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Abstract

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Keywords

compaction, wash, fill, coal, reclamation

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COMPACTION OF COAL WASH AS RECLAMATION FILL

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In this paper, detailed laboratory investigations were conducted on coal wash produced at coal mine, Wollongong, New South Wales, Australia. Geotechnical tests were conducted to determine the particle size distribution, compaction characteristics, shear resistance and collapse potential. The compaction tests were conducted under dry and submerged condition to examine the compactability and the strength of the coal wash. The laboratory tests show that compacted coal wash has good potential as effective fill for embankments, and land reclamation. Although coal wash is compacted under submerged condition, increased level of compaction has minimal effect.

1. INTRODUCTION

Wollongong, New South Wales located in the heart of coal mining and steel industry produces a mammoth volume of coal wash, blast furnace slag, mine waste aggregates and other granular by-products more than any other Australian city. Port Kembla is Wollongong's commercial harbor that solely caters for the coal and steel export market. Due to the demand for port facilities, a new 45 hectares Outer Harbour adjacent to the existing port structures will undergo major expansion via land reclamation to maximize the available land area in the port and to provide the maximum number of berths suitable for bulk cargoes and container handling to service regional importers and exporters. In Illawarra, large stockpiles of waste mine products such as coal wash and furnace slag have been produced 2.1 million tonnes per year. Due to the associated environmental concerns, the Port Kembla Port Corporation would consider the use of these locally abundant waste aggregates as the predominant reclamation fill, among the more conventional natural aggregates such as tunnel cuttings and used rail ballast from other parts of NSW.

The improvement of the heterogeneous waste materials like coal wash in terms of geotechnical properties has been conducted in the past (Indraratna 1994; Kamon 1997; Sarsby 2000; Pusadkar and Ramaswamy, 2005). Compaction method has been found to be useful to improve the load-deformation behaviour (stiffness) of underlying of soil layers, especially loose granular materials (Kettle, 1983; Koutsoftas and Keifer, 1990; Pan and Selby, 2002; Lee and Gu, 2004).

It is generally acknowledged that granular waste fill can be effectively reused and compacted in the field using dynamic compaction. Compaction rapidly decreases the soil porosity thereby improving the engineering properties of soil including friction angle and elastic modulus. However, there is no study conducted in the past to evaluate effects of compaction on the shear strength and collapse potential of coal wash located above or below ground water table. Evaluating the compaction characteristics of coal wash remain to be a most fundamental and essential component of this study.

2. CLASSIFICATION OF COAL WASH

The coal wash is a waste by-product of coal mining operations in the Illawarra. It is produced by the coal washery process used to refine raw, run-of-mine coal material. The properties of coal wash are not uniform because the mineral components are likely to vary from one place to another. The coal wash sample is well graded, black, and heterogeneous with varying constituent elements including coal and soils. These constituents depend on the nature of the surrounding geology and mining processes used. This can be a mixture of any rock or soil strata present in the coal seam being mined. The specific gravity of coal wash sample is 2.04. The plastic and liquid limits are 17.7% and 27.2%, respectively. Based on the Unified Soil Classification System, the coal wash can be categorized as well graded sand (SW) with a uniformity coefficient of 10–12. The D_{50} size is in the order of 2.5 mm, and the largest 20% of the particle fraction in the range of 6–10 mm.

Laboratory tests on coal wash conducted to evaluate its engineering properties include the following: compaction efficiency by standard Proctor method, degradation after compaction; permeability test; strength parameters using unconfined compression test and direct shear test; and collapse potential using modified oedometer test. Indraratna *et al.* (1994) and Rujikiatkamjorn *et al.* (2012) show that a sudden (collapse) settlement can occur when a granular soil is subjected to rainfall or rising ground water table. The magnitude of the collapse settlement is influenced by vertical effective stress, degree of compaction, particle size distribution, testing method, initial water content and inundation history. To investigate the collapse settlement behaviour of the coal wash, the samples were flooded in the modified oedometer at different applied vertical stress to obtain the corresponding sudden settlements.

3. TEST RESULTS AND DISCUSSIONS

3.1. Compaction Characteristics

Figure 1 presents the dry density-moisture content curve with zero and 5% air void lines. The dry density of compacted sample is plotted against the corresponding moisture contents to provide the standard Proctor compaction curve. The maximum dry density and the optimum moisture content for compacted coal wash are 1645 kg/m³ and 10.4%, respectively. The relative low maximum dry density compared to the conventional fill can be attributed to a lower specific gravity of 2.04. The long term settlement below compacted coal wash embankment can be effectively controlled because of its low dry density. The lower dry density Compaction curve (Figure 4) also shows that, for a large variation in moisture content, a significant change in dry density can be observed. However, in the

Figure 1. Dry density-moisture content relationships for coal wash.

Figure 2. The influence of moisture content on particle degradation after compaction.

field the moisture content must be restricted to 9–12% to achieve dry density close to maximum. This shows that coal wash can be easily compacted with conventional equipment over a wide range of the moisture contents.

During compaction, some particle degradation occurred, thereby causing a shift in the initial particle size distribution to the left, i.e. towards smaller particle sizes. The Breakage Index (*BI*) is proposed as a suitable method for representing degradation (Indraratna *et al.*, 2005). Figure 2 shows that as the initial moisture content increases, the extent of breakage due to compaction decreases initially, and then increases beyond an optimum moisture content of about 9.5%. In practice, at the site of port reclamation, where the compaction will be on the wet side of the OMC (10.4% from Figure 1), the extent of breakage may exceed around 10%. As shown in Figure 2, where the initial moisture content is close to the OMC, the breakage approaches a minimum value at moisture content of 7%.

