for about 13,000 residents. The Project consists of mainly six domestic blocks, a commercial centre and a semi-sunken carport; which is scheduled to complete in early 2013.

3 ENCOUNTERED HUGE AMOUNT OF MARINE MUD

The KT1A is sited in the middle of the premises of the former Kai Tak Airport, which was reclaimed from foreshore of Kowloon Bay in the early 1920s for the construction of the airport. The reclamation works in those years had not dredged away the marine mud on the seabed; which becomes one of the major construction constraints of KT1A. The marine mud is usually buried two to ten meters in depth below the ground surface. Site investigation reports indicate that KT1A will generate approximately 15,000 cubic meters [1] of marine mud, equivalent to a capacity enough to fill up six Olympic standard swimming pools! Marine mud is an unsuitable backfill material as it has high plasticity and moisture content, which is susceptible to volume change when pressed. The marine mud is sticky and not easy to be separated into small pieces and mixed with other materials. It is reckoned that marine mud does not have any "construction value". Conventionally, marine mud is disposed off site as waste to designated landfills (the 15,000 cubic meters of marine mud excavated from Kai Tak Site 1A is equivalent to an alarming total filling-capacity of 4 days of all the landfills in Hong Kong) or marine deposit sites. However, this dumping approach of the waste has always been an extremely difficult for engineers for it involves time consuming procedures for seeking statutory approval from Environmental Protection Development (EDP) (in accordance with ETWB TC No. 31/2004 or ETWB TC No. 34/2002 [2]) followed by expensive pre-treatment of the waste and transportation of the waste to the dumping sites, not to mention that the dumping activities will burden the environment greatly.

In response to the public's growing concern on burdening public landfills and polluting the marine environment and also inline with the environmental policy of HA, HD has developed the "Green Treatment of Marine Mud for In-situ Backfilling" in 2009 during the construction of the foundations of the Project that successfully treated 12,000 cubic meters of marine mud and used for filling back the excavations resulted

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[1] About 12,000m^3 of marine mud are excavated from the construction of domestic blocks foundation (Foundation Contract); the remaining of about 3,000m^3 of marine mud are excavated during the construction of the Commercial Centre, Carport and external works (Building Contract).

[2] 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).
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)

in the piling works[3]. The project Team of KT1A could apply the same green-treatment method for the remaining 3,000 cubic meters of marine mud excavated out in the Building Contract (Fig. 2) and backfill the treated marine mud at designated external areas. However, HD is not complacent with a single approach of treating the marine mud for backfilling works only.

[3] The innovative Green Treatment of Marine Mud for In-situ Backfilling has successfully treated the 12,000 cubic meters marine mud excavated in the KT1A foundation contract in 2009 [1]. This highly efficient and cost-effective method has been well received by the construction industry. HD has also won several environmental awards of this green treatment of marine mud.

Fig. 2 Marine Mud Encountered in the Building Contract

HD commits herself for a higher goal of sustainability and successfully develop another innovative technology for use in building works - Marine Mud Made Materials (MMMM) that can reform the waste to useful building materials. After carrying out further study of the materials and appointing a consultant for feasibility study, HD has developed the four types of MMMM namely MM Paving Block, MM Planter Kerb, MM Roof Tile and MM Protection Block (for protecting the water proofing membrane at the semi-sunken carport), which have been pilot-used in the Building Contract of KT1A. With the innovation, marine mud excavated from KT1A is all used back in the Project; i.e. the MMMM provides an effective solution for resolving marine mud waste issue in building developments.

4 DESCRIPTION OF MARINE MUD

Marine mud is described both in GEO (1994) [2] and the Hong Kong Housing Authority (HKHA) Earthwork Specification [3]. 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. 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)

4.1 Engineering Properties

Soil tests on undisturbed samples of marine mud carried out under HD Ground Investigation Term Contracts indicated the following engineering 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

The very high Plasticity Index I_P accounts for the plastic properties of the fine-grained KT1A marine mud. The plastic behavior of the material will expand further with high moisture content as indicated in the high moisture content and Liquid limit w_L of some marine mud samples. It is therefore required to reduce its swelling tendency before it can be used for mass production of MMMM at site.

