Mechanical Method for Turning Hong Kong Soils into Construction Materials Including Sand

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ABSTRACT

Sand is the most exploited raw solid material in the world. It can be used for construction of buildings, roads, railways, bridges, tunnels and beaches. According to United Nations' reports in 2019 and 2022, the world is facing a shortage crisis of sand, as one of the greatest sustainability challenges of the 21st century. Such sand shortage crisis around the world has affected the use of sand in Hong Kong since Hong Kong does not produce any sand. This paper presents a newly invented method for turning Hong Kong soils into construction materials including sand. The local completely decomposed granitic soil and volcanic soil in Hong Kong can be mechanically turned into the materials of gravel, sand, silt and clay. The gravel, sand and silt are siliceous solid particles and mainly quartz mineral particles. The clay is mainly kaolinite mineral. These materials with known and narrow particle size ranges can be used as the raw solid materials in construction and other industry. The method presented in this paper can offer a new sustainable and environmental-friendly and economic solution to the world' sand shortage crisis.

Keywords: Soil, Sand, Silt, Clay

1 Introduction

1.1 CDG and CDV soils in Hong Kong

Hong Kong soils are dominantly the completely decomposed granitic (CDG) soils and the completely decomposed volcanic (CDV) soils (GEO, 2017; Yue, 2013). The residual soils and colluvial soils also come from the CDG or CDV soils. The CDG or CDV soils are in-situ weathered soils and also called saprolitic soils. They are derived from in-situ chemical weathering of igneous rocks and retain the original texture, fabric and structure of the parent igneous rock. Residual soils are the in-situ soils derived from the CDG and CDV soils and do not contain any traces of the original texture, fabric and structure of the parent rock. Colluvial soils (or colluvium) are formed by slipping, flowing or rolling of saprolitic soils, residual soils and/or rock stones down slopes under the action of gravity and rainfall water. Public fill mainly is the excavated soil due to construction activities on ground.

Hong Kong soils are nature mixtures of siliceous mineral particles, clay mineral particles, and water. The siliceous mineral particles mainly include quartz mineral particles and generally have the particle sizes greater than 0.002 (or 0.0008) mm. They are further divided into gravel, sand, and silt with the particle sizes respectively between 63 mm and 2 mm, between 2 mm and 0.063 mm, and between 0.063 mm and 0.002 mm. They are the preserved minerals of the parent granitic or volcanic rocks. The clay mainly includes the clay mineral of kalinite and generally have the particle sizes smaller than 0.002 mm. The clay minerals are the weathering products of the parent granitic or volcanic rocks, where the weathering has chemically decomposed the feldspar and biotite minerals of the parent rocks into clay minerals. The quartz mineral is the only siliceous minerals that can resist the weathering.

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1.2 Objective of this paper

According to United Nations' reports (UNEP, 2019, 2022), the world is facing a shortage crisis of sand, as one of the greatest sustainability challenges of the 21st century. Such sand shortage crisis around the world has affected the use of sand in Hong Kong since Hong Kong does not produce any sand. This paper presents a newly invented mechanical method to convert the Hong Kong soil into the quality materials of siliceous mineral particles (or sand/sand/silt) and clay mineral particles (clay) (Yue, 2021). The test results demonstrate that these individual materials have high economic values for use in construction, other industries and agriculture in Hong Kong and other regions (Ma *et al.*, 2023; Song *et al.*, 2023). The author further discovered that the Hong Kong soil is a non-metallic ore of siliceous sand and clay minerals.

2 Mechanical Method

2.1 Brief

The mechanical method is a mechanical process of washing and sieving the general soil. It has four main steps. The first step washes the general soil into clean natural sand and soil slurry. The second step washes and sieves the soil slurry into clean fine sand and mud slurry. The third step washes and sieves the mud slurry into silt and clay slurry. The fourth step cycles the used water from the clay slurry and obtains clay material.

The method can convert the general soil into the particles of siliceous minerals and the particles of clay minerals. We have demonstrated that the engineering method is cost-effective, sustainable and environmental-friendly and produces an insignificant amount of carbon dioxide CO_2 and other green-house gases.

