Sustainable Waste Management and Recycling: Construction Demolition Waste

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GEOTECHNICAL ASPECTS OF RE-CYCLED CONSTRUCTION WASTES

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ABSTRACT. Performance of various construction waste materials in relation to possible geotechnical applications is examined in this paper. Four materials were considered: Freshly quarried basalt (for comparison purpose), quarry waste, building debris and crushed concrete. These materials were examined under various test conditions; namely dry, wet and mixed with 10% and 20% clay slurry. Tests were also carried out to examine how the performance of these recycled waste materials could be enhanced using geo-grids. Laboratory tests were carried out in a 305mm×305mm direct shear box. The results show the performance of the re-cycled materials is not significantly different to that of freshly quarried basalt, although the conditions under which the products were tested (ie dry, wet and smeared with clay slurry) appeared to influence their performances in a significant way. Recycled construction wastes are known to be susceptible to crushing under repeated loading. Accordingly, recycled construction wastes were subjected to repeated loading under three different test conditions: (a) freshly recycled wastes (b) soaked in clean water for a long period and tested under wet conditions and (c) soaked in contaminated water (containing concentrations of sulphates) and subsequently tested under wet conditions. The results show the recycled waste material exposed to water contaminated with sulphate exhibited a considerable amount of crushing during repeated loading but not particularly different from dry or wet materials.

Keywords: Construction demolition waste, Sustainable construction, Recycled aggregates, geo-grids, ground improvement.

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INTRODUCTION

Granular aggregates are widely used for concrete production, backfilling, highway/embankment construction, and sub-bases/ballast for roads and railway tracks, etc. They are also used for ground improvement purposes such as vibrated stone columns, gabion walls, slope stabilisation, load transfer platforms, etc. Large quantities of freshly quarried stones are normally used in these applications. However, it is possible for recycled construction waste products to meet the necessary design requirements of such applications and, assuming they are a practical alternative, a considerable amount of savings could result. This paper focuses on the performance of various recycled construction wastes in relation to possible geotechnical applications.

The UK construction industry faces significant concerns about material supply in the future. Natural mineral resources are not unlimited and the extraction causes increasingly unacceptable environmental damage and raises health and safety concerns. The industry also produces a large amount of waste material (concrete, brickwork, cement mortar), at about four times the normal rate of household waste production (Coventry and Guthrie, 1998), generated from activities such as demolition, excavation, site preparation and a range of other activities. Waste from construction sites in the United Kingdom totals some 70 million tonnes per annum. A report by Sir John Egan (1998), on the improvement of the construction industry, highlighted the need for eliminating or recycling waste materials and reducing construction costs.

There is great potential for minimising waste without compromising the quality of the design or the functionality of the project. The construction industry can make savings in material purchasing and waste disposal costs through an increased emphasis on waste reduction, reuse and recycling. The landfill levy in the UK will also alter the economics of choice between new and reclaimed materials because reused materials are exempt from this landfill 'tax'- they are not strictly classified as waste. Savings from waste minimisation should be welcomed in view of the survey published in 1994 (Latham, 1994), which highlighted the scope for increasing the efficiency of UK construction practices.

NATURE OF CONSTRUCTION WASTE

Construction wastes are mainly the result of demolition, rehabilitation of railway tracks and highway construction processes. These materials typically comprise heterogeneous materials with particle sizes ranging from gravel to boulders. In some cases unused construction materials are also categorised as construction wastes. They include harden 'Ready Mix' concrete, aggregates, unsuitable bricks and pavement blocks. As a consequence, there is considerable variation in mechanical strength both for each of the categories and for individual particles within each group. Such materials can be recycled and reused as replacement for more expensive traditionally-used coarse granular materials such as crushed rock.

The performance of all construction materials is strongly influenced by the conditions in which they are used. For example, the strength of dry stone may be different from wet stone. Stone mixed with fine material may behave differently from aggregates in wet or dry conditions. Smearing or clay contamination of stones can be a particular problem in many civil engineering applications eg, filter drains, stone columns, sub-bases for roads and railway track ballast, etc. (Bell et al., 1981). In addition, if the reuse of waste material is considered a viable alternative, these materials are often found in a poor condition at the site. For example, they can be covered with dust/mud or experienced softening due to prolonged exposure to rain/water. In addition, the performance of these materials is affected by repeated loading (Sivakumar at al 2004). The recycled construction wastes are particularly prone to particle crushing during shearing. The amount of crushing experienced by recycled wastes is also affected by the condition in which they are used, namely when soaked in water and/or when they come into contact with deleterious chemicals or agents. The purpose of this paper is to report some of the work carried out at Queen's University Belfast in relation to the reuse of construction waste for geotechnical applications.

