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Volume change observations from giant direct shear box tests on recycled 6F5 aggregates

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ABSTRACT: Recycled 6F5 aggregate consists of crushed hardcore materials, predominantly concrete, along with other demolition waste. It is a sustainable, cost effective and versatile material commonly used in major infrastructure and civil engineering projects. It has a range of applications including load distribution platforms, capping layers, sub-bases and general backfill. Knowledge and understanding of the material properties of recycled 6F5 aggregate is required to ensure economical and safe construction. The main parameter needed for geotechnical design is the angle of friction and it is usually obtained using shear apparatus such as the direct shear box. Specifications of 6F5 state that the maximum particle diameter be 125 mm, which is too large for standard shear box apparatus. However, City St George's, University of London has a Giant Shear Box facility with a shear plane area 2.25 m² and this has been used successfully to obtain a representative angle of friction of material with particles at this scale. In this paper the details of the development of shear and volume change of recycled 6F5 material when sheared at a relatively low vertical effective stress (50 kPa) is presented. The results show consistency with observations of geomaterials tested using conventional shear apparatus.

KEYWORDS: shear strength, shear box, dilatancy.

1 INTRODUCTION

Large construction projects which use heavy plant machinery (such as mobile cranes and/or piling rigs) require granular working platforms, particularly over weak and variable ground. In the United Kingdom, granular working platforms are often made from "recycled 6F5 aggregate". This classification (6F5) is defined as any recycled 6F5 aggregate made up of crushed hardcore materials including crushed concrete and natural stone. In general, this crushed material ranges in size from 0 to 125 mm (BSI, 2018).

Divall *et al.* (2024) states that the description often accompanying this material is that it should be a "well-graded material laid and fully compacted to Department of Transport (DoT) Specification and protected below with geotextile". Arguably, this description relates to the particle size and condition of the material but does not characterise the engineering properties necessary for geotechnical design.

The shear strength of the material is characterised by the angle of friction, ϕ', and is the predominant value required for determining the thickness of these granular working platforms (i.e. TWf, 2024; BRE, 2004). TWf (2024) states that high values of ϕ' (i.e. greater than 45 °) can only be used if suitably high-quality controls for design, inspection and maintenance are in place. However, the compressibility does not feature as heavily in design guidelines (i.e. BSI, 2018) but is important in avoiding "soft spots".

Tanghetti (2021) shows that material in which the grading curve has been scaled down to allow testing in standard apparatus can significantly under predict the value calculated for the shear strength. Following this, the study by Divall *et al.* (2024) first published angles of friction of recycled 6F5 aggregate from samples with various control levels in place. Owing to the size of the particles tested in the work the authors state it is necessary to test the material in suitably large – non-standard – shear apparatus. However, the stress levels in these studies (Tanghetti, 2012; Divall *et al.*, 2024) followed a pattern of 200 kPa, 300 kPa and 500 kPa but little is known regarding the shear or compressibility behaviour at relatively low stress levels.

This has led to a joint research project between City St George's, University of London and Tensar International Limited, a division of CMC. This study tested recycled 6F5 aggregate in a series of direct shear tests using the Giant Shear Box facility.

2 TEST DETAILS

2.1 *Giant Shear Box facility*

The tests were conducted using City St George's, University of London's Giant Shear Box facility (see Figure 1). The direct shear box has a shear plane area of 2.25 m^2 and capable of shearing up to 4,000 kg of granular material with grain sizes up to 125 mm in diameter. The facility has been described, in detail, by Divall *et al.* (2025).

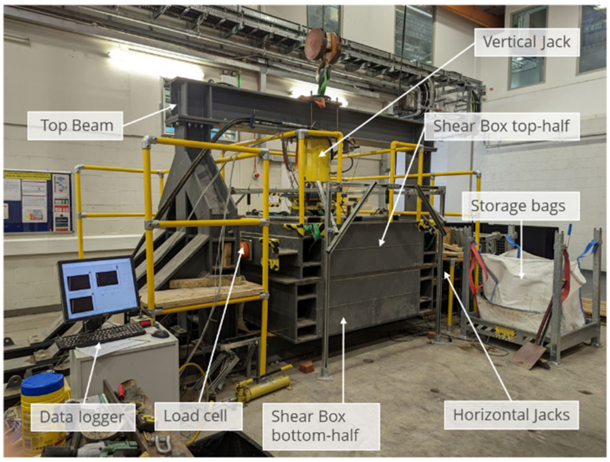

Figure 1. View of giant shear box facility (Divall *et al.*, 2024).