2.2 Step I for converting soil into clean sand and soil slurry

The Step I uses a rotary snail-type mixture to mix and wash the soil with water (Figure 1). Once the soil is mixed with water, the heavy and large particles are automatically settled at the bottom of the snail container. The light and small particles are suspended in the water and make the water become the soil slurry. The soil slurry usually contains the particles of clay, silt, and fine sand. The heavy and large particles include gravels, sands, and some fine particles of clay and silt.

Figure 1: *Step I for mixing and washing soil with water.*

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The soil slurry in the upper portion of the snail container is then poured into a large bucket. Then more water is added into the snail container for further mixing and washing. New soil slurry appears in the upper portion of the snail container again and is poured into the bucket. This adding water, washing the soil, and pouring soil slurry operation is repeated until both the new heavy and large particles and the new soil slurry becomes relative clean (Figure 2).

Figure 2: *Results of clean sand and soil slurry from Step I of mixing and washing soil with water.*

2.3 Step II for converting soil slurry into clean fine sand and mud slurry

The soil slurry portion obtained from Step I contains mainly silt and clay and some fine sands. The Step II is to separate the fine sand from the silt and clay materials in the soil slurry. The soil slurry is poured out of the container on a steel sieve with the aperture of 0.063 mm (or other sizes) (Figure 3). The soil slurry on the sieve is stirred and washed with additional water. The fine sand is staying on the sieve and the silt and clay become the mud slurry that is leaking through the sieve into the bucket. This stirring washing and sieving operation is completed when both the fine sand on the sieve and the leaking water become clean. As a result, the clean fine sand is obtained and collected from the sieve. The mud slurry is collected for the Step III treatment.

Figure 3: *Step II for washing and sieving soil slurry into fine sand and mud slurry with water*

2.4 Step III for converting mud slurry into clean silt and clay slurry

The Step III is similar to the Step II. Instead of using the steel sieve, the Step III uses the nylon filter cloth with aperture of 0.002 mm (or other sizes) as the sieve. The mud slurry on the sieve is stirred and washed with additional water. The silt is staying on the sieve and the clay slurry is leaking through the sieve into the bucket (Figure 4). This washing and sieving operation is completed when both the silt on the sieve and the leaking water become clean. As a result, the clean silt is obtained and collected from the sieve. The clay slurry is collected for recycle of the used water and clay material in Step IV.

Figure 4: *Step III for washing and sieving mud slurry into silt and clay slurry with water*

2.5 Step IV for recycle of used water from clay slurry and obtain clay material

Figure 5: *Step IV for recycling water from clay slurry and obtain clay material.*

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The clay slurry has the density of 1.0470 to 1.0054 g/cm^3. It can contain water of the weight 20 to 200 times more than the weight of clay material. We have found that it is statically placed in a container, the clay slurry can experience gravity-induced sedimentation. Clean water appears at upper container and clay material consolidates in lower container (Figure 5).

After 16 hours of the static sedimentation, more than 85% of the water in the original clay slurry would present at the upper container. The clay slurry can become highly saturated soft clay with density of 1.4 g/cm^3. Other methods can also be used for dewatering the soft clay. The water can be recycled for re-use in the proposed washing and sieving method.

The recycled water has been tested for its purity with Cary 100 UV-Visible Spectrophotometer. The test results show the quality of the recycled water is high. The water can have the clay content less than 3.33 ppm.

2.6 The use of electric power

The use of electric power for the Steps I, II and III can be illustrated with the following test examples. For a CDV soil from Yuen Lang, the electric power used for the Steps I, II and III are respectively about 2, 7 and 29 kwh for ton of the soil. For a CDG soil from Happy Valley, the electric power used for the Step III is about 27 kwh for one ton of the soil. The static sedimentation method used in Step IV does not use any electric power. The transportation and uplifting of soil, water, soil slurry, mud slurry and clay slurry are manually carried at present. Some electric power is needed if automatic conveyor belt is used to do the transportation and uplifting of these materials.

3 The Products of Materials with Known Particular Sizes

3.1 General

The mechanical method has been used to convert the local soils in Hong Kong and other soils from Shenzhen and other places of Mainland China into quality materials of gravels, sand, silt and clay. Some examples are given below for the illustration.