4. PERMEABILITY

Skarzynska and Michalski (1998) and Indraratna *et al.* (1994) report that the permeability of compacted coal wash varies between 2×10^{-4} and 5×10^{-5} m/s, depending the degree of compaction. The falling head permeability test was conducted on previously compacted specimens at various moisture contents. All specimens were saturated with the application of back pressure before measuring the falling head permeability. Figure 3 presents the permeability-moisture content relationship obtained from 6 compacted specimens. The permeability varies between 10^{-8} to 10^{-9} m/s which is comparable to low permeability soil such as clay. The permeability decreases with the moisture content up to

Figure 3. Permeability and moisture relationship after compaction.

Figure 4. Undrained shear strengths of coal wash samples compacted under dry and submerged condition.

about 12%, and thereafter increases again gradually. For all compacted sample, the measured permeability is very small, and this is advantageous in the view point of minimizing internal seepage and erosion. The main reason for this low permeability can be attributed to the well-graded nature of the aggregates and the good compaction properties that are comparable to silty sand.

5. UNCONFINED COMPRESSIVE STRENGTH TEST UNDER RELATIVELY DRY CONDITION (ABOVE WATER)

To investigate the influence of compaction on the compressive strength, the samples were prepared applying standard compaction energy to represent relatively dry environment (above water table). The samples were subjected to shearing immediately after the compaction. The maximum axial stresses vary between 20–200 kPa depending upon the moisture content which correspond to the undrained shear strength of 10–100 kPa (Figure 4).

6. UNCONFINED COMPRESSIVE STRENGTH TEST UNDER SUBMERGED CONDITION

As the coal wash is expected to be used for land reclamation, the influence of compaction condition on the compressive strength (i.e. under water or sea level) was investigated. The samples were prepared under both standard and modified Proctor compaction energy under submerged condition. The samples were placed in layers and compacted under water. Figure 4 shows the undrained shear strength of coal wash. The undrained shear strength is assumed to be half of the unconfined compressive strength. The undrained shear strengths upon submergence are in the range of 5–10 kPa regardless of the compacted

energy, these values are significantly below the undrained shear strength of samples compacted under conventional dry conditions.

7. DIRECT SHEAR TEST

Coal wash samples were compacted using the standard Proctor compaction at the optimum moisture content of 9.5%. Based on the shear stress and normal stress plot, the linear shear strength parameters of coal wash i.e. cohesion and friction angle are 4902 kPa and 38 degrees, respectively.

8. COLLAPSE POTENTIAL

The collapse potential is quantifiable in terms of the volume change that occurs when a soil is submerged in water. It is usually obtained by conducting oedometer tests on soil specimen. The collapse potential is expressed as a change in void ratio on wetting compared to the pre-wetting volume of the soil at any stress level (Indraratna *et al.*, 1994).

An indication of the collapse potential (C_p), as a function of the initial void ratio (e_0) and the change in void ratio (δe) is defined by:

$$C_p = \delta e / 1 + e_0 \quad (1)$$

Figure 5 represents the collapse potential during compression. It is seen that the collapse potential increases when the vertical stress becomes larger. At points of flooding (inundation), the instantaneous compression is significant for uncompacted specimens at high vertical stress. For compacted specimens, instantaneous compression upon inundation is suppressed significantly. The collapse potential ranges from 0.01–0.06 for non-compacted specimen that can be categorised as a medium to high collapsible soil. However, after compaction, the collapse potential is in the range of 0.05–0.025 which can be a representative of a medium collapsible soil. Hausmann (1990) stated that the collapse potential of a loose and dense sand are 0.05–0.1 and 0.01–0.02, respectively. It can be seen that the collapse behavior of compacted sand is comparable to densely compacted sand. Therefore, if the embankment constructed with coal wash is properly compacted, there should not be any problem of sudden deformation during the heavy rainfall or the rise of the sea level. In this regard, the coal wash can be regarded as an appropriate structural fill.

Figure 5. Collapse potential during compression.

9. CONCLUSION

Coal wash investigated in this study can be categorized as a well-graded sand (SW) on the Unified Soil Classification System. If properly compacted, the coal wash can yield a maximum dry density more than 16 kN/m^3 at an optimum moisture content of about 10%. The extent of breakage due to compaction decreases initially, and then increases beyond the optimum moisture content. The breakage approaches a minimum value at moisture content of 7%. The well-compacted coal-wash permeability varies between 10^{-8} and 10^{-9} m/s which is comparable to soil with low permeability such as clay. The finding of this study shows that there is a strong relationship between moisture content and dry density. The low permeability of compacted coal wash suggests the suitability for the construction of land reclamation to prevent any abrupt change in water table inside the embankment due to the sea level. In terms of shear strength, when coal wash is compacted under relatively dry condition representing above water or level condition, the undrained shear strength varied between 10 and 100 kPa. Unlike 'dry compaction', when coal wash is compacted under submerged condition, increased level of compaction has minimal effect. The collapse potential of compacted coal wash is comparable to densely compacted sand. Based on the preliminary laboratory findings, it is found that coal wash can be suggested as an appropriate structural field for land reclamation.

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