LARGE-SCALE LABORATORY ASSESSMENT OF GEOGRIDS TO REINFORCE GRANULAR WORKING PLATFORMS

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Abstract: The use of geosynthetics has found wide application in civil engineering. A significant potential use is in the reinforcement of temporary ground-supported working platforms that are critical for construction plant stability, in which safety is a vital issue. In 2004 BRE published BR 470 Working platforms for tracked plant to promote safety in the design, specification, installation, operation, maintenance and repair of working platforms. An objective is that safety should be achieved without unnecessary or excessive expenditure. A critical issue in the design of a platform is the thickness of granular fill required for any particular set of circumstances. In many situations it may be economic to incorporate geosynthetics to strengthen the working platform as an alternative to using a greater thickness of platform material.

BRE, has carried out a series of large-scale laboratory load tests to directly measure the effectiveness of introducing a number of geogrid products into granular load platforms bearing directly on a weak sub-soil. Tests were carried out on reinforced and un-reinforced platforms in a specially constructed 3m diameter confining ring in which 300mm square plate loading tests were performed. Applied load and plate deflection were monitored as well as internal stress and strain measurements within both the granular platform and the sub-soil. The test apparatus, instrumentation and test procedures are described and the principle results are presented. The implications of the findings with regards to safe and economic platform design are discussed. The inclusion of geogrid significantly increased bearing capacity of the granular platforms. The test procedure highlighted differences in performance between various grid types and detailed observations illustrated the mechanism of load transfer and ultimate failure in each case. The test could provide a standard procedure for comparative assessment of geogrid performance and quantification of performance criteria required in the published BRE design guide.

Keywords: laboratory test, biaxial geogrids, bearing capacity, instrumentation, reinforcing effect
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INTRODUCTION

At the time of publication BR470, Working platforms for tracked plant, this publication provided a simple design method for construction platforms and particularly for piling. Whilst careful selection of parameters for unbound materials produced reasonable platform depths, the design for reinforced platforms provided a very conservative solution. The possible improvement gain from reinforcement was further limited by the requirement for a platform to be stable without it. This was influenced by the CTRL accident in which the severing of geogrids necessary for stability was critical. The benefits that reinforced platforms can provide are therefore not being realised, both as safety in the event of poor parameter selection, improved care in design and construction and in the reduced use of fill materials.

BRE proposed capacity testing of aggregate layers reinforced with new grid products. It was considered that the platform design process would benefit from auditable testing demonstrating reinforced capacity. Versions of new grid were tested at smaller scale and showed improved performance, but when using realistic aggregate grading exceeded the capacity of the testing arrangement. The large scale necessitated testing in the BRE structures laboratory within confining rings of 3m diameter. The aims of the test programme described in this paper were:

- The generation of high quality data on the performance enhancement that can be gained from a variety of new and existing grids in controlled but near full-scale conditions that can be used to enhance understanding, for parameters for design and to feed into smaller scale tests or numerical analysis
- To provide data and if appropriate alternative design proposals specifically to accompany BR470

The first stage addresses the capacity testing of aggregate layers reinforced with new grid products. Three tests on Tensar grids plus a fourth control test on un-reinforced material formed the first stage of a programme that it is hoped will lead to improved design for reinforced layers using such grids.

TEST FACILITY AND APPARATUS

Tests were carried out on the concrete ‘strong floor’ of BRE’s large structures laboratory. This facility comprises a four-storey open laboratory with a thick heavily reinforced floor above a basement area covering the whole laboratory area. Vertical loading is applied to test models and full-size structures through pull-down rods or steel cables passing through a grid network of access holes to hydraulic jacking systems in the basement. The walls and internal landings provide reaction for applying lateral loads.

The test apparatus designed for this programme of work comprised two 3m diameter x 0.5m high pre-cast concrete soak-away rings stacked to make a 1m high mould to contain and restrain the test specimens. The rings were placed on a plywood base with a polythene sheet to separate the sub-base material from the timber. A loading frame was erected using two standard loading columns used in the laboratory and 30 tonne SWL cross-beam with mountings for an under-slung hydraulic jack. Reaction for applying vertical load through the jack was provided by tension rods attached to the cross-beam which passed through and were anchored on the underside of the strong floor.