3.2 The products of CDG soil

Figure 6 presents the photographs of the CDG soil from Happy Valley and its converted sand with gravel, silt and clay. Figure 7 shows the three curves of the particle size distribution (PSD) of the CDG soil, the CDV soil and the public fill. The weight percentages of gravel, sand, silt and clay are 11%, 37%, 4% and 48%, respectively. The gravel and sand in Figure 6 are further sieved into 12 individual particle sizes as shown in Figure 8. The three corresponding PSD curves of the gravel and sand are shown in Figure 9. The gravel and sand are well graded.

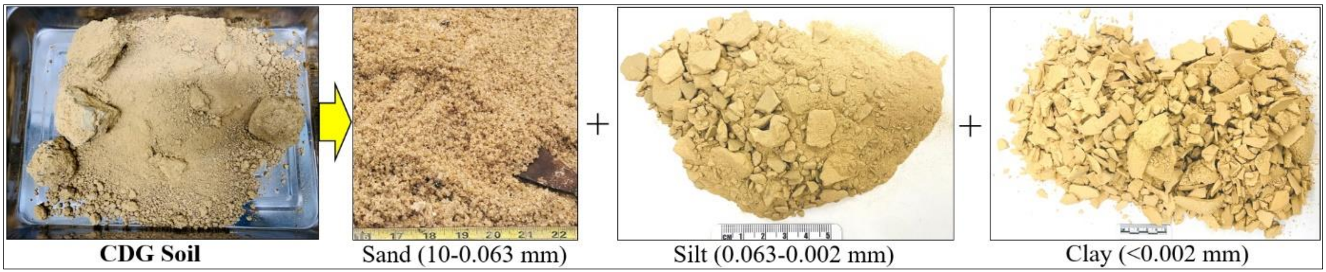

Figure 6: *Products of sand, silt and clay converted from a typical CDG soil from Happy Valley, Hong Kong*

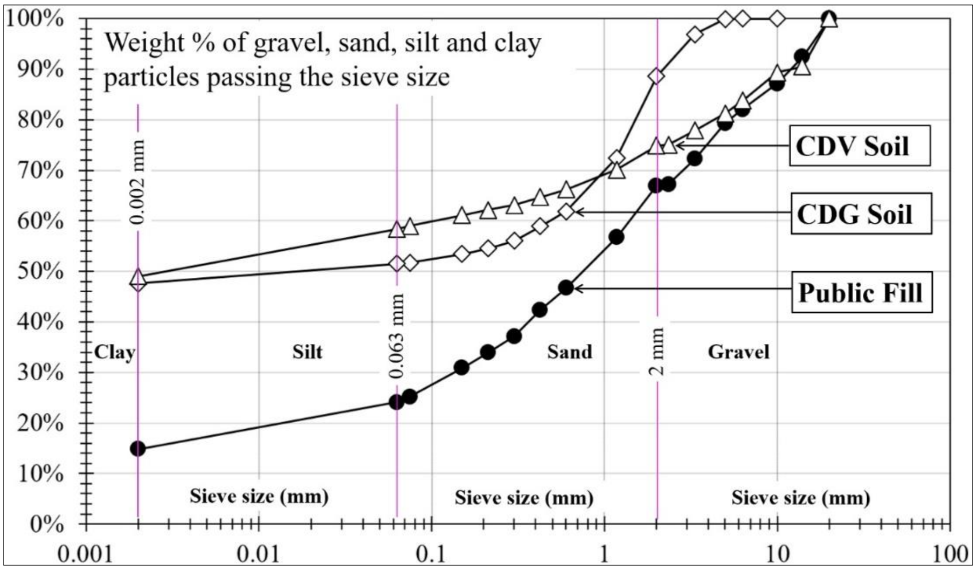

Figure 7: *Particle size distribution (weight percentages) of the sand, silt and clay converted from the CDG soil, CDG soil and public fill soil in Figure 6, Figure 13 and Figure 15, respectively.*

Figure 8: *The 12 individual particle sizes of the CDG sand in Figure 6 by dry sieve method*