4.2 Contamination Assessment

HD has carried out a series of contamination related assessments on the marine mud for the Project:

a) A land contamination assessment for the housing development at KT1A site was conducted in 2002 [4] to assess the extent of any land contamination and to recommend remedial actions where applicable. Initial desktop site appraisal was conducted which indicated that the underground fuel pipelines that ran within the adjacent KT1B Site were considered as the most probable source of contamination. Further reviews indicated that no soil or groundwater contamination problems were found within the KT1A Site and soil remediation was not necessary.

b) Twelve boreholes for soil samples were sunk in even distribution over the KT1A Site and KT1B Site with 5 of them were selected for groundwater sampling before commencement of the foundation works in 2009. Soil gas in terms of percentage methane and Lower Explosive Limit 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 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 also showed no exceedance in contamination criteria except that 5 soil samples were 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. 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 project. It was recommended that no long-term or short-term health and safety concern was identified. Therefore soil remediation was considered not necessary.

c) During the construction of foundations in 2009, ten 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 [5]. 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 [6]. 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 to be processed for use.

d) The Hong Kong Polytechnic University was appointed as the consultant for viability study of mass production of MMMM in 2010 which included also testing of the marine mud at shallow depth [7]. Test results indicated that the amounts of toxic and organic materials contained in the marine mud were low. As for biogas and odour emissions of MMMM, the levels of emissions were higher than conventional paving blocks when they were freshly cast. However, the levels of the emissions would be dropped to that comparable to conventional paving blocks in approximately 4 months.

In sum, both soil and water samples were not found to have contaminants exceeding the EPD's and other relevant criteria. There is no health or safety concern identified for future use of the Site as well as use of marine mud for production of MMMM at KT1A.

5. DESIGN OF MMMM

With the positive recommendations and preliminary results obtained in the viability study carried out by the Hong Kong Polytechnic University, the Project Team proceeded with a more detailed desk-top study on the design of MMMM. A number of rounds of tests (mainly 7-day, 14-day and 28-day compressive strength tests) and site batching trials (small-scale productions of approximately $1m^3$) were carried out before arriving at the design mixture that could maximize the use of marine mud and satisfy HA's performance requirements imposed for conventional blocks and tiles. The designed MMMM are found to be simple and practical for production at site and cost-competitive as compared to the easy way out of disposing it off site.

The design mix of MMMM is summarized in below Table 1:

Mix Proportion	
Components	**Percentage by Weight**
Marine Mud (Moisture content of 65%)	30%
Recycled Aggregate 5mm to 20mm	19%
Recycled Aggregate less than 5mm	13%
Cement	33%
Water	3.4%
Super-plasticizer	1.6%

Table 1 Mix proportion of MMMM

Cement is used as the important matrix medium of the MMMMe The cement used is ordinary Portland cement to BS EN 197-1: 2000 and HKHA's Specification CON1.M120. Portland cement used in MMMM severs many purposes [8]:

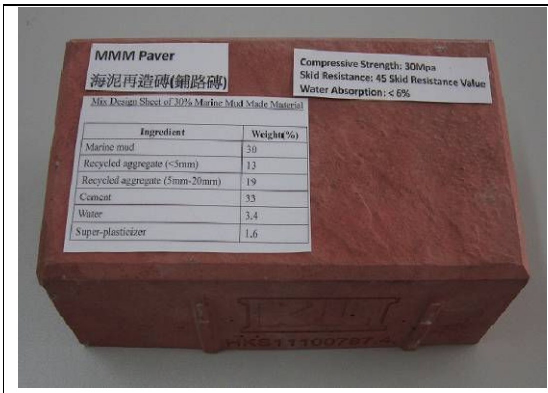
a. It stabilizes the marine mud through chemical reactions including consuming the moisture in marine mud as cement hydrates and hardens;;
b. It binds all components together including the recycled aggregates and the fine-grained marine mud;
b. It acts to limit the spread, via leaching, of contaminated materials to water courses or the underground;
c. It reduces toxicity of heavy metals by inducing changes in valence state, though the contents of heavy metals in marine mud are insignificant; and
e. It increases the mechanical strengths (shear and compression) of the blocks.

For MMMM to be more sustainable and cost effective, recycled aggregates recovered from construction and demolition waste are used in lieu of natural aggregates as the other major component of the mix. Two graded coarse and fine aggregates are chosen that contribute best in terms of compressive strength and skid resistance performances of MMMM - <5mm for fine aggregates and 5mm – 20mm for coarse aggregates with 10% fine value less than 100 kN and the flakeness index not exceeding 35%.

