A NEW FILL MATERIAL TECHNOLOGY FOR EX-MINING
LAND RECLAMATION AND CONSTRUCTION PURPOSES

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ABSTRACT

Rapid industrial and commercial expansion in recent years has created the need for more land. One of the options to create more land is to reclaim ex-mining land. Ex-mining land contains numerous mined out lakes and ponds. Numerous methods are available to fill these lakes and ponds. The ex-mining land consists of a variety of materials, such as sand, clay, slime and organic peat. A new land-fill method, which is economically competitive, technologically feasible and will not contribute to any environmental problems, was developed. It is based on flocculation of slurry slime with Natural Organic Polymer (NOP) or Poly Vinyl Acetate (PVC), mixed with residual soil and usage of the flocculated slurry slime as part of the fill material. The physical and geotechnical properties of the flocculated slurry were assessed by laboratory tests, including pH and Eh measurements, acid neutralization capacity determination, hydraulic conductivity and comparison and cost analysis with conventional fill materials, such as sands. The flocculated slurry slime was slightly alkaline, with pH 8.4, Eh value of 171 mV, negligible ANC, and hydraulic conductivity of 8x10^-3 - 7x10^-4 m/s. It was also found that the material is unlikely to cause significant change in redox conditions of the subsurface environment over a long-term period. The proposed method is more feasible as compared to other methods in comparison and cost analysis. In general, the flocculated slurry slime is suitable to be used as a fill material for land reclamation.

KEYWORDS: mining waste land, construction, fill material, classical methods, flocculated slurry slime

1. INTRODUCTION

During recent years, mine land reclamation and ecological rehabilitation has become the subject of common concern by countries in the world, and this trend is increasingly widespread. Land-use is a decision to be made by the society. Land-use can be changed – society can decide to change the land-use on a rehabilitated colliery from crops to housing or industrial estates, but mines have an obligation to ensure that no net loss in land capability occurs [1]. This must be the primary objective in rehabilitating mined land. Where land capability is not preserved, society is deprived of choice. Degraded lands can potentially support fewer land-use possibilities – no crops, for instance. Some argue that agreements with communities regarding land-use can be made prior to rehabilitation whereby a lower quality of rehabilitation is acceptable [2, 3]. This may occur, for example, if the pre-mining land capability is arable, but the community is satisfied with grazing as post-mining land capability. Such decisions, even when based on community preferences, do not promote sustainability. Soil formation takes thousands of years and, by only restoring a fraction of the original land capability, future generations are deprived of the choices that are available to this generation [4, 5].

Malaysia is an important country in mining production, and the exploitation of mineral resources plays a decisive role in national economy development. Currently, the mining industry is responsible for producing a sizeable proportion of the nation’s merchandise export income, and its relative importance is continuously increasing. Recent available data (2000) showed that the mining industry consisted of 87 mines extracting ores of gold, tin, nickel, copper, aluminium, manganese, iron and chromium [6, 7]. In addition, there are more than 18 establishments producing non-metallic minerals and construction materials. The number of mining operations is rapidly increasing as explorations continue to take place, particularly in the Perak, Penang and Selangor states. How to exploit mineral resources rationally but reduce all sorts of adverse effects on the human environment in its process, is a major event in people’s livelihood [8].

Due to blooming development and rate of urbanization in Peninsular Malaysia in recent years has created the need of more land, especially land near to the developed areas. Many urban areas have expanded to mined-out land which has numerous mined-out ponds. It has been estimated that urban population will double itself every 10 to 15 years and mined-out lakes and ponds in the way of
urban expansion will be reclaimed and utilized for the construction of industrial and industrial parks. There are numerous land reclamation projects being carried out in Malaysia to increase the total land area by reclaiming the ex-mining land. Currently, approximately 15% of the land area of Malaysia has been reclaimed over the last 35 years. The total reclaimed land area is increasing each year. Therefore, the amount of fill materials required also increases tremendously as the reclamation is ongoing, and the future sites to be reclaimed have to encroach into deeper sea. A large number of ex-mining lands had been reclaimed in the last decade for construction purposes. From time to time, cases have been reported in the press where houses or factories built over reclaimed ground had problems involving cracks on the walls, ceilings and floors [9, 10]. These problems are largely due to differential ground settlements resulting from consolidation of trapped slime lenses. This is an ongoing problem and will continue to be as long as buildings are constructed over improperly reclaimed land.