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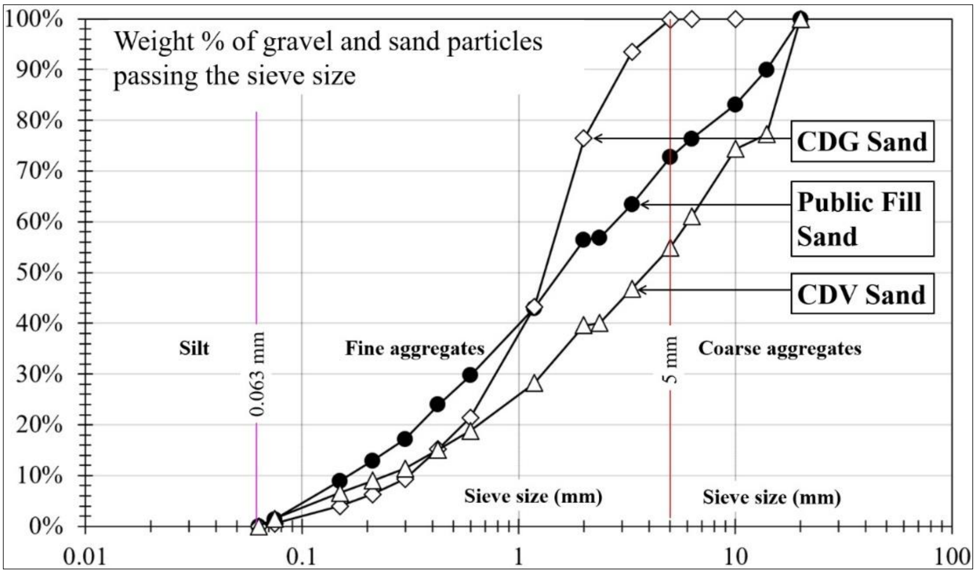

Figure 9: *Particle size distribution (weight percentages) of the sand converted from the CDG soil, CDG soil and public fill soil in Figure 10, Figure 14 and Figure 16, respectively.*

The Leica M205C stereomicroscope is further used to observe the particles of the sand, silt and clay. Figure 10 shows the nine stereomicroscopic images for the nine sub-groups of sand particles. The images clearly illustrate that the sand is dominantly quartz particles plus few feldspars. Furthermore, the Step III method can be further applied to wash and sieve the silt and clay into different size sub-groups.

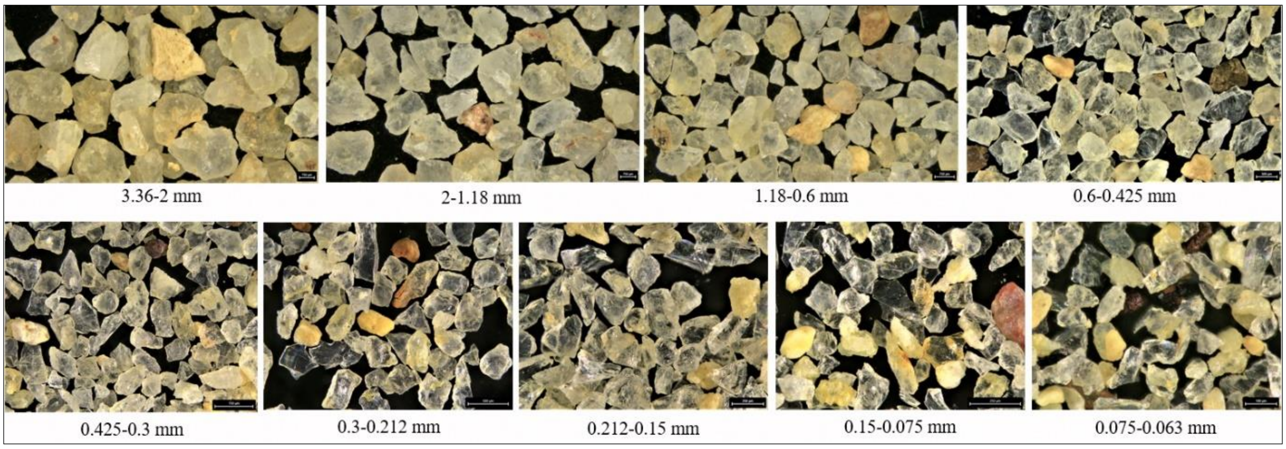

Figure 10: *Stereomicroscopic images of the sand converted from the CDG soil in Figure 6 and Figure 8*

Figure 11 shows the twelve stereomicroscopic images for the twelve sub-groups of silt particles with the particle sizes from 0.063 mm to 0.002 mm. The images clearly illustrate that the silt is also dominantly quartz particles plus few feldspars.