LABORATORY EXPERIMENTS

The laboratory work consisted of testing various coarse-grained or granular materials which included: (a) 40 mm size uniformly graded crushed basalt (b) crushed concrete prepared in the laboratory (c) building debris and (d) quarry waste. The materials were tested under various conditions: (a) dry (b) wet (c) smeared with clay slurry (d) long term soaking in water (e) long term soaking in water contaminated with sulphate. In addition, tests were also performed to examine the effects of introducing geo-grids in an attempt to enhance the performance of the recycled materials.

Material Types

The 40mm uniformly crushed rock was obtained from a local supplier (Whitemountain Quarries, Belfast). The crushed concrete was generated from concrete cubes, after they had been tested in the Material Testing Station at Queen's University Belfast. The cubes had an average compressive strength of 35 MN/m^2. The cubes were crushed and the resulting material was sieved. Particles having sizes between 20 and 40 mm were considered to be suitable for testing. The building debris was obtained from a convenient demolition site. The debris contained predominantly bricks (at least 95% by weight) and mortar. Wood content was removed and the debris was crushed and then sieved. Particle sizes between 20-40 mm were again considered suitable for testing. Quarry waste was supplied by John McCleery Quarries, a local quarry near Ballymactaggart, Co. Down. The material is commercially referred to as quarry dust.

Equipment

Tests on crushed rock, crushed concrete and building debris were carried out in a large direct shear box having dimensions of 305×305 mm. The large box is suitable for materials containing particles up to 50 mm (Head, 1994). Tests on quarry waste were carried out in a 100×100 mm shear box, which is better suited to materials containing smaller particles. The tests used four different vertical pressures. In the case of crushed rock, concrete and building debris, the materials were compacted in the box in three layers. Each layer was compacted using a Proctor hammer. Samples were sheared at 1.5 mm/min. During shearing the shear displacement, vertical displacement and the shear load applied to the sample were carefully recorded.

Material Preparation

Tests were carried out in four stages. In the first stage, the materials were tested under different conditions namely: dry, wet and mixed with 10% and 20% kaolin slurry. For tests on dry materials, the products were placed in the direct shear apparatus without any preparation. For 'wet' conditions, the specimens were allowed to soak in water overnight before testing. For tests on smeared materials, the following procedure was adopted: The required amount of dry kaolin powder was determined by the dry mass of the material to be tested in a mix ratio of 10:2. For example, 100 kg of dry material required 20 kg of dry kaolin powder in order to achieve 20% smearing. The powdered kaolin initially mixed with water to form a slurry 1.5 times the liquid limit. The slurry and the dry material were thoroughly combined in a concrete mixer. In the second stage of the programme, the above mentioned waste materials were tested under similar initial conditions but layers of geo-grid were included in the sample makeup to provide added strength to the test specimen. In the third stage of the testing, freshly crushed basalt, crushed concrete and building debris were tested in the large direct shear box in order to examine the performance of these materials under repeated loading. Samples were loaded and unloaded up to 8 times (single loading, 2, 4 and 8 loading cycles). When the cyclic loading tests were completed particle size analysis was carried out to determine the amount of particle crushing induced. In the forth and the final stage of the testing programme, crushed concrete were subjected to repeated loading up to 4 times. These samples were tested under three different conditions: (a) dry (b) long-term soaking in water and (c) long-term soaking in water contaminated with sulphate.

TEST RESULTS AND EVALUATION

For simplicity only a limited number of results are reported here. For further information refer to publications: McKelvey at al. (2002), Touhamia et al. (2002) and Sivakumar at al. (2004). During the shearing process, the samples were taken to the maximum shear displacement which could be applied in one direction in the large direct shear box apparatus. This corresponds to a shear strain of about 10% in all the tests. Most of the samples tested reached peak shear stresses at this strain. Samples tested in the wet and dry conditions exhibited the typical response of dense granular materials; initially showing a slight compression followed by a significant dilation. The applied vertical pressures did not significantly affect the amount of dilation of the samples. However, in the case of samples mixed with clay slurry, the volume change characteristics were untypical. The samples tested at low vertical pressures showed a tendency for dilation whereas the samples tested at high vertical pressures showed little or no volume change in the case of 10% mixing and a significant amount of compression in the case of 20% mixing. This may have been due to the lubricant effect provided by clay slurry. The maximum shear stresses achieved during the tests associated with vertical pressures were used to determine the strength parameters for each material.