In Malaysia, the most commonly practised method of reclaiming mined-out ponds by developers of housing estates or industrial parks is to lower the water level of the ponds and emplace fill material from one end of the pond. But “Lowering of Water Level and Emplacement of Fill Material Method” does not remove the soft slurry slime at the bottom of the ponds, and is carried out mostly on an ad-hoc basis without any prior detailed site investigation [11, 12]. Two other methods, an improvement over the earlier mentioned method, are the Displacement Method and Containment Method [13-15]. In the Displacement Method, fill material is dumped into the pond, resulting in slurry slime being pushed to one end of the pond, and displaced slurry slime is dug up and then carried away by trucks. In the Containment Method, the soft slurry is removed and underlying slime is contained in the pool within the pond. A geomembrane is then laid over the slime and fill material is placed on top. To speed up the consolidation process, vertical sand drains are installed to drain the slime beneath the membrane [16, 17]. Currently, most of the fill materials for land reclamation are sands sourced from seabed, and the cost of the material is a significant portion of the total project costs. If the flocculated slurry slime (with Natural Organic Polymer (NOP) or Poly Vinyl Acetate (PVC) as part of the fill material could be used as fill material for land reclamation, it would solve the disposal problem and also reduce the construction cost of land reclamation projects [18, 19].

Land reclamation is a complex, multidisciplinary and multi-process engineering system, and its implementation requires a scientific and rational evaluation and planning. For the mining industry, the land reclamation works were carried out earlier and have made great progress, but are still faced with many problems to be improved in the actual implementation process [20]. The objectives of this study were to investigate the suitability of using flocculated slurry slime as a fill material and to assess its potential environmental impact. The physical, geotechnical and geochemical properties of the flocculated slurry slime were examined.

2. MATERIALS AND METHODS

2.1. Description of the site

The study area, Bestari Jaya catchment, is located at 3°, 24’ 40.41” N and 101° 24’ 56.23” E, and is part of District Kuala Selangor in Selangor state. Bestari Jaya has three towns: Mukim Batang Berjuntai, Mukim Ulu Tinggi, and Mukim Tanjung Karang. The old name of Bestari Jaya is Batang Berjuntai. 2007, the name Batang Berjuntai was renamed "Bestari Jaya" due to censorship by the government, as "Batang Berjuntai" had phallic meanings in Malay. The Bestari Jaya was an old tin mining area for over 10 years. The whole catchment covers an area of 2656.31 hectares, located downstream at the embankment of Kampung Bestari Jaya and University Industry Selangor (UNISEL) main campus (Fig. 1). The catchment water flows downstream to River Ayer Hitam and River Udag which ultimately end up with Selangor River at 5 km upstream of Batang Berjunti Water Treatment Plant SSP2, a major water distributor to federal territory (Kuala Lumpur and Putrajaya) and Selangor state as well [21].

Bestari Jaya has a tropical and humid climate, with very little variations in temperature throughout the year (average temperature 32 °C during day and 23 °C at night). The annual average rainfall is 2000 mm, and 3000 mm with potential evaporation of 1600 mm per year. The area consists of myriad ecosystems which can be subdivided into several categories, such as degraded land, large open lakes and small ponds, earth drains and wetlands area, tin tailings (sand and slime tailings), and logged peat swamp forest land in the east. The contribution of storm water, peat swamp forest water and recent sand mining activity has caused severe environmental pollution due to drainage problems in the area. The area has a lot of big lakes and small ponds that are interconnected by earth drains. Excess water from these lakes and ponds is discharged to the existing earth drains at the downstream of the lakes and ponds. Flow routing had been carried out by applying the survey data. Some of the lakes flow across the downstream into open spaces and wetlands that run off into River Ayer Hitam, meet up River Udag, and ultimately end up to River Selangor at the Jalan Timur Tambahan road junction, east of UNISEL (Fig. 1) [22].