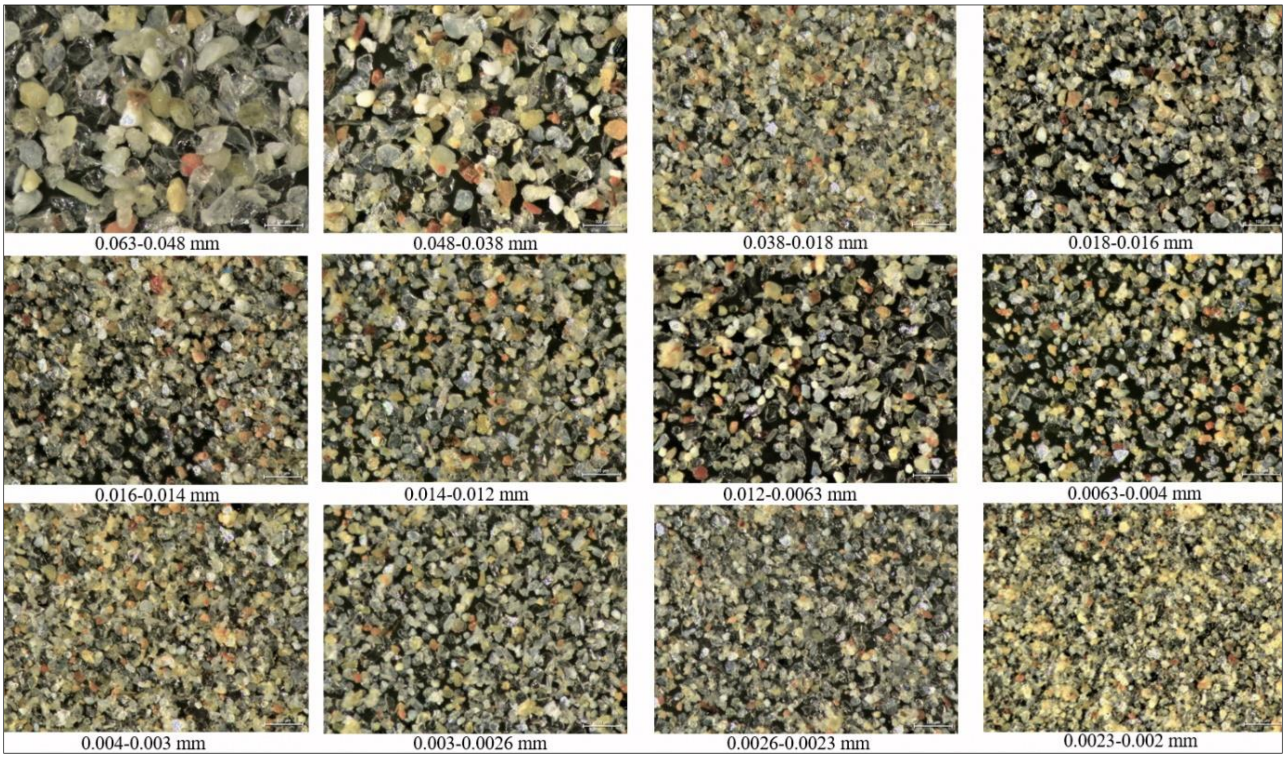

Figure 11: *Stereomicroscopic I mages of the silt converted from the CDG soil in Figure 6*

Figure 12 shows the seven stereomicroscopic images for the further sub-groups of clay particles with the particle sizes smaller than 0.002 mm. The first four images with the particle sizes from 0.002 mm to 0.001 mm in Figure 12 clearly illustrate that the particles are the combinations of siliceous mineral particles and the clay mineral particles. The image for the size from 0.001 mm to 0.0008 mm in Figure 12 shows that the clay mineral particles are more than the siliceous mineral particles. The image for the particle size smaller than 0.0008 mm in Figure 12 shows that the particles are dominantly clay mineral particles.

