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Load–settlement behaviour of a strip footing resting on iron ore tailings as a structural fill

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ABSTRACT

This study presents a laboratory investigation of load–settlement behaviour of a strip footing resting on iron ore tailings used as a structural fill. The footing was placed at various depths in the tailings bed. The relative density of the tailings was varied as D_r = 50%, 70% and 90%. An incremental load was applied on the footing while observing the settlement until the failure took place. The results obtained for tailings were compared with those for the sandy soil. It is observed that the load-bearing capacity and stiffness increase with an increase in footing embedment depth and relative density. Compared to load–settlement behaviour of Perth sandy soil, the tailings fill could have as high as 22 times and 13.5 times the load-bearing capacity and stiffness, respectively. Therefore, the replacement of sandy soil with iron ore tailings for structural fills is cost-effective, and moreover, this application contributes to environmental sustainability in construction.

1. Introduction

Building and construction works are normally associated with filling. Conventional fill material, commonly the local soil is used for this purpose. According to Ash Development Association of Australia, a structural fill is an earthen material specifically engineered or designed to provide a strong and a stable base to support structures. Structural fills are applied in engineering projects such as embankments, foundations, slopes, backfills, bridging layers, retaining functions, trenches, and highway and railway engineering projects, etc. The fill material is subject to meet some requirements such as good maximum dry density to enhance good compaction, high mechanical strength to allow less settlement when subjected to loading and consistent particle size distribution to allow good drainage characteristics. There is therefore an increase demand for the natural soil or simply to mine enough of this soil to sustain the various construction works seen around. This excessive demand for the local sand has push prices forward and it contributes to the budget which makes construction very expensive in modern times.

The identification of high quality and cheaper alternative materials as structural fills will incorporate cost effectiveness in modern construction. Western Australia (WA) is one of the top mining jurisdictions in the world. The state has very active and extensive mining activities that have existed for long period of time, especially iron ore mining. This has given rise to the generation of huge quantities of iron ore tailings to be handled. It is estimated that about 632 million tonnes of iron ore tailings are produced in the state annually [1]. It has also been reported that these tailings have similar engineering properties compared with conventional materials that could be acceptable as civil engineering and general purpose construction materials [2].

It is noted that the activities of the mining companies themselves involve some kind of filling. For instance, the construction of access roads to transport goods at the mine site, construction of tailings dams to store the tailings, and backfills. This therefore, makes it possible for the mine tailings to be considered for filling purpose internally by the mining companies and externally for engineering projects that require filling.

Structural fills could therefore be one of the potential applications of the iron ore tailings where huge quantities could be used to reduce significantly, the amount of iron ore tailings produced in the state (WA).

This study presents the load–settlement behaviour of iron ore tailings produced in WA, for its intended use as a structural fill to replace the conventional earthfilling materials for enhanced environmental sustainability.

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2. Review of past works

Several conventional and waste materials have been explored in fill applications especially in embankments. Kehagia [3] demonstrated the reuse potential of bauxite tailings as an embankment material and reported that the bauxite tailings were having good workability and compacted well which was good to be used as an embankment material.

In mining operations, filling is also a common habit that is adopted by most mines especially during backfilling. Normally, a part of the mine tailings is returned to the voids created from the mined-out areas as a backfill material. This happens mostly when open-pit mining technique is adopted which is common in some WA mines. For example, Choudhary and Kumar [4] used cemented mill tailings as a backfill for underground voids resulting from mining operations. The conclusion was that different paste mixes as a result of the material composition and the use of super plasticizer has positive influence on the strength of the cemented backfill.

During mine closure and rehabilitation, the common practice is that the backfilled tailings are covered with layers of soil as a growing medium of planted vegetation cover. This makes the surface safe for earthmoving machines, example bulldozers to travel and work [5]. Normally the layers on top of the tailings are stronger than the backfilled tailings. Hossain and Fourie [5] studied the performance of the ground when these machines operate on the sand embankment over these mine tailings. They reported that placing a thicker sand layer on top of the mine tailings may prevent near crest failure. In a similar study, Li and Aubertin [6] studied the strength behaviour of backfills in underground mines and proposed an improved solution by conducting experiments and numerical simulations.

