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Suitability of recycled construction and demolition aggregates as alternative pipe backfilling materials

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A B S T R A C T

This research was undertaken to investigate the suitability of recycled construction and demolition materials as alternative pipe backfilling materials for stormwater and sewer pipes. Three commonly found recycled construction and demolition waste materials, (crushed brick, recycled concrete aggregate and reclaimed asphalt pavement) were investigated to assess their suitability as a pipe backfilling material. The physical, geotechnical and chemical properties of these construction and demolition materials were compared with local engineering and water authorities specifications for typical quarried materials so as to assess their performance as a viable substitute for virgin quarried aggregates in pipe backfilling applications. Physical and geotechnical characterisation tests such as particle size distribution, specific gravity, water absorption, Los Angeles abrasion, California Bearing Ratio and modified Proctor compaction tests were undertaken. Chemical properties were also determined, including organic content, pH, trace element or total concentration and leachate testing of the construction and demolition materials for a range of contaminant constituents. In terms of physical, geotechnical and chemical assessment for pipe backfilling applications, recycled concrete aggregate and crushed brick were found to have the properties recommended by environmental protection authorities while reclaimed asphalt pavement material did not meet some of the specified requirements. Also shear strength properties were found to be equivalent or superior to those of typical quarry backfilling materials. This research indicates that traditional considered waste materials can be reused viably as alternate pipe backfilling materials.

1. Introduction

Many utility infrastructures such as water, sewers and gas pipelines are located beneath road pavements. It is necessary to dig trenches to repair or reinstall new pipelines and to subsequently backfill these pipelines. This is often the most convenient and cost effective method for installing pipelines. In the installation of pipelines, backfilling with good quality material is particularly important to ensure their service life. The most common backfilling method involves disposing of excavated materials and importing high quality granular materials. However, this process is not cost effective in terms of disposal costs, purchasing and cost of importing new materials, as well as the environmental implications of using virgin materials. This process furthermore requires virgin materials which need to be imported from quarries, a process which in turn results in the opening of new quarries and the long term decline of natural resources.

An attempt has been made in this research to reduce the use of virgin materials and to increase the reuse of Construction and Demolition (C&D) materials such as Crushed Brick (CB), Recycled Concrete Aggregate (RCA) and Reclaimed Asphalt Pavement (RAP) as pipe backfilling materials for stormwater and sewer pipes. However, recycling is a major concern and one of the main strategies around the world for sustainable development is to reduce the demand for virgin materials and associated transport and production costs, by using C&D waste materials which would otherwise be dumped at landfill sites (Tam, 2009; Blengini and Garbarino, 2010; Disfani et al., 2012). The geotechnical and chemical performances of these C&D materials were compared with the requirements of several local engineering and water authorities' specifications, including those of the Melbourne Water Authority (Melbourne Water, 2001) to assess the performance of recycled C&D materials as a viable substitute for virgin aggregates. Pipe backfilling specifications by state government water authorities worldwide specify requirements related to different properties such as strength,

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grading, particle density and compaction. If recycled waste aggregate meets the specified requirements, as well as the environmental requirements, the recycled aggregate can be considered a suitable pipe backfilling material. Based on the regulatory requirements, the geotechnical and chemical properties of the various recycled C&D materials were ascertained in this research to determine their suitability as a pipe backfilling material.

RCA is a by-product of construction and demolition activities of concrete structures. Concrete chunks are crushed into aggregates of variable sizes depending on the field of application. Various authors (Arulrajah et al., 2013; Rahman et al., 2013) have reported on the geotechnical properties of RCA in geotechnical and pavement sub-base applications.

CB is also a by-product of construction and demolition activities of buildings and other structures. Several authors have reported on the geotechnical properties of crushed brick in geotechnical and pavement sub-base applications (Arulrajah et al., 2012, 2013).

RAP is removed from roadways on a regular basis, leading to excessive stockpiles of used asphalt. This material is usually dumped in landfill without a sustainable method for reutilising it. Several researchers (Hoyos et al., 2011; Puppala et al., 2011) have reported the geotechnical properties of RAP in different civil engineering applications such as pavement sub-base and footpath embankment.

The engineering properties of other waste aggregates used as alternative construction materials in different developed and developing countries have also been reported by several authors (Clay, 2007; Reid, 2009; Hakkinen and Vares, 2011). Other waste materials that have generated recent interest in various geotechnical applications include: waste rock (Arulrajah et al., 2011), waste glass (Corinaldesi et al., 2005), recycled glass with C&D blends (Taha and Nounu, 2008; Hakkinen and Vares, 2011), fly ash (Horpibulsuk et al., 2012; Sukmak et al., 2013a,b) and recycled calcium carbide residue (Kampala and Horpibulsuk, 2013; Kampala et al., 2013).