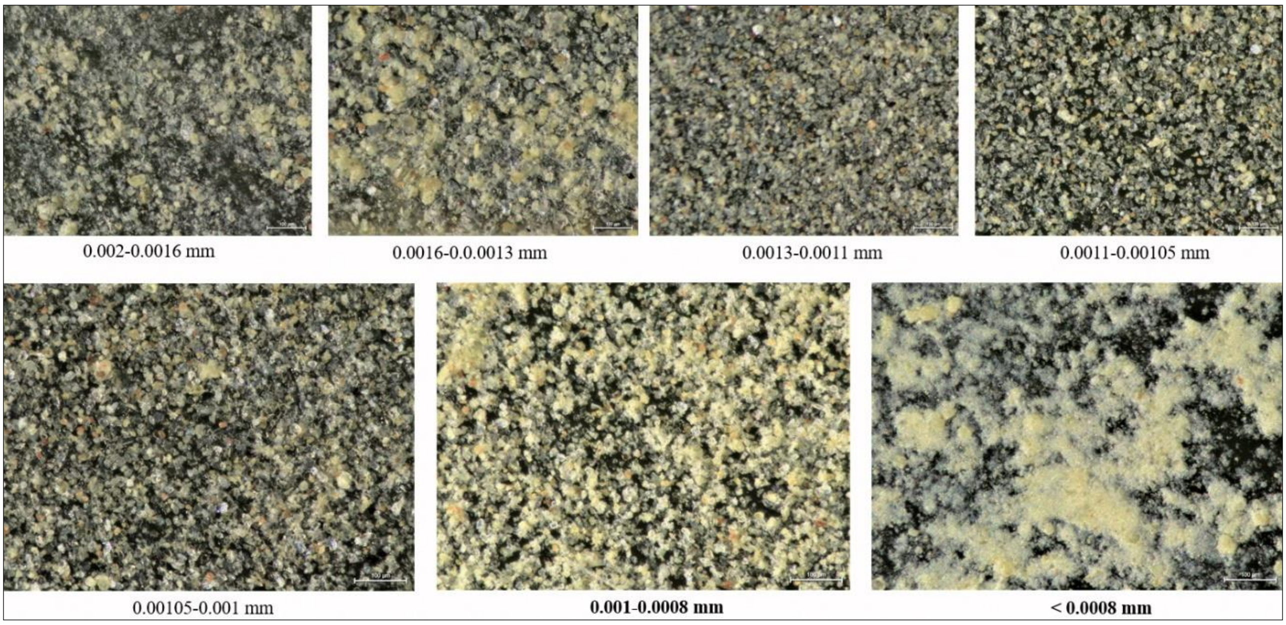

Figure 12: *Stereomicroscopic images of the silt and clay converted from the CDG soil in Figure 6*

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3.3 The products of CDV soil

Figure13 presents the photographs of the CDV soil from Shum Wan Road and its converted sand with gravel, silt and clay. Figure 7 shows the particle size distribution (PSD) of the CDV soil. The weight percentages of gravel, sand, silt and clay are 25%, 17%, 7% and 49%, respectively. The gravel and sand in Figure13 are further sieved into 14 individual particle sizes as shown in Figure 14. The PSD of the gravel and sand is shown in Figure 9. The gravel and sand are well graded.

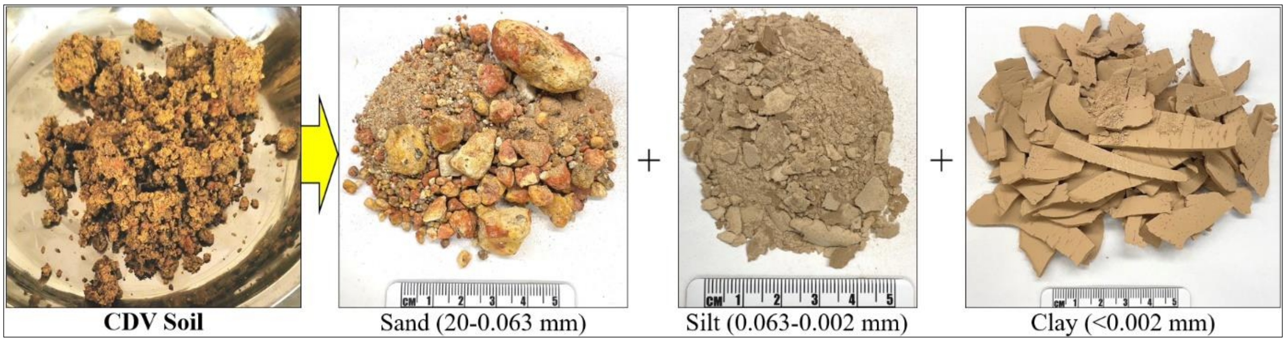

Figure 13: *Products of sand, silt and clay converted from a typical CDV soil from Shum Wan Road, Hong Kong*