The wetland (579.7 ha) is stretched along the north-western border of the site. Several useful plant species have been seen in the wetland while several harmful weed species have been also seen in the study area that cause blocking of water courses, and water becomes foul due to large masses of water leaves. This area is sandy in texture, and it is representative of entire ex-mining area in the country. The parent materials are riverine alluvium ones, with pH in range of 3.5-5.5 [21].
2.2. Subsoil conditions before reclamation

Prior to the reclamation work, soil investigation was carried out to gather subsoil information and engineering properties. Boreholes and trial pits were made at the site area so that more continuous visual information on the subsoil materials can be obtained (Fig. 2) [23]. Soft silty
clay was found at the mining land as well. The average thickness was about 5 m, and liquid limit and plastic index of the soft clay were in the ranges of 50-80% and 35-45%, respectively. Figure 3 shows the properties of the soft silty clay. It is underlain by a thick layer of medium to stiff silty clay and medium dense silty sand layers. Hard or very dense soil layer could only be encountered at about 45-55 m below the existing ground level [24, 25]. Granite bedrock was encountered in some boreholes at depths of 50-65 m. Summary of the subsoil profile is as shown in Table 1.

![FIGURE 3 - Physical properties of the soft clay layer.](image)

**TABLE 1 - Typical subsoil profile**

<table>
<thead>
<tr>
<th>Reduced Level (m)</th>
<th>Soil Description</th>
<th>Standard Penetration Test (SPT) Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 0 m</td>
<td>Heterogeneous mining land</td>
<td>0 to 30</td>
</tr>
<tr>
<td>0 m to -5 m</td>
<td>Very soft to soft silty clay</td>
<td>0 to 4</td>
</tr>
<tr>
<td>-5 m to -50 m</td>
<td>Medium stiff or medium dense silty clay or silty sand</td>
<td>6 to 30</td>
</tr>
<tr>
<td>Below -50 m</td>
<td>Very dense or hard soft layer</td>
<td>&gt;50</td>
</tr>
</tbody>
</table>

2.3. The potential problems of reclamation

The soft clay layer at the site has low shear strength and high compressibility characteristics.

Additional loading would be imposed to this soft clay layer due to the reclamation work. Two major potential problems were anticipated. These problems were (1) stability and (2) long-term settlement of the reclaimed platform [26]. Stability analyses were carried out, and it was found that with a gentle reclaimed platform side slope and proper control on the backfilling rate, the stability of the reclaimed platform will be under control, and this should not be a major concern. The platform will become more stable in the long term as the subsoil, especially the soft clay layer, gains strength with time. Settlement analysis indicated that long-term settlement will be excessive due to the highly compressible soft silty clay underneath the reclaimed platform [27, 28]. The settlement will take long time to complete. In addition, the highly heterogeneous ex-mines at the site may also cause unexpected settlement when subjected to fill load which causes the collapse of large voids within the landfill. The potential biodegradation process of some organic materials may also contribute to ground settlement [29].

2.4. Materials

The slurry slime samples originating from the mined-out ponds were collected from Bestari Jaya ex-mining catchment, flocculated by Natural Organic Polymer (NOP) or Poly Vinyl Acetate (PVC), and then mixed with residual soil [30]. The raw flocculated slurry had particle sizes ranging from μm to >1 cm in diameter, and particle shapes ranged from partially rounded to angular. Polyvinyl acetate, PVA, PVAc, poly (ethenyl ethanoate) is a rubbery synthetic polymer with the formula (C₄H₆O₂)n. It belongs to the polyvinyl ester family with the general formula -[RCOOCHCH₂]-, and is a type of thermoplastics.

