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Giant shear box tests on recycled 6F5 for tracked plant platforms

Tests de boîte de cisaillement géante sur 6F5 recyclé pour plates-formes d'usines sur chenilles

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ABSTRACT: The use of recycled 6F5 aggregate is widely seen as a necessary option in civil engineering projects to meet carbon offset targets. This material is used for a range of applications such as load distribution platforms, capping layers, sub-bases and general backfill. It can consist of fresh aggregate or recycled components and its engineering characteristics can, therefore, vary widely. Independent of the application, it is important to characterise accurately the material properties of the aggregate in order to guarantee safe, economical solutions. The angle of friction is often the main parameter required for geotechnical design and usually obtained by direct shear tests. However, when using standard laboratory equipment there is an upper limit to the size of particle that can be tested, rendering such apparatus inappropriate for obtaining the shear parameters of 6F5 aggregate, which has a specified size fraction of 0-125 mm. The paper describes the design of a series of giant shear box tests, with a shear plane area 2.25 m^2, on recycled 6F5 together with details of the testing procedure and the results of these full-scale tests.

RÉSUMÉ: L'utilisation de granulats 6F5 recyclés est largement considérée comme une option nécessaire dans les projets de génie civil pour atteindre les objectifs de compensation carbone. Ce matériau est utilisé pour une gamme d'applications telles que les plates-formes de répartition des charges, les couches de forme, les sous-couches et le remblai général. Il peut être constitué de granulats frais ou de composants recyclés et ses caractéristiques techniques peuvent donc varier considérablement. Quelle que soit l'application, il est important de caractériser avec précision les propriétés mécaniques du granulat afin de garantir des solutions sûres et économiques. L'angle de frottement est souvent le principal paramètre requis pour la conception géotechnique et est généralement obtenu par des essais de cisaillement direct. Cependant, lors de l'utilisation d'un équipement de laboratoire standard, il existe une limite supérieure à la taille des particules qui peuvent être testées, ce qui rend un tel appareil inapproprié pour obtenir les paramètres de cisaillement de l'agrégat 6F5, qui a une fraction granulométrique spécifiée de 0 à 125 mm. L'article décrit la conception d'une série d'essais en boîte de cisaillement géante, avec une surface de plan de cisaillement de 2,25 m^2, sur du 6F5 recyclé, ainsi que des détails sur la procédure d'essai et les résultats de ces essais à grande échelle.

Keywords: Piling platforms; full-scale testing; carbon reduction.

1 INTRODUCTION

During large infrastructure projects, such as the rail infrastructure project HS2 (one of the largest and most complex infrastructure projects ever undertaken in the UK), to facilitate the construction of the permanent works contractors must utilise temporary civil engineering structures (e.g. load distribution platforms, capping layers, sub-bases and general backfill). In the UK, the material widely used to create these structures is "recycled 6F5 aggregate". 6F5 is defined as any recycled aggregate made up of crushed hardcore materials including crushed concrete. In general, this crushed material ranges in size from 0 to 125 mm (BSI, 2018). The description accompanying material of this strength is "specified well-graded material laid and fully compacted to DoT Specification and protected below with geotextile". A characteristic angle of friction, φ', is required for determining the thickness of these tracked plant platforms. The recognised range that the industry usually assume is generally between 30°-45° degrees. BRE 470 (2004) recommends a maximum value of 45° for "strong" (rock compressive strength, q_c > 50 MPa) particle strength materials. An alternative industry practice guide, TWf (2019), states that values of φ' > 45° can only be used if suitably high quality controls for design, inspection and maintenance are in place. However, this can only be achieved if it is possible to obtain reliable values of the shear strength of the fill.

The inherent issues of both variability and particle size associated with 6F5 aggregate present significant challenges in measuring its characteristic shear strength parameters. It is not possible to obtain these parameters using standard apparatus because the particle size is too great. Even commercially available "large" direct shear boxes, which have plan dimensions of 300 mm x 300 mm, are too small to meet box diameter to particle size ratios recommended in both ASTM Standards (D3080, 2011) and BSI (1990). The heterogeneity of 6F5 aggregate results in it not being possible to use the technique of testing samples of the material in which the grading curve has been scaled down to allow testing in standard apparatus (Tanghetti, 2021). Therefore, to obtain reliable values of the shear strength parameters of 6F5 aggregate it is necessary to test the material in suitably large – non-standard –shear apparatus.