Figure 14: *The 14 individual particle sizes of the CDV sand in Figure 13 by dry sieve method*

3.4 The products of public fill soil

Figure 15 presents the photographs of the public fill soil from Tuen Mun Area 38 Fill Bank and its converted sand with gravel, silt and clay. Figure 7 shows the particle size distribution (PSD) of the public fill soil. The weight percentages of gravel, sand, silt and clay are 33%, 42%, 9% and 15%, respectively. The gravel and sand in Figure 15 are further sieved into 13 individual particle sizes as shown in Figure 16. The PSD of the gravel and sand is shown in Figure 9. The gravel and sand are well graded.

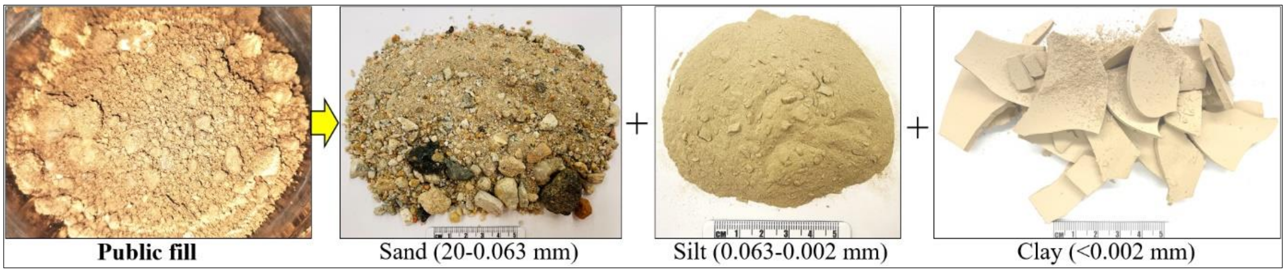

Figure 15: *Products of sand, silt and clay converted from a typical public fill soil from Tuen Mun Area 38 Fill Bank, Hong Kong*

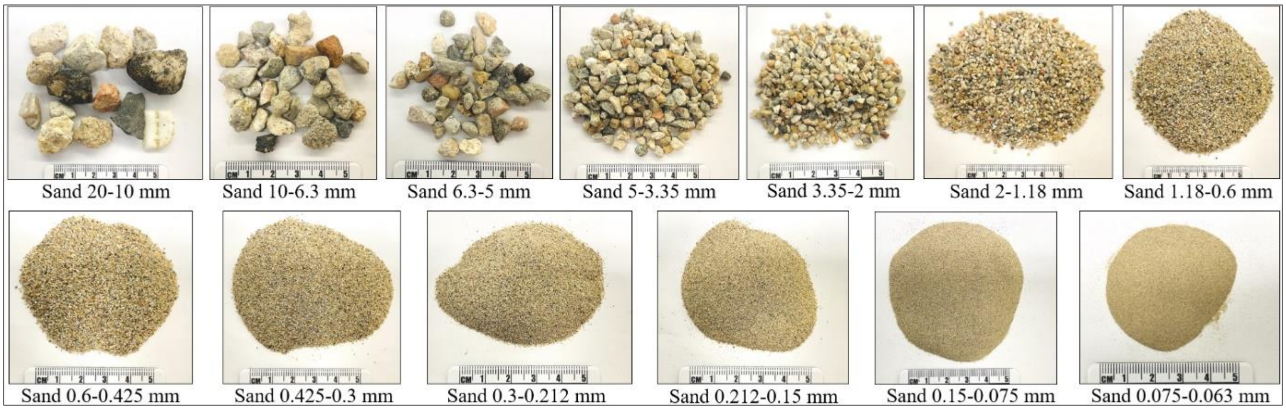

Figure 16: *The 13 individual particle sizes of the sand in Figure 15 by dry sieve method*