2.2 *Material*

The material met the UK Department of Transport (DoT) Specification for Highways Works Series 600 (Earthworks) for a category 6F5 aggregate. This category should contain particle sizes from 0.063 mm to 125 mm in diameter (National Highways, 2017). Although this specification provides limits for the grading, the material can be highly variable in the relative proportions of constituents and therefore the compression and shearing behaviour may also vary.

Figure 2 shows a summary of the proportions of constituents within the recycled 6F5 aggregate taken during the site sampling. The categories follow the same format used by Divall *et al.* (2014) where R_c is Concrete and concrete products, R_u is naturally sourced stone/rock, R_b are bricks/tiles, R_a is bituminous material, R_g is glass, X is other non-floating materials and FL is floating particles. There appears to be an almost even spread between the amounts of concrete, natural stone/rock and bricks/tiles.

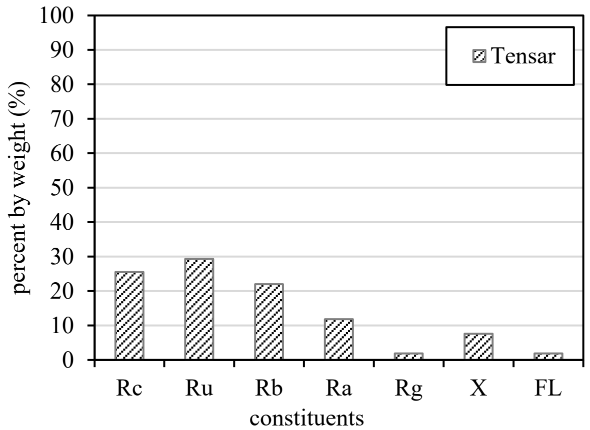

Figure 2. Constituents report from the site sampling

2.3 *Sample Preparation*

For each test recycled 6F5 aggregate was delivered by Tensar International Limited to City St George's heavy structures laboratory in five 1 m^3 capacity drop flap discharge bulk bags. Each bag was individually weighed before being placed into the shear box to determine the mass of material. The average weight of each bag was approximately 800 kg. The sample consisted of five layers, all of which were levelled and compacted using a small wacker plate (Figure 3) in two-minute intervals. This ensured a level surface between the placing each recycled 6F5 aggregate layer.

Figure 3. Compaction of a layer using a small wacker plate.

Figure 4 shows a sample of the compacted recycled 6F5 aggregate following the removal of the top half of the box following a test. The first two layers were prepared in the bottom half before the top half was attached, due to the size of the shear box. After assembling the top half, the remaining three layers were added. The third layer crossed the interface between the two halves of the box. After the compaction of each layer, the thickness was measured. The total thickness and mass of all layers were used to calculate the bulk unit weight of the sample. Once all the layers had been prepared, the square loading platen was positioned and the vertical loading system was assembled.

Prior to vertical loading and shearing of the sample, four 300 mm stroke linear potentiometers (positioned at each corner of the square platen) and two 300 mm stroke horizontal potentiometers (positioned on the bottom half of the giant shear box) were calibrated and used to measure the vertical and horizontal displacements, respectively.

Figure 4. Sample of recycled 6F5 aggregate following a test.

2.4 *Testing*

All samples were subject to compression in stages up to a vertical stress of 500 kPa. The vertical stress applied to the sample prior to the shearing phase varied for each test. Therefore, samples T3 and T1 were unloaded to vertical stresses of 50 kPa and 300 kPa, respectively, with T2 compressed further to a vertical stress of 600 kPa. See Table 1 for individual test details.

Table 1. Test series details

Test ID	Nominal vertical stress (kPa)	Moisture Content (%)	Bulk unit weight, γ_d (kN/m^3)	Voids ratio at start of test, e_i
T3	50	6.79	18.68	0.424
T1	300	6.88	17.48	0.444
T2	600	10.74	17.81	0.415

Following completion of the compression phase, each sample was sheared at a displacement-controlled constant rate of 0.3 mm per second. The test was concluded once the horizontal displacement had reached 300 mm. This is the maximum displacement of the shear box. A moisture content of the sample was taken upon completion of each test and used to calculate the dry unit weight of the samples.