The sticky marine mud has to be separated into smaller pieces during its mixing with other components for a thorough mixture in order to produce consistent products. If marine mud lumps cannot be separated into small pieces to thoroughly mix with other components during the mixing process, the lumps of marine mud inside the blocks will become the weak points when they are loaded hence jeopardizing its strength, skid resistance performances and etc.. It is also not acceptable if the lumps of marine mud come to the surfaces and affect the physical appearance of the finished products. Superplasticizer Rheomix 610P manufactured by BASF is used to act as an agent to disperse the marine mud lumps into trowel-able form facilitating an even and smooth mixing of the marine mud with other components. The superplasticizer also enhances the workability of the mix that enables production of the blocks and tiles with consistent physical appearances.

6. FOUR TYPES OF MMMM

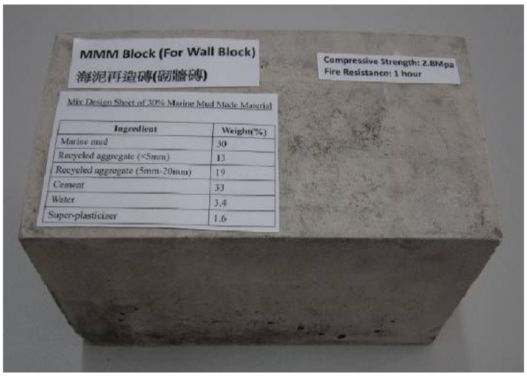
Four types of MMMM namely, MM Paving Block, MM Planter Kerb, MM Roofing Tile, and MM Protection Block for Waterproofing Membrane of the Semi-sunken Carpark are manufactured in KT1A (Fig. 3).



<u>MM Paving Block</u>
(200 x 100 x 80 mm thick)
Approx. 300,000 pieces are used, covering 6300 m^2, over 85% of the external paving area

<u>MM Planter Kerb</u>
(230 x 115 x 65 mm thick)
Approx. 7,300 pieces are used, covering 17500 m long, over 85% of the perimeters of the external planters

<u>MM Roof Tile</u>
(400 x 400 x 35 mm thick)
Approx. 23,000 pieces are used at the roofs of five domestic blocks, amounting 17500 m^2



<u>MM Protection Block</u>
(200 x 100 x 115 mm thick)
Approx. 50,000 pieces are used covering 1050 m^2, 100% of the periphery walls of the Semi-sunken Carport

Fig. 3 The Four Types of MMMM Products

The four types of MMMM have replaced over 85% of the conventional blocks and tiles originally intended for use in the project. Over 350m^3 of the excavated marine mud have been consumed in the production of MMMM.

The performances of MMMM are not inferior to the conventional blocks and tiles. MMMM produced at KT1A have been tested to a higher testing frequency than the conventional blocks and tiles; results indicated that MMMM perform consistently well above the required standards. The results are summarized in Table 2 below:

MMMM	Acceptance Criteria	Performance of MMMM Achieved in KT1A
1. MM Paving Block	Same as conventional paving blocks - Characteristic compressive strength ≥ 30Mpa  - Skid Resistance Value (SRV) ≥ 45  - Water absorption < 6% by weight	- Average 38MPa (no individual result < 30 MPa) - Average SRV = 83 (no individual SRV result < 45) - < 1%
2. MM Planter Kerb,	Same as conventional planter kerbs (HKHA's Specification, EXT3.M150, Clay Brick Pavers and BS6677:Part 1:1986, Clay and calcium silicate pavers for flexible pavements) - Mean Transverse Breaking Load: min 3.0 kN	- ≥ 19.0 kN

	 - Individual Transverse Breaking Load: min 2.0 kN - Compressive Strength ≥ 7Mpa	- ≥ 16.3 kN - Average 44.5Mpa (no individual result < 7 Mpa)
3. MM Roof Tile	Same as conventional roof tiles (HKHA's Specification, WAT6.M260, Roofing Tiles; BS473,550:1990, Concrete roof tiles and fitting) - Average Breaking Load ≥ 490 N	- Average Breaking Load = 7754 N (no individual result < 490 N)
4. MM Protective Block,	Same as conventional protection wall block (HKHA's Specification, MAS1.M040.P, Masonry Units as Marine Mud Made Materials, BS6073:Part1:1981, Precast concrete masonry units) (BS476, Fire tests on building materials and structures - Compressive Strength ≥ 7.0 MPa - One hour Fire Resistance Period	- Average = 55.5 MPa (no individual result < 7 MPa) - Pass
5. Marine mud	HKHA's Specification, MAS1.T010.P, Tests for Environmental Concerns - Toxicity Test - Water Pollution Test - Biogas Emission Test - Odour Emission Test	Not exceed EPD's and other relevant standards