A portable reference frame was assembled using a proprietary system of spanning beams and cross ties. A steel loading plate of 300mm x 300mm was constructed to apply load to the surface of the test granular blanket. The loading plate was designed such that the plate was >12 x the maximum particle size (14mm) of the granular blanket, the total specimen diameter was 10 x the plate size and the plate size is similar to the depth of the granular blanket. A high load capacity spherical seating was positioned between an electronic load cell and the loading plate to accommodate plate tilt. Figure 1 shows a schematic of the test set-up.

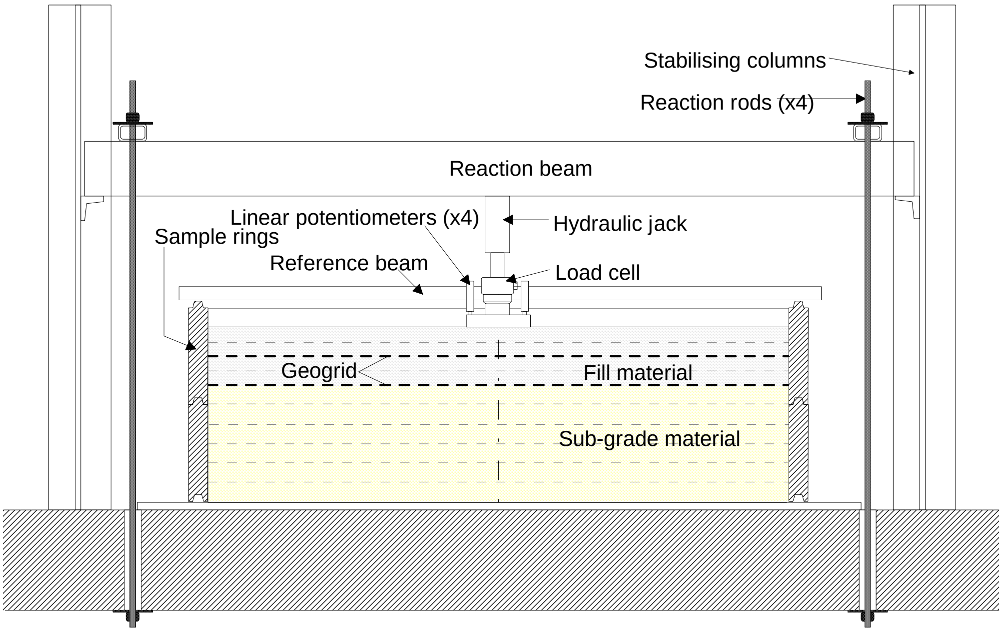

Figure 1. Schematic of test set-up

MATERIALS

The final choice of materials followed careful consideration of the objectives of the programme and the practicalities associated with the achievable quality control of large volumes of material. It was agreed that for this initial test programme, the sub-grade material would comprise a loose, dry granular material that could be placed with moderate ease under controlled conditions to achieve repeatable properties over a series of tests. The fill forming the granular blanket comprised gravel.

Geogrid reinforcement

Three grid types were tested: Type A, a triangular pattern grid; Type B, a biaxially oriented integrally extruded geogrid with rigid junctions and stiff ribs and Type C, a second triangular pattern grid. All the geogrid comprised pre-cut circular samples slightly smaller than the internal dimension of the concrete retaining rings.

Granular blanket

Testing was carried out by an independent UKAS accredited laboratory. Fill characterisation consisted of:

- Particle size distribution by Wet sieve analysis (BS1377: Part 2: Clause 9.2: 1990).
- Dry Density Moisture Content Relationship using 2.5 kg hammer in a 1 litre mould (BS1377: Part 2: Clause 3.3: 1990).
- Determination of shear strength by direct shear (BS1377: Part 7: Clause 5: 1990) and (Specification for Highway Works Vol.1 Clause 636 Part 2).

In addition to the tests described above, the maximum range of density under dry loose poured and heavy compaction conditions was assessed in the BRE laboratory. Table 1 summarises the granular properties.