![IUPAC name poly (1-acetyloxiethylene)](image)

2.5. Characterization of physical and geotechnical properties of flocculated slurry

The tests used for physical and geotechnical characterization of flocculated slurry are shown in Table 1. The physical and geotechnical tests were conducted in accordance with either British or ASTM Standards. Some of the test procedures have been described by Head (1982, 1984, and 1986) [31-33]. The laboratory direct shear test [31] and triaxial consolidated drained (CD) test [33] were conducted to measure the stress–strain and shear strength behaviour of the flocculated slurry.

![TABLE 2 - Tests used for characterizing physical and geotechnical properties of flocculated slurry slime.](image)

2.6. Characterization of geochemical properties of flocculated slurry

2.6.1. General characterization

The flocculated slurry was analyzed for its elemental content, pH, acid neutralization capacity (ANC), redox potential (Eh), and electrical conductivity (EC). The pH of the flocculated slurry at a solid/water ratio of 1/1 was measured using Hydrolab MSS USA. The ANC of the material was determined by titration of a 100-g sample with 0.02 N HCl. The Eh was determined at room temperature (23 ±2 °C) using a platinum electrode and...
Ag/AgCl with 3.33 mol L\(^{-1}\) KCl as reference electrode. Then, Eh measured using Ag/AgCl with 3.33 mol L\(^{-1}\) KCl was converted to the equivalent Eh, measured with a standard hydrogen electrode (SHE) using the following relationship [34]:

\[
E_{\text{H}_{2}\text{O}} = E_{\text{measured}} + 206 - 0.7(t - 25) \text{ mV}
\]

where, \(t\) is the temperature in °C, at which the Eh was measured.

The EC was measured using a Hydrolab MS5 USA. The flocculated slurry was submerged in deionized distilled water at a solid/water ratio of 1/1. The set-up allowed oxygen diffusion through the water surface and, therefore, partially oxic condition prevailed. Measurement was continued until measured Eh and EC values were stabilized. These measurements monitored the possible time-dependent changes in the leachate characteristics under a partially oxic condition [35]. This simple set-up was designed to simulate field conditions in which the flocculated slurry would be submerged as the groundwater tables are commonly near to the ground surface in all the reclaimed sites in Malaysia.

2.7. Comparison and cost analysis

In Malaysia, the most common method of reclamation practised by developers for construction purposes is lowering of water level and emplacement of fill material method. Two other conventional methods of reclamation currently practised are the displacement and the containment methods [36, 37]. Comparative analysis of currently practised methods with the proposed flocculation and admixing method has been accomplished by the author. Similarly, theoretical comparison of reclamation costs of displacement and containment methods, as well as lowering of water and emplacement of fill material and the proposed flocculation and admixing methods was carried out but cost analysis of the proposed method was only explained herein due to the ambiguity of results.

3. RESULTS AND DISCUSSION

3.1. Physical and geotechnical properties of flocculated slurry

The basic physical properties of flocculated slurry are summarized in Table 3. The physical properties of local sand are also included for comparison. The flocculated slurry had a much higher specific gravity and dry density than the ordinary sand, which means that the self-weight of the flocculated slurry is high. This is beneficial for land reclamation as the larger the self-weight, the larger the overburden pressure to consolidate the soft mined-out beds.

The typical grain size distribution of the flocculated slurry is shown in Fig. 4. According to the unified soil classification system (USCS), the material can be classified as well graded, which is ideal for pavement construction, road construction and land reclamation. The mean diameter of the flocculated slurry was around 0.5 mm, which was larger than that of ordinary sand. Generally, fill material with a large mean grain size is preferred, as the larger the mean grain size, the greater the hydraulic conductivity and the greater the shear resistance [37].