Figure 1 shows the relationship between the maximum shear stresses plotted against the maximum vertical pressures for crushed rock and concrete tested with the four different initial conditions (results obtained on crushed building debris is not shown here). In the case of crushed rock, it appears that the slope of the failure envelope, □', is quite significantly influenced by the testconditions. The □' for dry material is approximately 51°. This soil parameter reduced to 48° when wetted,. This further reduced to 42° was observed when mixed with 10% clay slurry. However, the amount of slurry had a less significant effect on the frictional angle- with the 20% clay slurry content - only causing a further small reduction in the □' value to reach 40°. It also appears that the stones mixed with 20% clay slurry exhibited an apparent small amount of cohesion with c' = 7 kN/m^2 being measured. This phenomenon can possibly be explained by the strength of the slurry, where it is either trapped between particles or contained within the void spaces. The slurry was applied to the dry crushed rock at 1.5 times the liquid limit. Since the crushed rock was dry when the slurry was applied, this may have resulted in some water being absorbed from the slurry causing a marginal gain in strength in the slurry paste itself. Similar behaviours were observed with all other materials.

The best performance in relation to shear strength of the various materials tested was obtained for the traditionally quarried crushed basalt, which showed an angle of internal friction of 51° in the range of pressures used in the tests. This value reduced to 40° when smeared with 20% kaolin slurry. These findings are comparable with results from a previous study (Bell et al., 1981) where tests were carried out to examination the effect of clay contamination in pavement sub-bases. Recycled crushed concrete yielded a value of 39° in the dry state, reducing to 30° when smeared with kaolin slurry. The building debris gave a result of 37° in the dry state but this reduced to 35° when tested in the wet state. The crushed concrete exhibited a reduction of about 10° in the angle of internal friction compared with that of high quality crushed rock. The reduction for the quarry waste was 5° to 7° depending on test conditions. For building debris, the reduction may be as large as 13° though no tests were actually carried out on smeared building debris. A reduction in □' amounting to 10° will reduce the overall shear resistance by 60%. Designers should also consider that recycled materials may experience particle crushing when subjected to shearing. The amount of particle crushing is most significant in situations where these materials are used under repeated loading.

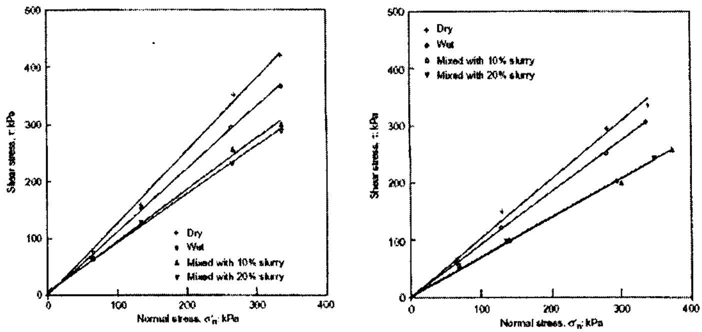
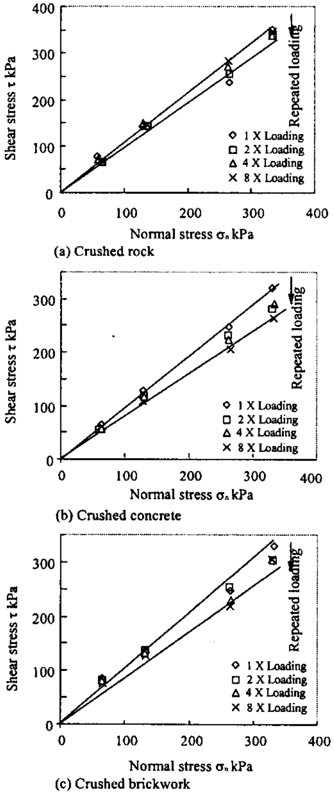


Figure 1 Failure envelopes for crushed rock and concrete

Figures 2 shows the relationship between the maximum shear stress and the maximum vertical pressure for all three materials tested under 1,2,4 and 8 loading cycles. An estimated angle of internal friction ϕ' for basalt under one loading is approximately 47 degrees but this is reduces to 45 degrees after 8 repeated loading (Note- the material in this testing programme is different from the material reported previously). The reduction in the friction angle is small and negligible for practical applications. In the case of crushed concrete, the angle of internal friction, ϕ', is approximately 43 degrees based on the first loading cycle, which reduces to 38 degrees after 8 loading cycles. The reduction in the angle of internal friction due to repeated loading is significant and cannot be ignored.