Other studies have also focused on the use of fly ash from coal thermal plants as a fill material. Baykal et al. [7] used a mixture of fly ash and crushed ice that is common in cold regions as an embankment material. The mixture was compacted together and they noted that the crushed ice introduced some moisture to the fly ash and this strengthened the material with time which led to the increase in compressive and tensile strengths in the embankment.

Trivedi and Sud [8] conducted a laboratory plate load test experiment to analyse the load settlement behaviour of a compacted ash intended to be used as a structural fill. They observed that the settlement on footing on compacted dry ash is higher than on ash compacted wet and at lower degree of compaction; less than 90%, a shear failure may occur.

Chiaro et al. [9] used a blend of coal wash and steel slag as a structural fill material for the reclamation of Port Kembla outer harbour near Wollongong in Australia. The parameters they considered specifically for the port reclamation were shear strength, bearing capacity, permeability, swelling and particle breakage. Their research concluded that steel slag content from 30% to 45% in the blend met all the expected requirements and the blend material could be used successfully for the project.

Trivedi and Sud [10] presented an experimental investigation for footing on coal ash subjected to various loads. Their finding was that the failure of the ash fills is dependent on material characteristics of the ash, size and depth of the footing, and the settlement ratio.

Alizadeh et al. [11] used a mixture of type 1 Portland cement, class F fly ash, fine aggregates and water; together known as controlled low strength materials (CLSM) as a structural fill for bridge abutment to replace conventional earthfill materials. The important parameters they considered were flowability, compressive strength and bond strength. They have reported that the higher temperatures accelerate early strength but lower the strength gain in the later stages when the CLSM material is ageing. They recommended that, in using CLSM, their findings could be used as an initial guide in choosing raw materials and their proportions in structural fills for bridge abutment based on minimum strength requirements.

From the review above, it can be concluded that the use or iron ore tailings which is produced in large quantities in WA as a fill material is very limited or simply unavailable. Most studies have concentrated extensively on fly ash as a fill material in waste utilisation. However, the absence of significant lime and clay minerals in iron ore tailings makes it fit as granular and cohesionless geomaterial which could satisfy most geotechnical design requirements for structural fill [9,10].

The study will therefore investigate the load–settlement behaviour of iron ore tailings which is available in large quantity in WA as a large volume civil engineering application in structural fills. In this case, the majority of the iron ore mine tailings could be recycled and reused for economy and environmental sustainability in construction.

3. Experimental

A number of model tests on both surface and embedded footings on the iron ore tailings bed were carried out. This laboratory model was developed by Kazi et al. [12] at the Geotechnical Engineering Laboratory, Edith Cowan University. The experimental procedure of the model tests are presented in the following sections.

3.1. Materials

The iron ore tailings were collected from Mount Gibson Iron, Extension Hill, Perenjori (WA). Fig. 1 shows the particle-size distribution curve of the tailings received. Size analysis of the tailings show that it ranges from fine (75 μm) to coarse (⩽32 mm). The physical and chemical properties of the tailings are shown in Tables 1 and 2, respectively [1]. As per the Unified Soil Classification System (USCS), the mine tailings were classified as well graded sand–silty sand. The tailings consisted of 6.5% fines and it was used in its air-dried form. The mine tailings were sieved and the material ⩽19 mm was used for the experiment.

3.2. Test details

The tests were conducted in a laboratory model tank with internal dimensions of 1200 mm length, 400 mm width and 800 mm height. This was made from 25 mm thick Perspex material which is buttressed with high strength steel metal frame to absorb the load reaction.

The footing on which the load was applied is made up of a strip footing consisting of 40 mm thick rigid steel plate with length and width 390 mm and 80 mm respectively. The base of the footing was intentionally made rough by cementing a thin layer of the

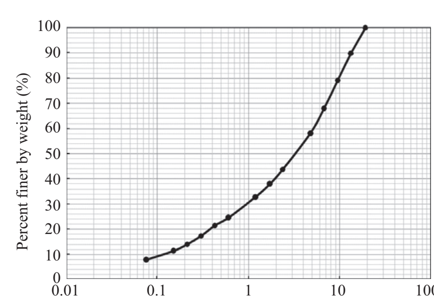

Fig. 1. Particle-size distribution curve of iron ore tailings.