3 RESULTS

3.1 *Compression and swelling*

Figure 5 shows the compression of samples during the increases of vertical effective stress applied before shear testing. All samples were first taken to a stress of 500 kPa prior to being unloaded/loaded (as appropriate) to the test value described previously.

This ensures that all samples had a similar stress history and is reflected in the similar values for initial voids ratio, e_i. T3 was 0.424, T1 was 0.444 and T2 was 0.415. Given the scale of the experimentation these results were considered to be within the acceptable range.

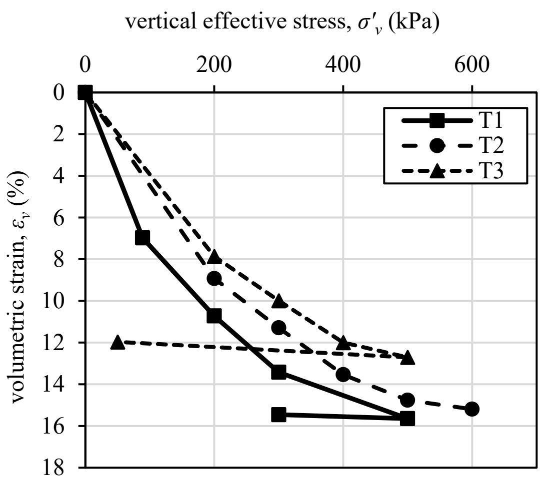

Figure 5. Volumetric strain (ε_v) v. vertical effective stress (σ'_v) for all tests.

It is also possible to calculate the one-dimensional compression modulus, M', for all the material tested. The average M' value for the recycled 6F5 aggregate was 4.423 MPa. Assuming a Poisson's ratio of 0.3 the average Young's modulus, E, was therefore calculated to be 4.028 MPa.

Figure 6 shows the equivalent data but for isotropic compression of the samples with vertical effective stress, σ'_v, plotted to a $\log_{10}$ scale v. the voids ratio, e. A normal compression line along with the swelling/recompression line have also been shown to coincide with the data. Using the equations below:

$$e = e_0 - C_c \log \sigma'_v \quad (1)$$

$$e = e_\kappa - C_s \log \sigma'_v \quad (2)$$

Where e_0 is the voids ratio value at $\log \sigma'_v = 1.0$ kPa on the normal compression line, e_κ is the voids ratio value at $\log \sigma'_v = 1.0$ kPa on the swelling/recompression compression line with C_c and C_s representing the coefficients of compression and swelling, respectively. Figure 6 together with Equations (1) and (2) give the values of $C_c = 0.22$, $e_0 = 1.02$ and $C_s = 0.02$. The C_s was considered negligible which is expected for a mainly large particle-based specimen set.

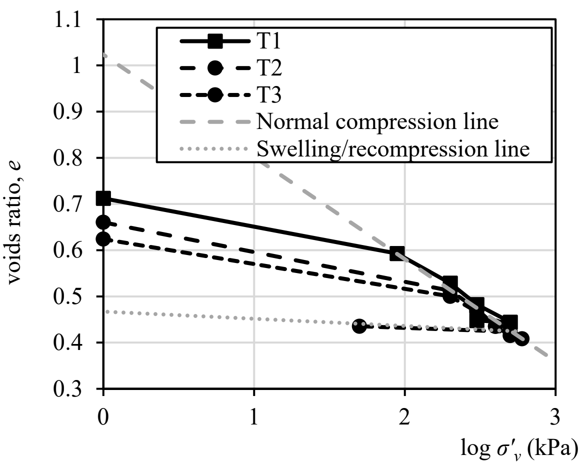

Figure 6. Voids ratio (e) v. $\log_{10}$ vertical effective stress ($\log \sigma'_v$) for all tests.

3.2 *Shear strength*

The essential features of soil strength for the tested recycled 6F5 aggregates can be seen by inspection of the shear and vertical effective stresses at particular stages of shear strain. Therefore, plots of normalised stress, τ/σ'_v, and vertical strain, ε_v, v. shear strain, γ_s, for all tests are presented in Figure 7 (a), (b) and (c).