A similar performance was observed when building debris was taken through the sequence of loading cycles. The angle of internal friction ϕ' was approximately 43 degrees when the analysis was based on the first loading cycle but it reduced to 39 degrees when the sample was taken through 8 loading cycles. The reduction in the angle of internal friction of these materials was largely due to particle crushing caused by the repeated loading. Immediately following the test the specimen in the shear box was carefully examined to assess the amount of particle crushing. Three distinct layers were identified when crushed concrete and building debris were subjected to repeated loading: (a) the top layer generally contained intact material and it showed no significant evidence of particle crushing. (b) the middle layer contained distinctively different material from the original material used, particularly in the case of crushed concrete. The intense shearing process stripped off the mortar (hardened cement paste) surrounding the 12mm aggregates, which were originally used in manufacturing the concrete. This formed a thin lens of 12 mm aggregate at mid-specimen level and (c) the bottom layer contained smaller particles and the stripped hardened mortar from the concrete along with the original material used in preparing the specimens.



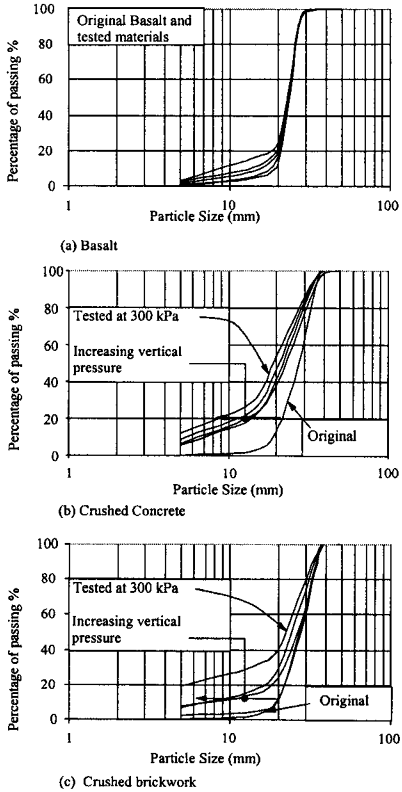


Figure 2 Failure envelopes during repeated loading. Figure 3 Particle size analysis on tested material

After each test and upon completion of the particular loading cycle, the tested material was sieved in order to establish the particle size distribution. Figure 3 shows the particle size distribution for basalt, crushed concrete and crushed brickwork subjected to a number of loading cycles under various vertical pressures. As can be seen, basalt was more resistance to particle crushing. The coefficient of uniformity C_u ($C_u = D_{60}/D_{10}$) of the original material was approximately 1.15. This increased slightly to 2.3 after 8 loading cycles when sheared under 300 kPa of vertical stress. It appears then that crushed concrete and building debris are very susceptible to particle crushing. The amount of crushing experienced by the re-cycled products appears to have increased with the magnitude of vertical pressure and the number of loading cycles. The coefficient of uniformity C_u of the original crushed concrete and building debris were 1.15 and 1.6 respectively. Following the shearing process through 8 loading cycles under 300 kPa of vertical pressure, the respective uniformity coefficients increased to 4.5 and 7 for crushed concrete and brickwork.

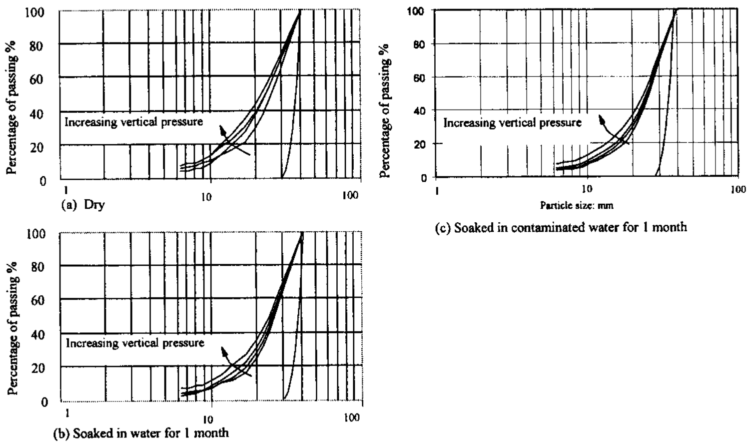


Figure 4 Particle size analysis on dry, soaked and soaked with contaminated water