This led to a collaboration between SCS Railways (Skanska, Costain, STRABAG S1 & S2 Joint Venture) – one of the joint venture organisations constructing HS2 - and City, University of London to develop a reliable method to measure the characteristic shear strength parameters of 6F5 aggregate. This study was based on testing 6F5 aggregate obtained from a number of HS2 sites in a series of direct shear tests using the Giant Shear Box facility developed at City, University of London, Tanghetti *et al.* (2019, 2021).

2 TEST DETAILS

2.1 Giant Shear Box facility

The City, University of London Giant Shear Box facility (Figure 1) has been described in Tanghetti *et al*. (2019 and 2021). A series of comparative tests reported by Tanghetti (2021) provided confidence in the use of the large shear box for testing large (≤ 100 mm) particle size materials at higher values of normal stress, which are consistent with the range of stresses typically encountered in engineering practice. The facility comprises of a large split box (internal dimensions 1.5 m x 1.5 m x 1 m) constructed from 254x254x132 UC steel sections. The upper half of the box is prevented from moving horizontally during shear by a reaction frame, while the bottom half is free to move horizontally in order to shear the sample. To minimise friction between the top and bottom of the box during shearing, Acetal sheets are fixed to the lower and upper flanges of the top- and bottom-halves of the box, respectively. Prior to testing standard machine grease is applied to these sheets to provide additional lubrication.

The system to facilitate the movement of the bottom half consists of three I-beams, which are firmly attached to a strong floor in the laboratory and have the role of providing runways in which machine skates can slide. This arrangement retains the bottom half of the shear box laterally to ensure horizontal movement occurs in the direction of shear only.

The shear force is applied to the sample through four 500 kN hydraulic jacks (maintained in position by a reaction frame), which push the bottom section of the box in a horizontal direction creating a horizontal shear plane. The normal load is applied by a single 5 MN hydraulic jack fixed to a beam that is bolted to the reaction frame. The vertical stress is applied to the sample via a platen comprising a stiffened 30mm thick plate designed to minimise deflections even at the maximum applied stress.

During testing potentiometers measured vertical displacement in four positions on the loading platen and the horizontal displacement in two positions on the bottom half of the box. Two load cells mounted between the inside of the reaction frame and the top half of the box measured the horizontal force applied to the shear plane during shear and resisted by the stationary top-half of the box. In addition, an in-line pressure transducer also recorded the hydraulic pressure required to move the bottom-half of the box by the hydraulic jacks. All measurements were recorded on a bespoke LABVIEW data logger.

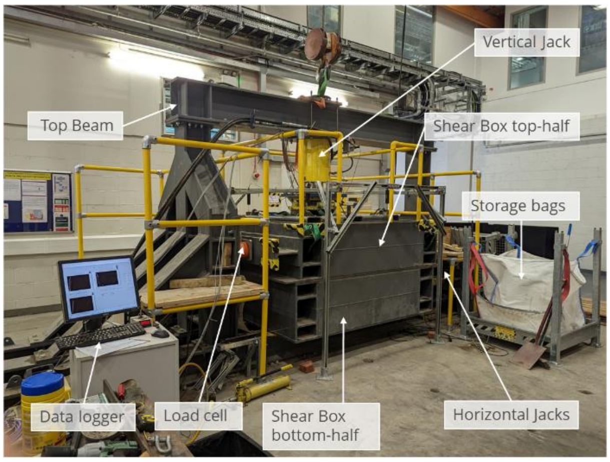


Figure 1. View of Giant shear box facility.

2.2 Material

The recycled 6F5 aggregate reported in this paper was described as "medium level control". This description referred to both the particle size distribution and the constituent materials in the aggregate. The distribution by weight of the constituent parts of this aggregate together with the particle size distribution are presented in Figures 2(a) and 2(b), respectively. This data was obtained by sampling, conducted by SCS Railways, directly from the construction site prior to the material being bagged for transporting to City, University of London for testing.

