Full-scale plate load testing and validation of Tensar's T-Value approach for Tensar Mechanically Stabilised working platforms on cohesive subgrades.

Research locations

University of Saskatchewan, Saskatoon, Saskatchewan, Canada as well as sites in Krakow, Poland and San Diego, USA

Testing Conducted

- Large scale plate loading tests
- Mostly 1.0m wide plates with loadings of up to 1000kN
- A range of aggregate types stabilised with Tensar InterAx® geogrids on cohesive silty clay subgrade soils.
- Total number of 20 tests were performed

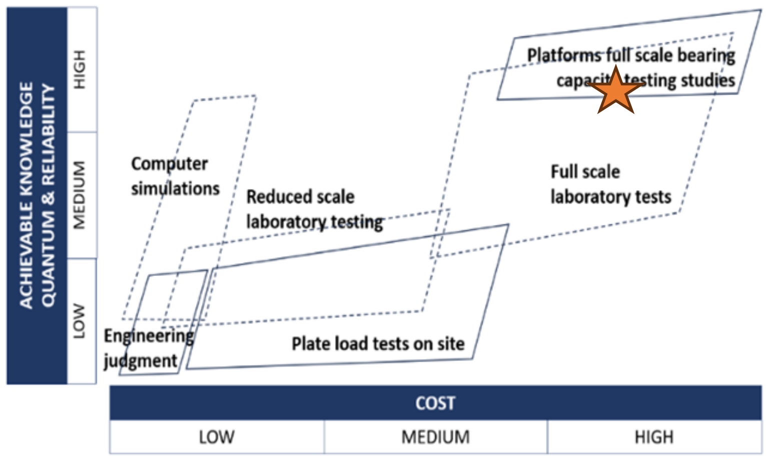


Figure 1: Interrelationship between working platforms engineering facets (Zamara et al (2023) modified after Hugo et al (1991)

Sections Tested

A range of platform thicknesses and aggregate types were tested to reflect the range of different fill types used in working platform construction. In total, 20 full scale platform tests to ultimate bearing capacity were carried out across three locations.

<u>At Saskatchewan, Canada:</u>

- 0.3m thick well-graded angular crushed rock aggregate with one layer of Tensar InterAx geogrid and a 1.0m square plate
- 0.6m thick well-graded angular crushed rock aggregate with two layers of Tensar InterAx geogrid and a 1.0m square plate
- 0.3m thick well-graded angular crushed concrete aggregate with one layer of Tensar InterAx geogrid and a 1.0m square plate
- 0.3m thick medium to coarse sub-angular natural sand with one layer of Tensar InterAx geogrid and a 1.0m square plate

At Krakow, Poland:

- 0.25m thick well-graded angular crushed rock aggregate with one layer of Tensar InterAx geogrid and a 1.0m diameter plate

At San Diego, USA:

- 0.3m thick uniform angular crushed rock aggregate with one layer of Tensar InterAx geogrid and a 0.6m diameter plate

Key Findings

- For a wide range of aggregates incorporating Tensar InterAx geogrid, tested at full scale to ultimate bearing capacity, it has been shown that the Tensar T-value approach consistently and accurately predicts the ultimate bearing capacity of working platforms on clay (undrained) subgrades across a range of shear strengths.
- The results showed significant increases in the bearing capacity factor (Nc) available in the Tensar mechanically stabilised platforms.

Introduction

A distinct stabilisation function was established initially for Tensar's "first generation" of stabilisation geogrids, where mechanical interlock and particle confinement were identified as being important to improve the performance of a resulting Mechanically Stabilised Layer (MSL) instead of relying on the physical characteristics of the geogrid alone.

To investigate the mechanical stabilisation capabilities of Tensar stabilisation geogrids, an extensive research programme was undertaken using very large triaxial testing to allow the derivation of the Tensar Stabilised Soil Model (TSSM) strength envelope. Parametric studies in plane strain and axisymmetric FEA were then used to determine ultimate bearing capacity of granular working platforms both with and without the inclusion of a Tensar stabilisation geogrid. (Lees & Clausen, 2020) [(1)]

Figure 2 – 1.0m x 0.5m large triaxial test rig

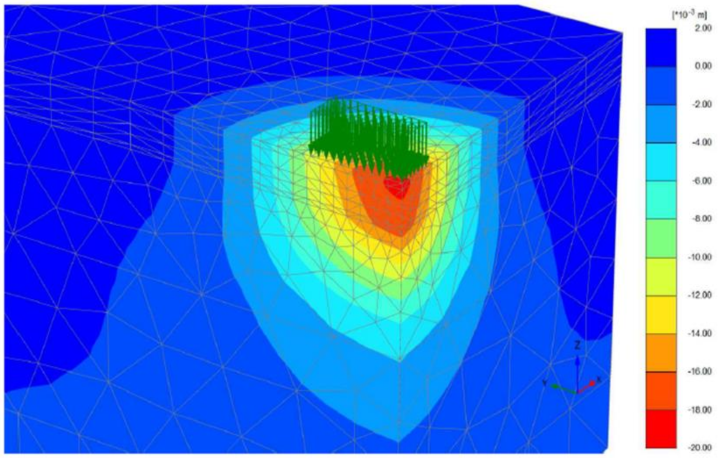


Figure 3 – example of Finite Element Analysis model

Full scale plate loading tests were carried out to validate the methodology[1] and as a practical application of this work, Tensar introduced the “load transfer efficiency” or “T-Value” design approach for working platforms in 2019 resulting in many hundreds of working platforms being successfully constructed by adopting the “T-Value” approach as part of platform design assessment.