Table 1. Characteristics of gravel blanket

Characteristics	**Properties**					
Particle size distribution	Gravel (%)		Sand (%)		Silt and clay (%)	
	98.9		0.8		0.3	
Dry density / moisture content relationship	Moisture content (%)	0.1	1.6	3.5	5.1	7.9
	Dry density (Mg/m^2)	1.70	1.65	1.62	1.64	1.60
Shear strength by rapid direct shear	Apparent cohesion (kN/m^2)			Angle of shearing resistance (deg)		
	15			49.0		

Sub-grade

Sub-grade properties were characterised by stiffness and strength testing of samples and in situ small plate tests:

- Particle size distribution by Dry sieve analysis (BS1377: Part 2: Clause 9.3: 1990).
- Dry Density Moisture Content Relationship using 2.5 kg hammer in a 1 litre mould (BS1377: Part 2: Clause 3.3: 1990).
- Determination of shear strength by direct shear (BS1377: Part 7: Clause 4: 1990).
- Consolidation properties in oedometer (BS1377: Part 5: Clause 3: 1990).

Table 2. Sub-grade properties

Characteristics	Properties					
Particle size distribution	Gravel (%)		Sand (%)		Silt and clay (%)	
	0.0		99.8		0.2	
Dry density / moisture content relationship	Moisture content (%)	0.0	2.1	3.9	5.8	8.1
	Dry density (Mg/m^2)	1.62	1.56	1.57	1.57	1.57
Shear strength by rapid direct shear	Apparent cohesion* (kN/m^2)		Angle of shearing resistance (deg)			
	4		33.5			
Consolidation properties in the oedometer	Pressure range (kN/m2)		M_v (m^2/MN)			
	0 – 25		0.133			
	25 – 50		0.114			
	50 – 100		0.0659			
	100 - 200		0.0496			

* The value of apparent cohesion results from a linearization of the data points – this material dry will not exhibit any cohesion.

INSTRUMENTATION

The test series was instrumented to measure applied load, loading plate deflection, vertical displacement at discrete points within the granular fill and sub-grade materials and vertical stress within the fill and sub-grade.

Load application

An NCB pattern 30 tonne capacity compression load cell with dedicated readout was set up and calibrated against a BRE 500kN Denison (Class A) compression testing machine. Load application was by hydraulic jack under-slung from a reaction beam and was transmitted to the loading plate via a high load capacity spherical seating.

Loading plate deflection

Four high-precision linear potentiometers with maximum 50mm travel were mounted on the beam spanning the test confining ring. These devices calibrated within the manufacturers specification of <0.1% linearity for accuracy and repeatability. They were set to measure the deflection of each corner of the square loading plate.

Surface and sub-surface settlement

A markers system was devised to allow precision monitoring of induced vertical displacements pre- and post-test. Each maker comprised a galvanised ‘twist’ nail with domed head and a proprietary plastic disc marker to act as a bearing collar. This was to prevent ‘punching’ of the central pin to ensure movement and was dictated by the movement of the surrounding sand or gravel. In test #1 markers were placed at 0.15m intervals 0.1m below the top of the sub-grade in two mutually perpendicular radial profiles between the centre and confining ring. Similarly markers were located between the loading plate and the confining ring at the upper surface of the fill (surface of test sample). Further markers were included in subsequent tests at levels within the fill and within the top 0.3m of the sub-grade sand.

Surveying was by levelling using a Wild NA2 precise level with optical vernier with an invar survey staff, capable of 0.01mm resolution and better than 0.1mm accuracy at short range. Marker movement was calculated relative to structural datum bolts on the laboratory floor. The vertical elevation of each marker was measured in relation to the datum bolts during sample construction before burial. Surface settlement points were re-levelled after the load test and markers at depth within the sample were carefully revealed and re-levelled as excavation proceeded.

In situ earth pressure

Eight miniature earth pressure cells based on a design by Nottingham University were utilised in the tests. These cells are 64mm diameter and 11mm thick with a 38mm diameter active face. Each unit was instrumented by BRE with a balanced bridge gauge set and sealed. Nottingham cells were initially calibrated by application of dead weight applied via an intermediate layer of rubber. Further calibration trials were carried out by bedding cells horizontally on sand constrained in a mould and applying dead weight loading.

A further pressure cell was a standard Kulite miniature earth pressure cells used extensively by BRE in past research in mainly cohesive soils. The Kulite cells are 65mm diameter and 15mm thick with a 25mm diameter active face. These cells have traditionally been calibrated hydraulically with excellent results.