![Figure 4 - Typical particle size distribution curve of flocculated slurry.](image)

The hydraulic conductivity measured for the flocculated slurry was in the range of \(8 \times 10^{-5}\) to \(7 \times 10^{-4}\) m/s depending on the density of the material. The ranges of friction angle measured from shear strength tests are shown in Fig. 5a for the triaxial CD tests on saturated specimens, and Fig. 5b for the direct shear tests on dry specimens. The friction angles measured by the triaxial tests range from 38.9 to 41.6° for loose and 43.5 to 47.0° for dense saturated specimens under a confining pressure of 50-200 kPa (Fig. 5a). Direct shear tests on dry flocculated slurry indicated that the friction angles for loose specimens ranged from 29.0 to 40.0° (Fig. 5b). These values were much higher than those for sand under the same conditions. This is a favourable property as high friction angle will ensure greater slope and foundation stability, which are crucial to the design of land reclamation [38]. It should be noted that a range of friction angles is presented instead of just one friction angle. This is because the friction angle for the flocculated slurry is affected by the confining pressure which is a function of depth below the ground level [39].
3.2. Geochemical characteristics

The pH of leachate generated from the flocculated slurry using deionized distilled water at a solid/water ratio of 1/1 was around 8.4. This pH value is within the common pH range for soils and groundwater. The material had a rather low ANC (Fig. 6) in comparison with the clay that underlies the reclaimed sites. Sand has practically negligible ANC. The ANC of a material is derived from acid adsorption and dissolution of acid-soluble minerals [40]. The low ANC value indicates that flocculated slurry is not resistant to acid attack.

Another important property of the flocculated slurry is the Eh value. Initial Eh value (measured with Ag/AgCl reference electrode) for the flocculated slurry was 171 mV at a solid/water ratio of 1/1. The deionized distilled water added to the flocculated slurry originally had a measured Eh of 289 mV. Therefore, it can be concluded that when placed in the reclaimed site, the material will create a slightly reducing condition. The Eh would continue to decrease rapidly within days after placing in water and would gradually stabilize thereafter, as illustrated by Fig. 7. It was found that the values stabilized after 120 days. The decrease was accompanied by a rise in EC, which could be attributed mainly to the time-dependent mineral dissolution. These observations were due to the presence of traces of sulphide minerals, or other reduced minerals present in the slurry [41]. These minerals could gradually oxidize under oxic conditions and release H⁺ as well as other ions into the pore water. As a result, there was a marginal drop in pH from the initial pH 8.4 to a final pH of 7.9 [42].

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3.3. Methods comparison with the newly developed method

3.3.1. Lowering of water level and emplacement of fill material method

This method of reclamation is widely practised by developers of housing estates or industrial parks in Malaysia. Reclamation is often carried out on ad-hoc basis without any prior site investigation. The water in mined-out pond is lowered and fill material, usually tailing sand from nearby dumps, is pushed in from one end of the pond [43-45]. The soft slurry slime at the bottom of the pond is not removed and some of the slurry slime would seep into the voids of the fill material and other ones, being consolidated on the pond bottom. It is almost impossible to predict the total time needed for the development of a competent, consolidated ground as classical methods for determination of consolidation deal with small strain settlement [46].

This method of reclamation involves dewatering in the mined-out ponds by pumping out and disposing off
the supernatant. Any indiscriminate extraction of water can cause drawdown slope instability, particularly if the sides of the pond are steep. Secondly, slurry slime is soft with no bearing strength or shearing strength; the soft slurry slime would seep into the voids of the fill material, resulting in localized soft spots. Another shortcoming with this method is that it is almost impossible to predict the total time needed for the development of a competent and consolidated ground in areas reclaimed with this method [47].

3.3.2. Displacement method

Raju and Hoffman (1996) [48] used this method for a reclamation project in the Selayang area in Kuala Lumpur in the 1980s. Soft slurry slime was displaced by pushing in sand fill in a prescribed direction. A layer of geomembrane is laid over the entire pond surface and sunk by laying sand bags or dipping fill material over it. The slurry slime is then displaced as more fill material is dropped onto the surface of the geomembrane. When the slurry slime is displaced, a mud wave is developed in most parts of the sand fill. This mud wave will increase the height of the fill material required to displace the slurry slime. After displacing the slurry slime to one end of the pond, the slime is excavated. Fill material is then pushed in from one end of the pond.