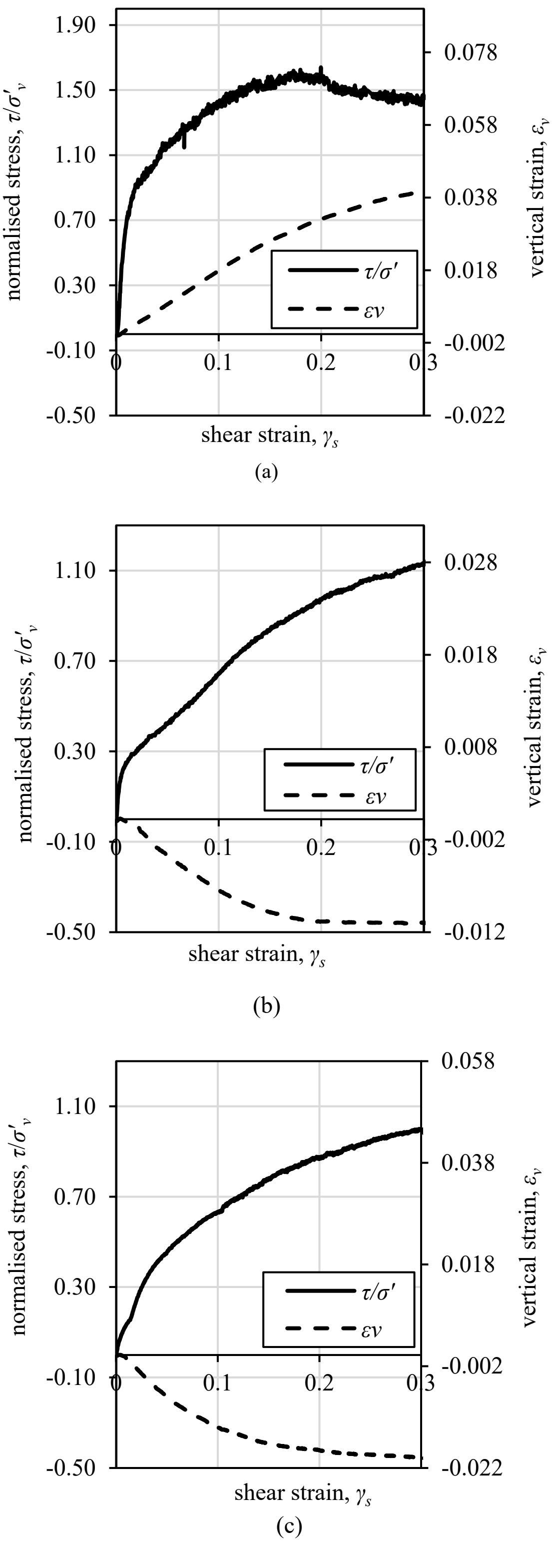

Figure 7. Plots of normalised stress (τ/σ'_v) and vertical strain (ε_v) v. shear strain (γ_s) for all tests (a) T3, (b) T1 and (c) T2.

Tests T1 and T2 had reached a state of little to no volumetric strains at around 20 % shear strain. It is clear that for the test conducted at the lowest stress level (T3) the vertical strain behaviour could be considered to be approaching a point of zero volume change at 30 % shear strain. In addition, Figure 7 (a) shows that following no initial compression there was continuous increase in the dilation of the sample.

However, in order to account for the dilation for comparison with the results obtained from the higher vertical effective stress levels, it could be possible to estimate the angle of friction, ϕ', using the stress-dilatancy approach based on Taylor (1948). Equation 3 relates the normalised stress, τ/σ'_v, during shearing to the angle of friction, ϕ', and the angle of dilation, ψ, where $\tan\psi = -\delta y/\delta x$. (Atkinson, 2007):

$$\tau/\sigma'_v = tan(\phi' - \psi) \quad (3)$$

Figure 8 would indicate that at $\delta y/\delta x = 0$ the normalised stress is approximately 1.44 and an angle of friction of 55.2 °. This is marginally less than the peak angle of friction of 57.7 °.