SAMPLE CONSTRUCTION

Sample construction procedure was designed to maximise repeatability in the engineering properties of both sub-grade and blanket fill materials.

Sub-grade

Kiln dried sand was obtained in approximately 25kg bags. For the first test this sub-grade material was batch weighed to give the required mass for each 0.1m layer to attain an in-situ density of 1.53Mg/m3, also the average of the maximum and minimum densities for the sand measured in the laboratory. The sand was placed by pluviation, each weighed batch distributed evenly over the area of the sample, raked flat and moderate tamping applied to attain the required density according to the pre-set layer height noted by depth markers on the confining ring. Each sample consisted of 6 x 0.1m sub-grade layers. Settlement pins and miniature earth pressure cells were placed at pre-determined locations as the sample was constructed. Each test construction involved the manual handling and careful placement of 6.5t of sand.

Granular blanket

The gravel fill was oven dried after delivery and re-batched according to the mass required for each 0.075m test layer to attain an in-situ density of 1.53Mg/m^3, also the average of the maximum and minimum densities for the gravel measured in the laboratory. The gravel was also placed by pluviation in a similar manner to the sand and tamped to attain the correct density. Each test construction also involved the manual handling and careful placement of 3.3t of gravel.

Geogrid reinforcement

Where used, the circular geogrid layers were carefully placed, one on the top of the sand sub-grade and one at mid-depth of the granular blanket. The grid, which has a relatively strong set, was held flat by distributing numerous small steel weights so as not to apply any significant pre-loading to the sand. The grid was buried under the first layer of gravel, each steel weight being removed from beneath the loose-poured gravel so as not to remove load or disturb the grid at the sand / gravel interface. The second layer was installed in a similar manner between the second and third gravel layers.

TEST PROCEDURE

Loading

Immediately following sample construction, the load reaction beam was craned into place and secured using tie rods as indicated in Figure 1. The loading plate was carefully positioned and levelled at the centre of the sample and the high load capacity spherical seating and compression load cell located centrally on the plate. The hydraulic jack was screwed into a locating plate on the underside of the beam and fine alignment of the loading system carried out. The reference beam and linear potentiometers were mounted and all instrument pre-loading readings recorded on a data logger. Once the jack was in contact, load was applied so as to produce a steady rate of penetration of the loading plate. All tests were run to produce a total plate penetration of approximately 40mm. Figure 2 shows the complete test set up. Surface level marker pins can be seen on mutually perpendicular radii.

Supplementary load tests

In addition to the main central plate tests, additional tests on 100mm square plates were carried out in a similar manner off-centre in line with the reaction beam at approximately half radius of the sample. The purpose of these tests was to establish the bearing capacity of the un-reinforced granular blanket at shallow depth and the implied shear strength of the materials. Similar tests were carried out on the same vertical profile on the upper surface of the sand sub-grade after removing the granular blanket.

Figure 2. Complete test set up

Test excavation

After removing the reaction beam and jack, the loading plate and the reference frame, the surface pins were re-levelled and removed. Gravel was carefully excavated to reveal pins at lower levels that were also re-levelled. In-situ earth pressure cells were removed during this operation. Where present, the layers of geogrid were uncovered and their vertical deflection profile measured on two mutually perpendicular diameters. The sand sub-grade was similarly removed in layers and the buried pins re-levelled prior to removal. All the materials were re-batched for subsequent sample construction.

TEST FINDINGS

Bearing capacity

The principal result from each of the three tests with geogrid reinforcement and the fourth control test was bearing capacity. The results represent the ability of the three geogrid systems to enhance the bearing capacity of similar un-reinforced granular fill overlying a weak sub-grade, modelling the relative behaviour of an un-reinforced construction platform and those incorporating layers of geogrid under conditions common to all tests.

Central loading plate

Tests #1, #2 and #3 respectively incorporated grid Type A triangular pattern grid, Type B biaxially oriented extruded geogrid and Type C triangular pattern grid. In test #1 a maximum load of 67kN was applied to the loading plate resulting in an average deflection of 37.8mm. The maximum bearing pressure was 744kN/m^2. In test #2 a maximum load of 66.9kN was applied to the load plate resulting in 38.4mm average deflection. The maximum bearing stress was 744kN/m^2. In test #3 a maximum load of 83.8kN was required to produce 39.0mm average deflection. The maximum bearing stress was 931kN/m^2. Test #4 was carried out with the same sub-grade and granular blanket parameters but no reinforcement was installed. A maximum load of only 35.3kN resulted in 44.1mm average deflection of the load plate. The maximum bearing stress was 392kN/m^2. Figure 3 shows the average loading plate deflection plotted against applied plate load for each test.