The specified limits for the grading of the material are plotted in Figure 2(b) together with the grading curve for the material sampled for testing. From this it can be seen that the "medium control" material is within the contractually agreed limits for recycled 6F5. However, there is still considerable variation within these limits. The constituents of the batches of 6F5 from which material was taken for shear testing, presented in Figure 2(b), indicate that the aggregate consisted of 45-55% "concrete or concrete products" and roughly 25% "clay masonry units" but only 20% "unbound aggregates". In Figure 2(a) the constituents given are; R_c - "Concrete, concrete products & concrete masonry", R_u - "Unbound aggregate, natural stone & Hydraulically bound aggregates", R_b - "Clay masonry units (i.e. bricks & tiles), calcium silicate masonry units & aerated non-floating concrete, calcium silicate", R_a - "Bituminous Material", R_g - glass, X - "Other: Cohesive (i.e. clay & soil), gypsum plaster, miscellaneous - metals (ferrous & non-ferrous), non-floating wood" and FL - "Floating Particles - given as the percentage remaining".

2.3 Sample preparation

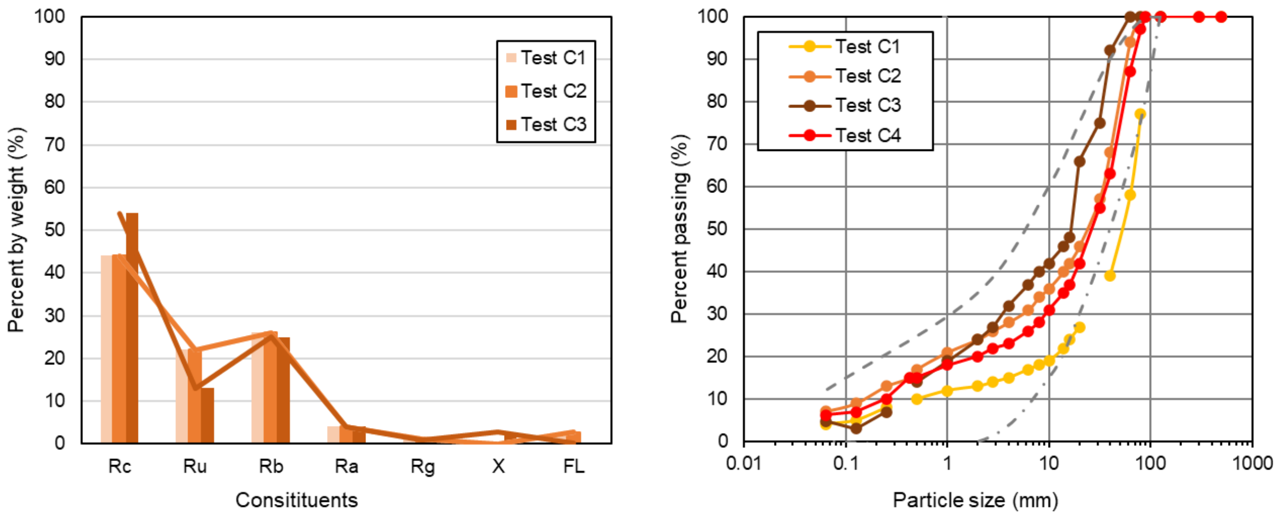
Material was delivered to City, University of London in five 1 m^3 capacity full drop flap discharge bulk bags. Each bag was filled with approximately 800 kg of material but was weighed prior to being placed in the shear box to obtain the exact mass of the sample.

Samples were prepared by compacting the 6F5 aggregate in the box in layers after having first removed any aggregate over 125 mm or metal rebar components. To ensure each layer was uniform it was compacted using a small wacker-plate that was passed over the material layer for 2 minutes. The sample was formed of five compacted layers with an average thickness of approximately 200 mm. Because of the size of the box, the first two layers were first prepared in the bottom half before the top half was put in position. Once the box was fully assembled the three further layers could be prepared. In this way, one of the layers spanned the interface between the two halves of the box.

Following the compaction of each layer its thickness was determined. The sum of the thicknesses together with the sum of the mass of each layer allow calculation of the voids ratio and density of the complete specimen to be determined. Once the fifth material layer had been prepared the loading platen was lifted into place and the vertical loading system assembled.