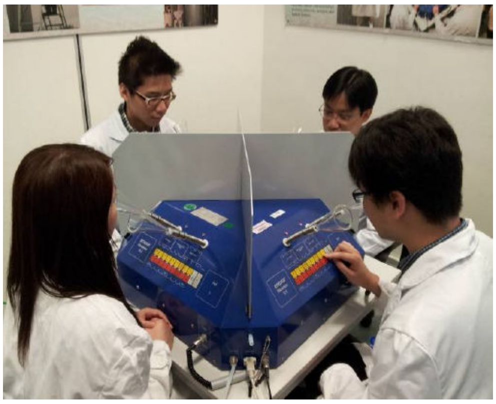
		

Table 3 Performance Requirements of MMMM Products

Apart from the resemblance in physical properties between MMMM and conventional blocks, there is also no significant difference between the two categories of blocks in their physical appearances such as colour, surface finish, texture and shape.

7. MASS PRODUCTION

The final challenge for the Project Team then comes to the development of a practical and efficient mass production system at site that could produce MMMM with consistent quality. In collaboration with the Main Contractor and their consultant, Professor Alfred Kwan of University of Hong Kong, the project team carried out production trials at commencement of the contract for the required factory set up, plant, production logistics and quality control measures for the mass production of the MMMM.

After several rounds of trial, it is observed that well mixing of the components can be best achieved if the marine mud is worked close to its liquid limit [10]. Water is added to soak the marine mud before mixing with the super-plasticizer. The mixer blades of the pan mixers are also specially chosen to increase the up and down movements of the components during mixing in the pan mixers (Fig. 4). It is also important to premix the recycled aggregates with cement separately before adding in the marine mud-superplasticizer mixture.

Pan Mixer No. 1 *Pan Mixer No. 2*

Fig. 4 Mixer Blades in Pan Mixers

The production rate of MMMM at site is 1400 blocks daily in 14 batches consuming approximately 3m^3 marine mud. The detailed mass production logistics is attached at Annex A. The set up of the temporary factory for the mass production of MMMM is illustrated in Fig. 5.

Fig. 5 Temporary Factory for Production of MMMM at Site

8. COST EFFECTIVENESS

The cost for the pilot use of MMMM in KT1A is approximately 5.7M, amounting to 0.33% of the contract sum of KT1A Building Contract; which includes the cost of the temporary product plant at site and development costs.

Taking MM Paving Block (the largest usage in KT1A) as an example, the unit rate of the pilot use of MMMM is $6.5, approximately 63% and 44% higher than the conventional paving block and the most common environmental-friendly paving block available in the market (blocks made of recycled glass bottles) respectively. After deducting the development and associated costs for the pilot use of the MMMM and cost for the original dumping arrangement of the waste (including the transportation cost for approximately 250 truck-trips), the cost of MM paving block is $4.5, on par with the cost of environmental-friendly paving block and 11% higher than the cost of conventional paving block (Table 3). The MMMM is considered very competitive in resolving the marine mud waste issue encountered at site.

Blocks / Tiles (Total Number Produced)	**Unit Rates of MMMM**	**Unit Rates of Conventional Blocks / Tiles**
Paving Block (300,000 Pieces)	$4.5	$4.0
Planter Kerb (7,300 Pieces)	$5.5	$5.0
Roof Tile (23,000 Pieces)	$6.0	$5.0
Protection Block (50,000 pieces)	$4.5	$4.0

Table 3 Comparison of Unit Rates of MMMM with Conventional Products

It is anticipated that the cost of MMMM will be further decreased and their competitiveness will be on par with conventional blocks and tiles with the followings are promulgated when MMMM are widely adopted by the industry:

a. EPD to accept a controlled delivery system to transport the marine mud off site to current tiles and blocks production factories for a larger scale of production and erection of a temporary production plant at site is not required;
b. The cost-effectiveness of producing MMMM is enhanced with the technology matures; and
c. Optimization of the MMMM design.