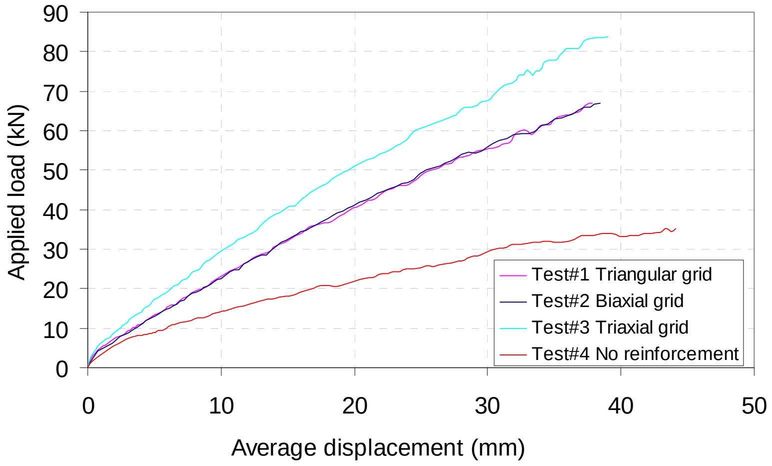

Figure 3. Average load plate deflection plotted against applied plate load for each test.

Supplementary plate loading tests#

Small surface load tests on un-reinforced gravel and sub-grade materials were carried out. These test results have been used to back-calculate material shear strength. The average value of bearing capacity factor, Nγ, for the gravel fill tests suggests an angle of shearing resistance, *φ'*, significantly above 50°. Laboratory tests indicated an angle of shearing resistance of 49° but the Mohr failure envelopes for granular materials show pronounced curvature, particularly at low stresses, and higher values would be expected if related to surface conditions. Similar analysis of tests on the sand sub-grade suggests an angle of shearing resistance of around 42° or 43°. This is significantly higher than results from laboratory tests (33°), which did not show a particularly curved Mohr failure envelope.

Stress measurements

Stress measurement in granular soils with relatively small cells is notoriously difficult. Stress arching or stress ‘attraction’, caused by a relatively hard inclusion, are common problems. The measurements made during the four tests are difficult to interpret, taken at face value. On the basis that the cells immediately below the loading plate should measure the actual applied load / plate area, all the stress measurements in each test were modified in proportion to that applied stress. In test #1, #2 and #3 higher stresses were concentrated within the reinforced fill.

Approximately 50% of the stress apparently dissipated within the granular blanket in test #2 and #3. A substantial proportion (about 80%) of the applied stress in test #4 was transmitted through the blanket to the sub-grade.

Displacement

Settlement pins

In test #1 limited settlement pins make the data unsuitable for contouring. Recognition of the potential value of this data prompted the inclusion of additional pins in test #2 (Type B biaxially oriented geogrid). More comprehensive use if settlement pins was established for tests #3 and #4 (Type C triangular geogrid and un-reinforced). Figure 4 shows displacement contours for tests #2, #3 and #4. The modelling suggests some small displacements extending deep within the sub-grade with the use of the biaxial grid, although no actual measurements were made at that depth.

The contrast between test #3 Type C triangular geogrid and test #4 (no reinforcement) has potentially greater significance. With the Type C triangular grid, any significant displacements are clearly confined within the reinforced blanket and strains are more widely distributed. In the un-reinforced situation the vertical displacement profile indicates more of a 'punching' failure and the load capacity was greatly reduced.