A major disadvantage is the incomplete displacement of slurry slime within the trough of karstic limestone bedrock topography. In Raju and Hoffman reclamation project, it was reported that the entrapment of slurry slime within the troughs of karstic limestone was one of the reasons for the creation of localized soft spots in the reclaimed ground [48]. As a result of floors, drains and other poorly supported parts of buildings constructed over such an area, it suffered damages and cracks were formed. A second disadvantage is that the displaced slurry slime has to be discarded, and quite often, is just dumped into another pond nearby, or into some nearby drainage systems [49].

3.3.3. Containment method

The containment method does not displace the slurry slime in the pond. Instead, the slime is contained within the pond and compressed in situ. This method has the advantage of requiring lesser fill material for the backfilling of the pond. Yee (2010) [50] stated that this method requires the removal of topmost 500-mm layer of the soft material. The initial layer of the fill material has to be placed carefully so as not to exceed the bearing strength of the underlying soft slime. Geo-membranes are often used as a separation and reinforcement layer. Fill material is placed by sand pumping and conveyor belt system in uniform layers with depths not exceeding the bearing capacity of the underlying slime. The underlying soft slime is allowed to consolidate, whereby resulting in increasing shear and bearing strengths. When a stable condition is attained, side tipping can be used to speed up the works. Often vertical drains are installed to speed up the consolidation of the slime [51].

Like the displacement method, there are some shortcomings in the containment method as well. Yee [50] stated that topmost 500-mm of slurry without shear and bearing strengths has to be removed. However, investigations carried out by the writer showed that slurry slime in the test ponds was thicker. As such a substantial amount of slurry has to be removed, it can result in environmental problems. The initial layer of the sand fill has to be placed very carefully so as not to exceed the bearing capacity of the underlying material. The sand fill process has to be carried out in uniform layers with depths not exceeding the bearing capacity. Such sand filling requirements are difficult to achieve [52].

3.3.4. Admixing of flocculated slurry slime with soils

An alternative method which is economically competitive, technologically feasible and which will not contribute to any environmental problem is to flocculate the slurry slime with NOP or PVC, and to use the flocculated slurry slime as part of the fill material. Tests carried out by Chow and Weng [53] have shown that slurry slime with NOP or PVC have higher engineering strength and better settlements, and a shorter time to achieve complete settlement. Chow and Weng [53] explained that NOP or PVC-flocculated slurry slime admixed with residual soil or tailing sand distinctly have better physical (i.e., higher increasing solid concentrations, higher rate of decrease in the voids ratio and moisture content) and higher engineering strengths (i.e., higher shear strength and higher bearing strength). The flocculated slurry slime is mixed with either residual granitic or schistose soil, depending on their availability, or with tailing sand, often found in the tailing dumps in the vicinity of the ponds. The admixed material is then emplaced in the pond as part of the fill material [53].

In this proposed method, a holding pond is excavated beside the pond earmarked for reclamation. An ideal site for the location of the holding pond is on slightly higher ground.

Material excavated from the holding pond is used for the construction of bunds resulting in a higher holding-pond capacity. Alternatively, the excavated material can be used as a source of admixing material [54].

Slurry and very soft slime from the bottom of the pond designated for reclamation is pumped out using submersible suction pumps until the layer of soft slime is reached. Mixing is best achieved by passing the slurry and the flocculating reagents along a 20-50 m long sluice box fitted with transverse riffles. Theflocculated slurry is then allowed to settle in the holding pond, and the clear supernatant is allowed to be drained off into a nearby pond, or into the drainage system [55].

The still wet flocculated slurry is then admixed, preferably with granitic soil or schistose soil. The minimum admixed ratios for granitic soil/NOP-flocculated slurry,
granitic soil/PVAC-flocculated slurry, Schistose soil/NOP-flocculated slurry, Schistose soil/PVAC-flocculated slurry admixtures are between 0.75-1.00. If tailing sand is used for admixing, the minimum admixing ratios for tailing sand/NOP-flocculated slurry and tailing sand/PVAC-flocculated slurry are between 3.0 and 5.0. The admixed material is then pushed back into the designated pond in layers of about 500-mm thickness, taking steps to ensure that the initial layer of admixed material does not cause a shear failure in the underlying soft slime [56].