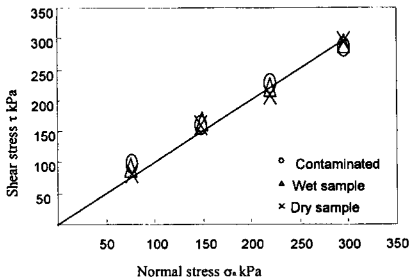


Figure 5 Failure envelope on dry, soaked and soaked in contaminated water (after 4 loading cycles)

It is believed that the performance of recycled materials may deteriorate with time if they are exposed to harsh environs, such as the chemically contaminated water used in this testing regime. This will be a particular problem when using recycled concrete and building debris. Ingress of water into the crushed concrete and building debris can lead to an increased susceptibility to particle crushing under repeated loading. The presence of any contaminants in the water, particularly sulphates, can accelerate the weakening of these recycled materials. A series of tests were performed to examine the performance of crushed concrete during long term storage or exposure to water and sulphate-contaminated water. Tests were performed under repeated loading conditions in which the samples were subjected to four loading cycles under various vertical pressures. Particle size analysis was carried out to evaluate the degree of crushing in each case. Figure 4 shows the particle size distribution of the tested materials after four loading cycles, whilst Figure 5 shows the strength envelopes of the crushed concrete after the same loading cycles. It appears that there is no significant difference in the angle of internal friction of the crushed concrete (at least after four loading cycles) regardless of the testing conditions. However the recycled concrete underwent a considerable amount of particle crushing. The amount of crushing is not particularly affected by the testing conditions (ie dry and soaked in water and contaminated water). Further tests were carried out to examine ways in which the performance of the recycled materials can be improved. Initial consideration was given to include geo-grids in the sample materials tested in the large shear box Touhamia et al. (2002). The results have shown that the angles of internal friction of the recycled materials can be increased by at least 10° by incorporating geo-grids in the backfill operation using recycled construction wastes.

CONCLUSIONS

It is known that the availability and ready supply of high-quality natural aggregates poses stiff competition for the reclaimed aggregates industry. However, the market is large and there are opportunities to increase the use of reclaimed aggregates. Concrete, particularly high-grade crushed concrete and building debris such as brickwork, have considerable potential for use in general bulk backfill operations/applications. The strength requirement in such applications is generally modest and deformations are not considered to be critical. In addition, these materials can be used in various ground improvement applications without necessarily compromising the quality of the design. The work reported here examined the performance of various recycled construction wastes. The results show that their mechanical performance is satisfactory for general geotechnical applications envisaged. However, one of the major problems or drawbacks associated with these recycled waste products is their susceptibility to crushing or 'crushability' and particulate breakdown under intense repeated loading regimes.

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REFERENCE

1. BELL, A.L., MCCULLOUGH, L.M. and GREGORY, B.J. (1981) Clay contamination in crushed rock highway sub-bases. Proc. of the 2nd Australian Conference on Engineering Materials. Sydney.

2. COVENTRY, S. and GUTHRIE, P.M. (1998) Waste minimisation and recycling in construction – design manual. CIRIA SP134.

3. EGAN Sir J. Rethinking construction: the report of the Construction Task Force to the Department of the Environment, Transport and the Regions. DETR, London, 1998.

4. HEAD KH. Manual of soil laboratory testing – volume 2, 2nd edn. John Wiley & Sons, Inc. 1994.

5. LATHAM M. Constructing the team: joint review of procurement and contractual arrangements in the United Kingdom. BRE Construction Industry Final Report 1994.

6. McKELVEY, D., SIVAKUMAR. V, BELL, A. and McLAVERTY. G.(2002). Shear strength of recycled construction materials intended for use in vibro ground improvement. Ground Improvement Journal, Vol 6, pp 59-68.

7. TOUHAMIA. M., SIVAKUMAR., V and McKELVEY, 2002. Application of Geo-grids in re-use of waste materials. Construction materials, Vol. 16

8. SIVAKUMAR V., McKINLEY J. D. and FERGUSON.D. Reuse of construction waste: performance under repeated loading. Geotechnical Engineering, Vo. 157, No. 2 pp 91-96.