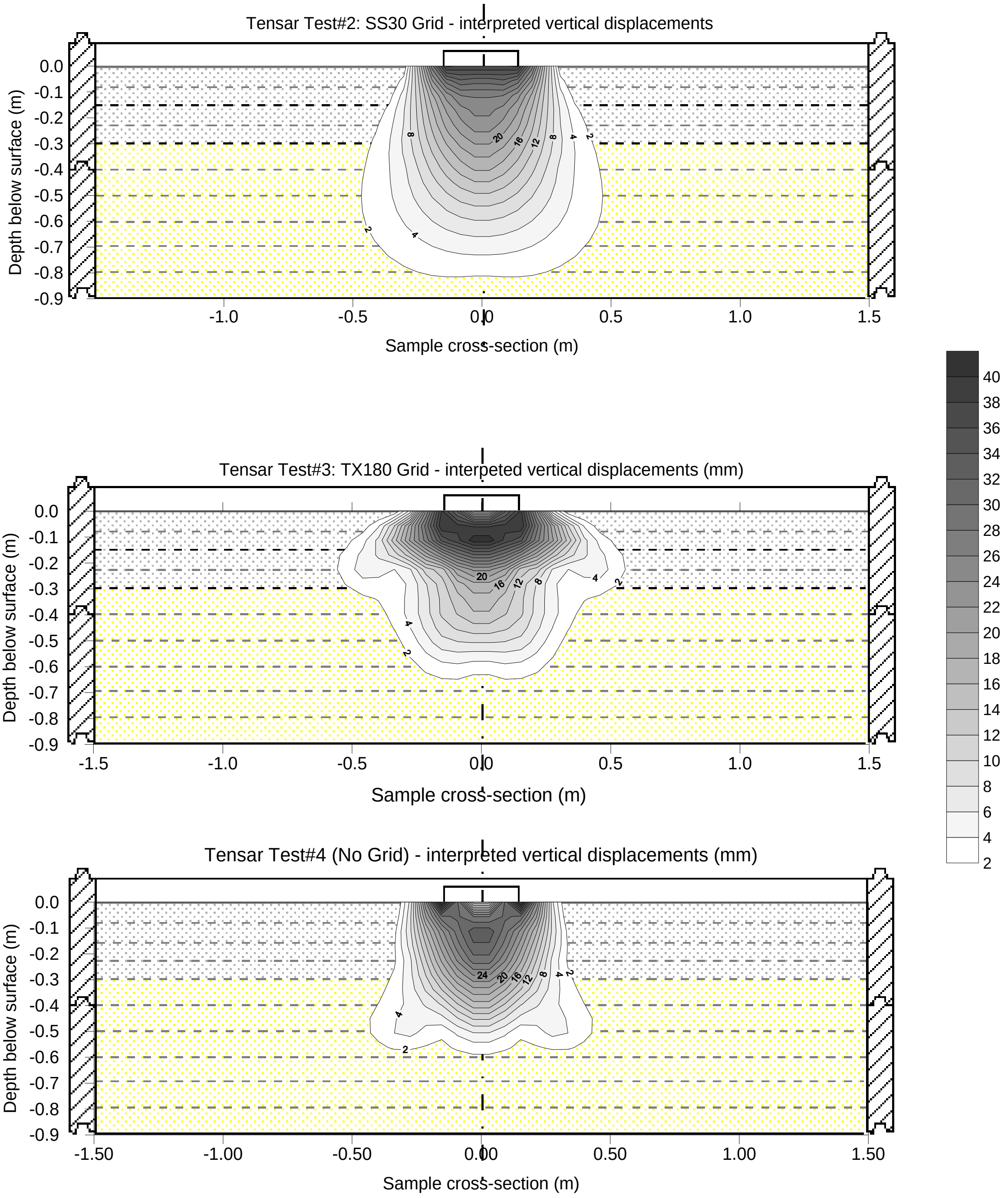

Figure 4. Interpreted displacement contours for Test #2, #3 and #4

Geogrid deflection

During the excavation of tests #2 and #3 deflection of the geogrids directly below the loading plate was recorded. Figure 5 shows the measured deflections of the biaxial grid in relation to the settlement point deflections for the same test and the actual excavated grid.