2.4 Testing

Following compaction of the samples and completion of the assembly of the apparatus. All samples were first loaded to a vertical stress of 500 kPa (at this stress level the force applied to the top cap was 1125 kN). This gave all samples the same pre-consolidation stress and therefore similar stress histories. Six samples were included in this series of tests. Three were sheared following the application of the peak vertical stress of 500 kPa and the other three following unloading to a vertical stress of either 200, 300 or 400 kPa.



(a) (b)

Figure 2. Recycled 6F5 (a) Constituents report and (b) Particle Size Distribution plot with acceptance limits.

Shearing commenced once all displacements following compression or unloading, as appropriate, had reached a plateau. The shear force was applied by increasing the pressure to the horizontal jacks at a constant rate causing the bottom-half of the Giant Shear Box to move. The test was stopped once both the horizontal potentiometers measured displacements greater than $\Delta h = 300$ mm (for a typical sample height z = 1000 mm this corresponded to a shear strain, γs, of $\Delta h/z = 30\%$). In most cases this allowed significant post peak shear strength behaviour of the samples to be observed

3 RESULTS

3.1 Application of vertical stress

Figure 3 shows the average settlement for one of the six samples, obtained from the measurements of the four vertical potentiometers, when the sample was subjected to an increased normal stress via the vertical jack. The loading was increased in a number of steps with settlement allowed to stabilise before the next increment of loading was applied. As indicated above, all six tests were pre-loaded to 500 kPa.

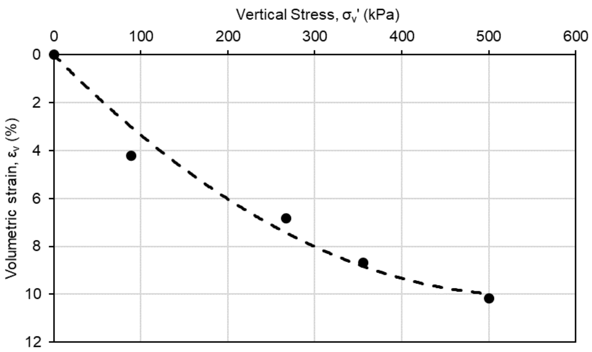


Figure 3. Sample behaviour during compression.

3.2 Shearing

In direct shear box tests the area of the shear plane decreases with displacement and, consequently, although the normal force acting on the top cap of the specimen remains constant, the stress acting on the shear plane will increase. Similarly, in the analysis of the result of direct shear tests the variation of the area of the shear plane with displacement is accounted for in the calculation of shear stress. Therefore, to quantify the relationships during shear between shear stress and shear strain, γ_s, or volumetric strain, ε_v, values of shear stress, τ, should be normalised by the vertical stress, σ', at the same displacement.

Figure 4 shows the results of a shear test conducted at an initial vertical stress (i.e. before shearing commenced) of 200 kPa having been initially compress to and unloaded from 500 kPa. As would be expected from a soil that has been compressed to a significantly higher value of stress than its *in-situ* state, this sample displays a “dense” (or “dry of critical”) response to shearing. This is manifest by dilation and a distinct peak value of normalised shear stress. Post peak the rate of dilation decreases and at the end of the test both the normalised shear stress and the volume of the specimen were approaching a steady state. At this stage the Giant Shear Box had reached the end of travel and so it was not possible to achieve critical state.

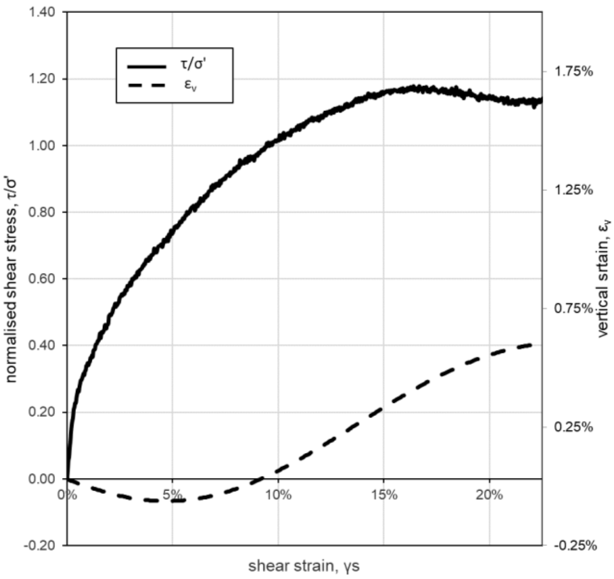


Figure 4. Sample behaviour during shearing.