9. BENEFITS

The innovative MMMM has multifold environmental and economical benefits:-

9.1 Environmental Benefits

a. It avoids the disposal of marine mud to landfills as waste; i.e. less burdening the landfills;
b. It avoids the disposal of marine mud to marine deposit sites; i.e. less damage to the marine environment; and
c. As marine mud is processed directly on site and reformed for use in KT1A, it eliminates huge amount of carbon emission and air pollutants generated in the transportation of the waste to landfills or dumping sites as well as import transportation of the original building materials.

9.2 Economical Benefits

a. It offers the industry a simple and efficient solution for converting the waste into useful construction products; which saves a lot of overhead cost (the ample time required for obtaining the permit from EPD for disposing the waste is no longer required – an extremely difficult task for engineers);
b. It saves the pre-treatment and transportation costs for dumping the waste to landfills or marine dumping sites; and
c. It saves cost for importing conventional blocks and tiles for the project.

10. CONCLUSION AND WAY FORWARD

The benefits of the innovative MMMM have been fully demonstrated in KT1A - they are practical, cost-efficient, environmental-friendly and effective in reforming marine mud waste to useful building materials. It is feasible to mass produce MMMM of consistent qualities not inferior to conventional tiles or blocks. Of the large amount of marine mud excavated from KT1A, they are all consumed and used back in the Project; i.e. without the need of dumping the waste off site adding costs to the project and the environment.

EDP has commented that the HD's green treatment of the marine mud waste by recycling the marine mud on site sets the industry, both government departments and private companies, a good reference case in resolving the waste issue. The building contractors also reckon the green treatment technology effective and efficient in resolving marine mud waste found at site. There are other construction works to be carried out in the whole Kai Tak Development, it is expected that huge amount of marine mud will also be generated from these works if excavations at reclaimed area are carried out. The innovative MMMM technology could definitely provide a simple and effective resolution for the environmental issue. In fact, HD has already been approached by Civil Engineering and Development Department and a contractor for details of MMMM for they encounter the same issue in the area. HD will continue to share our experience gained and field records obtained in the project to other departments, consultants and contractors through issue of technical papers, forums and meetings. It is anticipated that the eco-friendly and cost-effective technology will be more widely adopted in both public and private sectors eventuating a more sustainable industry hence community.

HD's development of the green treatment technology of reforming marine mud waste in KT1A has show-cased organizations can innovate can contribute for sustainable community; engineers should not be complacent with existing accomplishments on environmental protection nor set limits for developments for sustainability.

The World is in our hands.

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ANNEX A

PRODUCTION OF MARINE MUD MADE MATERIALS

Production Cycle of MMMM

Day 1

1. Sort and weight components (see Fig. I to Fig. iii).
2. Measure water content of marine mud.
3. Soak marine mud in 2/3 of the total water required (see Fig. iv).

Day 2

1. Pre-mix cement and recycled aggregates in Pan Mixer No. 1 for 2 minutes (see Fig v).
2. Put soaked marine mud into the Pan Mixer No. 2. Add in the remaining 1/3 water required, super-plasticizer and colour pigment. Mix the components for 2 minutes (see Fig. vi).
3. Transport the mixed components in Pan Mixer No.2 to Pan Mixer No. 1 (see Fig. vii). Mix all the components for another 3 minutes (see Fig. viii).
4. Carry out Slump Test to the MMMM mixture (see Fig. ix; designed slump = 50mm).
5. Cast the MMMM mixture into moulds (see Fig. x) on top of a vibrating table. Compact the MMMM for 2 minutes (see Fig. xi).
6. Cover the moulds with polyethylene sheet and cure the MMMM for 24 hours.

Day 3

1. Demould the MMMM.
2. Cure the MMMM by water-spraying twice a day for another 7 days.

Fig. i Marine Mud

Fig. ii Sorting Recycled Aggregates

Fig. iii Superplasticizer Rheomix 610P Manufactured by BASF

Fig. iv Soaked Marine Mud

Fig. v Pre-mix Cement and Recycled Aggregates in Pan Mixer No. 1

Fig. vi Mix Soaked Marine Mud, Water and Superplasticizer in Pan Mixer No. 2

Fig. vii Trowel-able Marine Mud Mix (to be transported from Pan Mixer 2 to Pan Mixer 1