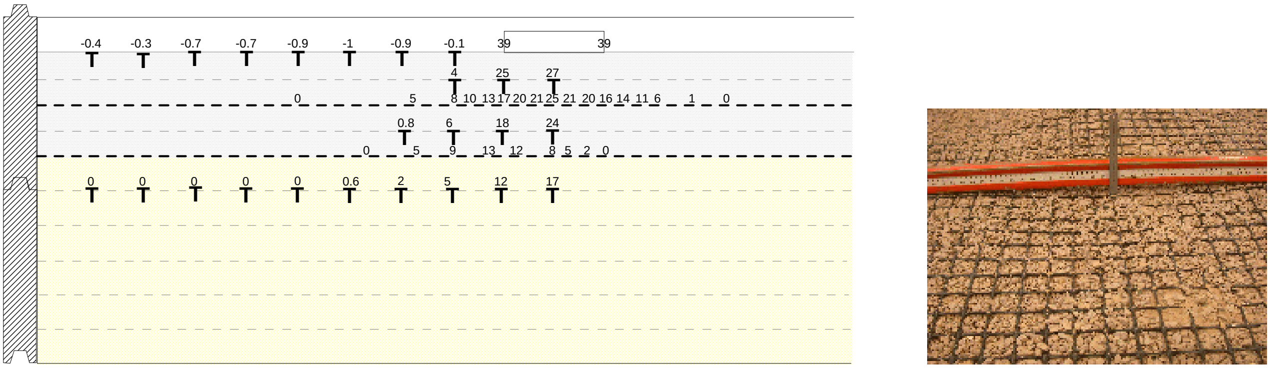

Figure 5. Measured deflections of the biaxial grid in relation to the settlement point deflections

DISCUSSION

The use of geogrids for the reinforcement of fill materials has many applications in the construction industry. Their application can encourage the use of a more settlement-conscious approach and can widen the use of unbound materials. Both are to be encouraged. Proper design relies on good data, and the tests described in this paper have provided some comparative data for un-reinforced and reinforced sand and gravel materials. These tests show significant improvements in stiffness and bearing capacity resulted from the use of different grid designs. The triaxial grid design clearly out-performed the other patterns in these comparative tests and approximately doubled the bearing capacity offered by the un-reinforced granular blanket of the same thickness. The implication of this result is that the thickness of an un-reinforced platform designed to BR470 could be reduced without loss of capacity by the introduction of appropriate geogrid reinforcement.

The use of stress measurement in the tests indicated the potential for design methodology improvements as well as product data but improvements in the reliability and effectiveness of the cells is required. The internal displacement measurements were very effective and gave both reliable and accurate data, although considerable care and attention to detail was required in the installation, monitoring and excavation. Overall, the test rig developed for this programme of tests satisfied all the requirements.

The materials used for the granular blanket and sub-grade are not wholly representative of normal site applications. A well graded granular fill such as Type 1 or other suitable granular material as defined in Series 600 or 800 of the Manual of Contract Documents for Highway Works, Volume 1 - Specification for Highway Works would generally be used for in a working platform design and limiting sub-grade conditions would likely be a soft cohesive soil. A further series of tests is planned at the time of writing this paper which will incorporate reinforced and un-reinforced Type 1 for the granular blanket and a low shear strength cohesive soil as the sub-grade. Stress measurement will incorporate cells better suited to the materials and displacement measurement will be further enhanced to incorporate real time measurement, both at the surface and at depth within the blanket and sub-grade. Pore water pressure measurements will be included.

CONCLUSIONS

- A new test rig using loaded plates to test a sub-grade soil and granular reinforced or un-reinforced platform fill in 3m diameter samples has been constructed and operated successfully in the heavy structures test laboratory at BRE.
- Four tests have been carried out successfully utilising two triangular pattern geogrids, a biaxial geogrid, and an un-reinforced control test.
- The results from the laboratory plate loading tests indicate significant improvement in bearing capacity of the granular blanket / sand sub-grade when two layers of geogrid reinforcement are introduced, compared with the un-reinforced situation.
- The three grids tested, substantially improved the performance of the granular blanket alone by a factor of ∗2.
- The performance of the gravel fill reinforced with the Type A triangular and Type B biaxial grids was very similar but the gravel fill reinforced with the Type C triangular grid performed significantly better.
- The introduction of geogrid reinforcement to a granular blanket over a weak sub-grade had a significant benefit in concentrating both a higher proportion of stress and soil vertical displacement within the blanket. Stress measurements implied that the inclusion of the geogrid acts to spread the applied load and displacement. The results also illustrate the fundamental difference between spreading and concentrating strain within the reinforced fill and the ‘punching’ failure when loading an un-reinforced fill.

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