3.3 Determination angle of friction, φ'

The peak shear stress and vertical effective stress for each of the six tests are plotted in Figure 5 from which it is possible to calculate the angle of friction for the 6F5 aggregate material. A line of best fit has been drawn (passing through the origin) and this yields an angle of friction of $\varphi' = 47.6°$. The coefficient of determination, R^2, of this line is 0.9923. Given the scale and variability of the material over the six tests this is considered to be a very good fit to the Coulomb friction model. This is demonstrated further by a confidence interval of $\varphi_{90}' = 47.6° \pm 2.1°$ at the 90% confidence level, which is also plotted in Figure 5.

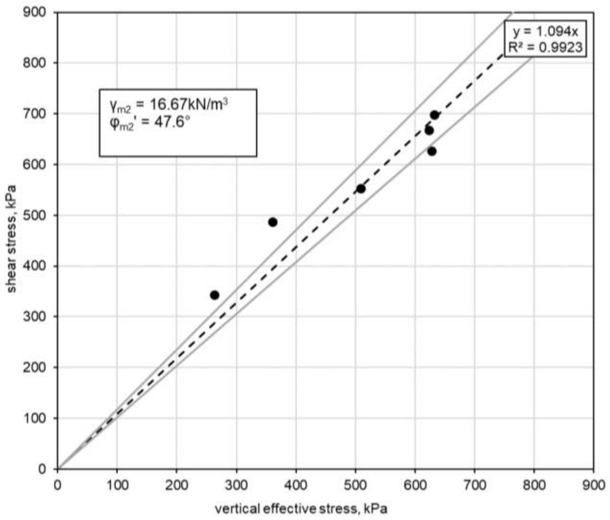


Figure 5. Peak angle of friction from six Giant Shear Box tests.

4 CONCLUSIONS

In geotechnical design it is important to characterise accurately the material properties of any aggregate to guarantee safe, economical solutions. In this paper a series of Giant Shear Box tests were carried out at City, University of London with SCS Railways to ascertain the characteristic angle of friction, φ', of recycled 6F5 aggregates.

Six tests were conducted at a range of vertical stresses on the recycled 6F5 aggregate taken from some HS2 construction sites. Each test used approximately 3.5 tonnes of material and showed a very consistent set of results.

The results indicate the characteristic angle of friction, φ', was found to be 47.6° and with a confidence interval of $\varphi_{90}' = 47.6° \pm 2.1°$ at the 90% confidence level. Although the quality of the material was considered to be a "medium" level of control (i.e. test results reviewed by designer together with regular inspection and maintenance, as specified in TWf, 2019), the material showed a higher value than the 45° generally accepted as the maximum value specified in current guidance. This angle of friction, φ', if adopted during the design phase, has the potential to reduce the tracked plant platform thickness and potentially have a saving in terms of material, cost and carbon.

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REFERENCES

ASTM D3080/D3080M (2011). Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. ASTM International. West Conshohocken, PA, USA.

BRE (2004). Working platforms for tracked plant. BR 470.

BSI (1990). BS EN 1377-7:1990 - Methods of test for soils for civil engineering purposes - Shear strength tests (total stress), British Standards Institution.

BSI (2018). BS EN 13285:2018 - Unbound mixtures. Specifications, British Standards Institution.

Tanghetti, G. (2021). Stability of Working Platforms for Tracked Plant. Doctoral Thesis, City, University of London.

Tanghetti, G., Davies, M. C. R. and Goodey, R. J. (2021). Comparison of small- and full-scale shear box tests on large particle size aggregate, In: *Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering, Sydney 2021*, Sydney, Australia, pp. 75-80.

Tanghetti, G., Goodey, R. J., Divall, S., McNamara, A. M. and McKinley, B. (2019). Design and development of a large shear box for testing working platform material, In: *Proceedings of the XVII ECSMGE-2019*, Reykjavik, Iceland, pp. 1-7.

TWf (2019). TWf2019:2 Working Platforms - Design of granular working platforms for construction plant: A guide to good practice. Temporary Works Forum, c/o Institution of Civil Engineers, One Great George Street, London, SW1P 3AA, England.