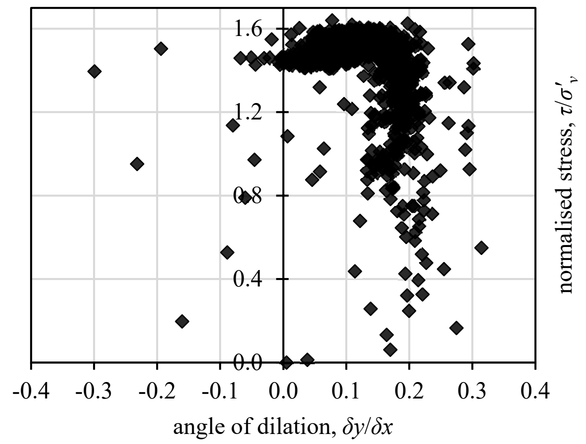

Figure 8. Normalised stress (τ/σ'_v) v. dilatancy ($\delta y/\delta x$) for T3.

The peak value of shear stress together with the corresponding vertical effective stress for all tests are plotted in Figure 9 together with three interpretive soil models:

- Coulomb line assuming no apparent cohesion
- Coulomb line representing the best fit line
- Curved "Hvorslev envelope" – i.e. a line passing through all the points.

Although T3 displays evidence of dilation, there is still good agreement with the two tests conducted at the higher vertical effective stress level with a Coulomb line assuming no apparent cohesion. For comparison, recently published results (Divall *et al.*, 2024) from a series of tests also carried out on recycled 6F5 aggregate shows an angle of friction of $\phi' = 47.6\,^{o} \pm 2.5\,°$. This material therefore sits within the 95 % confidence interval speculated in the work.

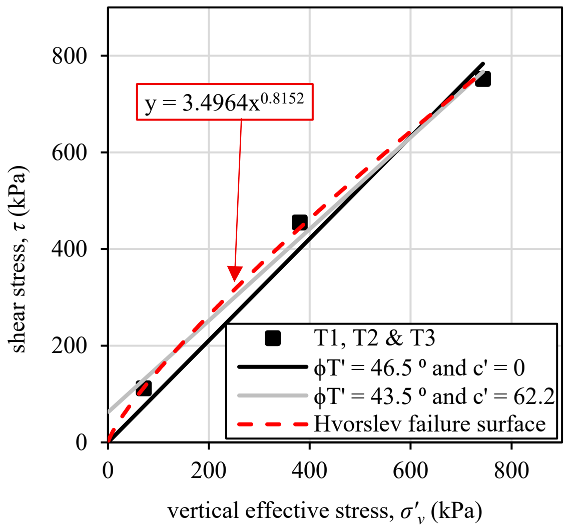

Figure 9. Angle of friction for the tested recycled 6F5 aggregated supplied by Tensar, ϕ'_T.

4 CONCLUSIONS

Three giant shear box tests were conducted on recycled 6F5 aggregates to determine its compression and shearing behaviour. The lowest level (50 kPa) was chosen to investigate the behaviour at a relatively low stress level. It was shown that C_c = 0.22, e_0 = 1.02 and C_s = 0.02. In addition, the angle of friction that can be inferred from the Coulomb lines are:

- Angle of friction, $\phi' = 46.5\,^{o}$ and apparent cohesion, $c' = 0$ kPa.
- Angle of friction, $\phi' = 43.5\,^{o}$ and apparent cohesion, $c' = 62.2$ kPa.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

Atkinson, J.H. (2007). The Mechanics of Soils and Foundations. CRC Press, UK.

BRE (2004) *BRE 470 Working Platforms for Tracked Plant Good Practice Guide to the Design Installation Maintenance and Repair of Ground Supported Working Platforms*, Garston Watford, UK.

BSI (2018) BS EN 13285 2018 Unbound mixtures Specifications, BSI, London, UK.

National Highways (2017) *Manual of Contract Documents for Highway Works Volume 1 Specification for Highway Works Series 600 Earthworks.* National Highways.

Divall, S., Davies, M.C.R., Stallebrass, S.E., Mahony, J., Quintavalle, S., Bowen-Bravery, J., Johnson-Watts, T. & Mulligan, R. (2024). Giant shear box tests on recycled 6F5 for tracked plant platforms. *Proc. of the XVIII European Conference on Soil Mechanics and Geotechnical Engineering*, Lisbon, Portugal, pp. 2249 – 2253.

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, Australia, pp. 75-80.

Taylor, D.W. (1948). Fundamentals of soil mechanics. John Wiley & Sons, New York, USA.

Temporary Works Forum (2024) *TWf2024:3 Working Platforms Design and Construction of Granular Working Platforms for Construction Plant: A Guide to Good Practice*. Temporary Works Forum, London, UK.