Fig. viii MMMM Mixture

Fig. ix Conduct Slump Test to MMMM Mixture

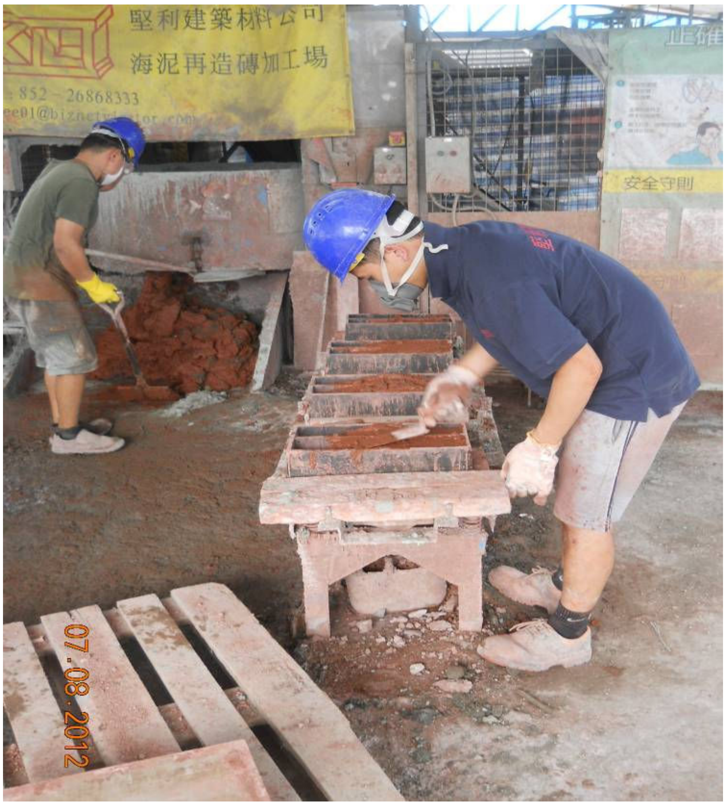

Fig. x Cast MMMM Mixture into Moulds

Fig. xi MMMM (MM Paving Blocks) After Compaction

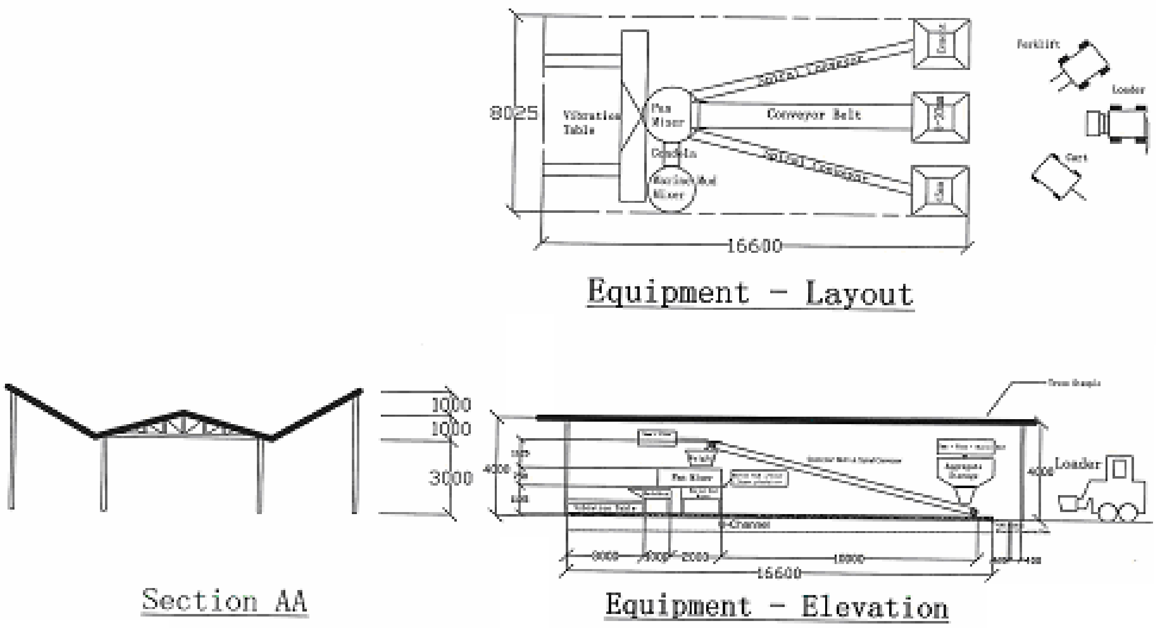

Fig. xii Sketch on Set-up of the Temporary Factory