There is an urgent need to look into reuse options for recycled C&D waste materials as alternative materials in different civil infrastructure projects, including those in geotechnical engineering sectors (Beyer et al., 2009). This could finally lead to landfill avoidance and an improved level of sustainable development (Blengini and Garbarino, 2010; Lindsey, 2011). A number of studies are available on geotechnical characterizations of C&D materials that have been used as road pavement sub-base granular materials (Hoyos et al., 2011; Puppala et al., 2011; Rahman et al., 2013). However, none of these addressed pipes backfilling applications or environmental risks of using C&D materials. More importantly, there has been limited research reported that addresses critical environmental concerns and risks attributable to using C&D materials in civil engineering applications (Disfani et al., 2012).

The physical and geotechnical properties of C&D materials used in sub-base applications have been proven by several researchers. Limited knowledge is available on the application for pipe backfilling and environmental impacts during service life of the C&D materials. Therefore, geotechnical properties and environmental impacts of such C&D materials should be studied. However, a comparison of the properties of the predominant C&D materials is also required as this will be of importance to consultants, contractors, designers, local councils, state road authorities, operators and end-users alike in their potential usage in civil engineering applications. Hence this study assesses the suitability of C&D materials for pipe backfilling. As the utilization of these alternative C&D materials is relatively new for pipe backfilling applications, it is essential that basic geotechnical and chemical tests are undertaken to thoroughly assess their suitability. This research presents geotechnical and chemical laboratory experiments on three predominant types of C&D materials and also investigates the environmental risks through contamination.

2. Experimental procedure

The recycled materials studied in this research had a maximum aggregate size of 19 mm. The samples were first oven dried at 60 °C until they were fully dried. Laboratory tests were subsequently undertaken on the above mentioned recycled aggregates, targeting their usage as alternative pipe backfilling materials.

2.1. Physical testing

Specific gravity and water absorption tests of coarse aggregate (retained on a 4.75 mm sieve) and fine aggregate (passing through a 4.75 mm sieve) were undertaken according to ASTM C127 (2007). The pH tests were performed in accordance with BS 1377 (1990). Organic content tests were performed in accordance with ASTM D2974 (2007). Hydraulic conductivity tests were performed in accordance with ASTM D2434-68 (2006). The constant head method was used to measure the hydraulic conductivity. Following the standard test method for resistance to degradation of small size coarse aggregate by abrasion and impact in the Los Angeles (LA) machine, LA abrasion test was conducted according to ASTM C131 (2006). The particle size distribution of C&D materials was conducted by sieve analysis according to ASTM D422-63 (2007).

2.2. Geotechnical testing

Modified compaction tests were undertaken on the recycled materials according to ASTM-D1557 (2009) standard. As the maximum particle size was 19 mm, a cylindrical mould with an internal diameter of 152.4 mm was used. California Bearing Ratio (CBR) tests were carried out according to ASTM D 1883 (2007) on specimens subjected to modified Proctor compaction energy at the Optimum Moisture Content (OMC) and soaked for 4 days to simulate the worst-case scenario (Vicroads, 1995).

The large Direct Shear Test (DST) was conducted for the C&D materials at normal stresses of 30 kPa, 60 kPa and 120 kPa. These values represent the range of stress that C&D materials will be exposed to in filed application and the tests were conducted as per ASTM D5321 (2008). The tests were terminated once the horizontal shear displacement reached approximately 75 mm. A shear rate of 0.025 mm/min was maintained throughout the shearing stage as per ASTM D5321 (2008). This strain rate was found to be slow enough to allow for the excess pore pressure to dissipate during the shearing phase. The static triaxial tests were performed in an automated triaxial testing system with specimen dimensions of 100 by 200 mm (diameter by height) for all recycled material types. All aggregates were oven dried over 24 h and allowed to cool before water was added to achieve the optimum moisture content. The aggregates were mixed with water to the required percentage of dry weight, by hand mixing with the use of aggregate splitter. The mixture was kept for 12 h in a closed container to absorb water uniformly throughout the sample. It was then compacted to 98% of Maximum Dry Density (MDD) into the split mould by eight layers. The compaction was carried out by a mechanical compactor with modified compaction energy for each layer. A confining effective stress range of 50–200 kPa was applied, which corresponds to shallow – moderate overburden pressure. The triaxial sample was compressed at the given confining pressure under consolidated drained conditions. A small amount of back pressure was applied, to enable water to flow slowly through the pore pressure line. The back pressure was increased until the pore pressure coefficient was at least 0.95.