4 Conclusions and Recommendations

4.1 Conclusions

Hong Kong soils and public fill are nature mixtures of siliceous mineral particles, clay mineral particles, and water. The invented engineering method can cost-effectively, sustainably and environmental-friendly convert the local soils into individual particles of gravel, sand and silt and clay. The gravel, sand and silt are solid particles of siliceous minerals and mainly quartz minerals. The clay is mainly the clay mineral kaolinite. Hence, Hong Kong soils (CDG and CDV) are non-metallic ore of siliceous minerals and clay mineral.

To convert one ton of the CDG or CDV soils into one ton of gravel, sand, silt and clay, the total electric power can be respectively about 2, 7 and 29 kwh. The total is 38 kwh. Since the price for one kwh is HK$1.214, the electric costs are respectively about HK$3, 8 and 35 for producing gravel and sand, fine sand, silt and clay. The total electric cost is HK$46. The value of the one ton of gravel, sand, silt and clay materials is much more than HK$46.

4.2 Recommendations

Figure 17 shows the conceptual design of the automatic mass production line for massively converting local soil (public fill) into gravel, sand, silt and clay. A conveyor belt system is used to transport and uplift the soil and gravel/sand/silt for washing, rinsing and storage piling. A sinkhole, channel and pipe system is used to transport and pump the water, soil slurry, mud slurry and clay slurry.

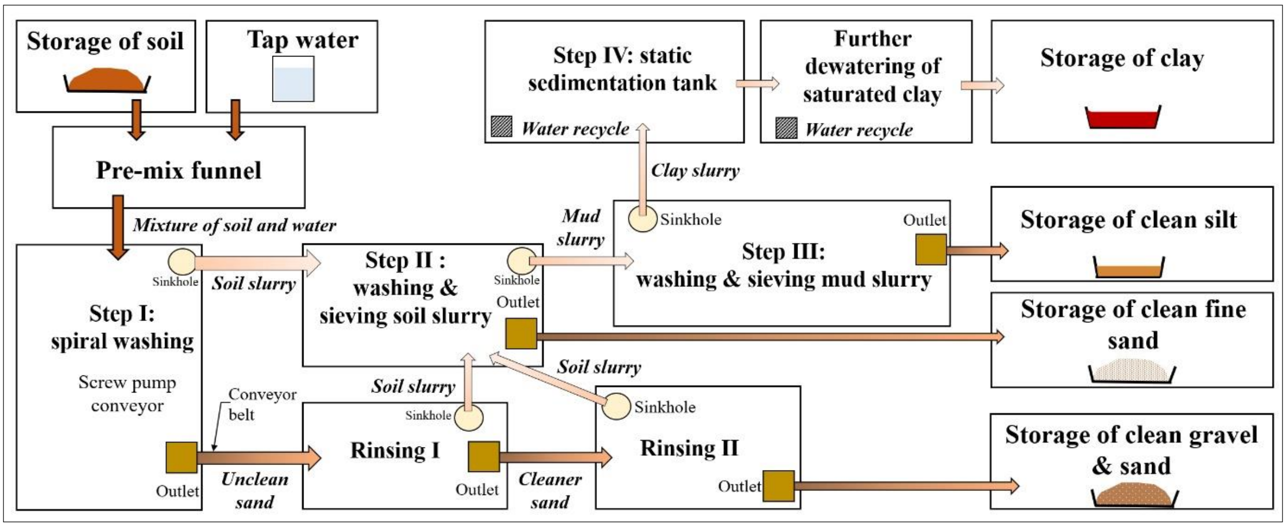

Figure 17: *Automatic mass production line for converting local soil (public fill) into gravel, sand, silt and clay*

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The gavel and sand and silt can replace the imported marine sand for land reclamation. The gravel can be used as coarse aggregate and the sand can be used as fine aggregate for production of concrete. The silt can be used to replace the carbon-intensive cement content for production of concrete. The method can be applied to a range of engineering applications and offer an innovative and environmentally friendly solution to supply useful construction materials for use in the local construction industry. The clay can have many uses in construction and material industries and agriculture.

5 Declarations

5.1 Acknowledgements

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