Following this, fill material comprising either tailing sand or residual soil is emplaced over the admixed material. This method of reclamation does not involve the dumping of slurry slime into another pond, as it forms part of the admixture. As such, there will not be environmental problems.

### 3.4. Comparative cost of reclamations

A theoretical comparison of reclamation costs of displacement method and containment method, lowering of water and emplacement of fill material method and the proposed flocculation and admixing method was carried out. Costing was carried out for three lakes with sizes of 3, 5 and 10 hectares. Comparison was also carried out for various pond water depths.

Results showed that lowering of water level and emplacement of fill material method is the cheapest. It costs only RM 0.74 to reclaim one square foot when the depth of the pond water is 3 m. The cost, however, increases with the depth of the pond water, rising to 1.14 per square foot for a water depth of 5 m, RM 1.54 per square foot for 7 m water depth, RM 1.94 per square foot for 9 m water depth, RM 2.34 for 11 m water depth, and RM 3.14 for 15 m water depth.

The containment method is the most expensive of the four reclamation methods discussed above. For a pond with 3 m of water, the reclamation cost is RM 4.48 per square foot if the slurry slime to be removed is about 1-m depth. The cost goes up if the slurry slime to be removed is thicker, rising to RM 6.30, RM 7.27, RM 12.05 and RM 15.83 for the removal of 2, 3, 5 and 7 m of slurry slime, respectively. Likewise, if the depth of water in the pond increases, the reclamation cost goes up accordingly. Between the displacement method and the proposed flocculation and admixing method, the former method is cheaper if the pond water is 3 m deep and the slurry to be removed is between 5-7 m, 9-11 m and 15 m; the displacement method is also cheaper if the slurry to be removed is less than 3, 5, and 7 m thick, respectively.

Results of the theoretical costs comparison showed that the depths of the pond and thickness of the slurry slime layer to be flocculated or removed are important factors which affect the cost rate of reclamation. The size of the pond affects the total costs but not the cost rate. The lowering of water level and emplacement of fill material method is the cheapest amongst the four methods discussed. However, this method is also the most inefficient one. The proposed flocculation and admixing method is environmentally friendly as there is no disposal of slurry slime from the pond. All the slurry slimes are flocculated and used as part of the fill material, hence reducing the amount of fill material as well. The methodology is technically feasible and economically competitive.

### 4. CONCLUSIONS

In Malaysia, the most common method of reclamation practised by developers of housing estates and industrial parks is lowering of water level and emplacement of fill material method. This method results in a number of technical problems, amongst which is that slurry slime portions are entrapped in the voids of the fill material and within the troughs of the karstic limestone bedrock. Also, it is almost impossible to predict the total time required to achieve a competent and consolidated ground. Two other conventional methods of reclamation currently practised are the displacement and the containment methods but both also have a number of shortcomings. The proposed flocculation and admixing method is technically feasible, economically competitive and environmentally friendly. It is recommended that the slurry slime has to be pumped out from a pond, flocculated with NOP or PVAC, and then, the flocculated slurry slime is admixed with residual granitic or schistose soil, or as a last resort, with tailing sand. The admixed materials are then put back into the pond as part of the fill materials.

Investigations on the physical, geotechnical and geochemical characteristics of the flocculated slurry show that the material has favourable engineering properties which make it suitable to be used for land reclamation. The flocculated slurry is rather weathering resistant. The absence of acidic leachate generation due to redox reactions from the flocculated slurry also rules out the possibility of acid generation and excessive leaching of the material. In addition, the material is rather stable in its redox characteristics. However, further studies that focus on field monitoring are still required as there may be unexpected long-term environmental consequences arising from the massive use of flocculated slurry in reclaimed sites. Time-dependent reactions, such as redox processes and mineral dissolution kinetics under field conditions, and the possibility of catalysis by indigenous microorganisms, must be monitored. Ultimately, life-cycle assessment approach will be needed to identify the best solution for the admixing of flocculated slurry with residual soil in Malaysia.

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