Using similar development and research methodologies, Tensar’s Next Generation InterAx stabilisation geogrids were included in the T-Value design approach in 2022 and showed improved performance over the first generation stabilisation geogrids despite their physical characteristics being lower.[2]

The features and benefits of the Tensar InterAx geogrids and shown in figure 4 and were developed to improve particle confinement and promote increased mechanical interlock with the granular fill which allows the use of more granular fill types than available previously.

Features and benefits of Tensar InterAx geogrid

- Three aperture shapes and sizes
- Compressible caps
- High aspect ratio
- Central hexagon

Figure 4 - Tensar InterAx geogrid exhibiting particle confinement and mechanical interlock

Testing of Tensar InterAx geogrids

To determine the stabilising effect of Tensar InterAx with a range of different fill materials, a programme of testing was commissioned to take place predominantly at the University of Saskatchewan in Canada. Project sites in Poland and the USA were also identified as opportunities for full scale testing.

Early testing at Saskatchewan

Tensar initially carried out a programme of research at the University of Saskatchewan in Canada to investigate and confirm the benefits of a Tensar Mechanically Stabilised Platform incorporating Tensar InterAx geogrid.

Test set ups

A 1.0m square steel plate, shown in figure 6, was used to apply vertical loads to granular platforms constructed at a formation level exposed at the bottom of the trench shown in the figure 5. The trench was excavated to remove the dry crust of material and expose the soft to firm silty clay beneath. The aggregate was placed and compacted in layers at optimum moisture content. The load was applied to the plate by a hydraulic cylinder with a capacity of 1000kN. This level of loading required a significant counterweight to allow the load to be applied and so the “bridge” structure also shown in figure 5 was constructed to allow two loaded trucks or concrete blocks to be positioned and provide sufficient resistance to the hydraulic cylinder during the tests.

Figure 5 – full scale testing set up at the University of Saskatchewan, Canada.

The results of these initial Saskatchewan tests were used as part of the development of the Tensar T-Value approach for working platform applications and showed:

- Consistently higher peak loads with the Tensar mechanically stabilised platforms when compared with the non-stabilised controls.
- These peak loads were also sustained for longer in the mechanically stabilised platforms and were found to be higher just before platform failure.
- Bearing capacity factor (Nc) improvements between 52% and 245% were calculated as the ratio of the ultimate bearing load at the top of the platform to the undrained shear strength of the subgrade.

Further full scale plate load testing to validate T-Value

The research programme was subsequently expanded to include different platform fill types to reflect a range of materials typically encountered in working platform construction. As well as the facilities at Saskatchewan, site based testing took place at a location in Poland and another in San Diego in the USA. Details of the tests carried out at each of these locations are given below.

A total of 20 tests were carried out across these three locations.

The work previously carried out to develop the Tensar T-Value approach for use in the design of working platforms allowed Tensar's engineers to predict the results of this expanded programme of full scale plate load testing. These predictions were compared to the measured results across 20 full scale plate load tests to assess the validity and accuracy of the T-Value approach incorporating Tensar InterAx geogrids.

Figure 6 - completed test at Saskatchewan showing bearing capacity failure of the 1.0m^2 steel plate positioned under the counterweight bridge shown in

Testing at the University of Saskatchewan

Once again, a 1.0m^2 plate was pushed into the mechanically stabilised platforms incorporating Tensar InterAx geogrid, until ultimate bearing capacity was reached, as illustrated in figure 6. The load applied to the plate was measured continuously by a load cell and plate settlement was measured by displacement transducers. An optical level recorded the level of the "bridge" to correct for any movement.

Test conditions

Subgrade:

- The material on site was a soft to firm silty clay which when tested using shear vanes and CPTu at every test location, gave a range of undrained shear strength (Su) between 22kPa and 61kPa across the 18 tested platforms.

Aggregate:

- Three different aggregates were used: well-graded angular crushed rock, well-graded angular crushed concrete and medium to coarse sub-angular natural sand.

Further details for the crushed rock are shown in figures 7 and 8 with further details of the fill types summarised below.

- Well graded angular crushed rock – Maximum particle size 37.5mm with less than 5% fines, LA abrasion 18%, peak secant friction angle of 55 degrees and coefficient of uniformity greater than 5.
- Well graded angular recycled crushed concrete – Maximum particle size 25mm with less than 5% fines, LA abrasion 34%, peak secant friction angle 45 degrees and coefficient of uniformity of greater than 5.
- Well graded sub- angular coarse sand – Maximum particle size 9.5mm with less than 5% fines, a uniformity coefficient of more than 4 and peak secant friction angle of 39.5 degrees.

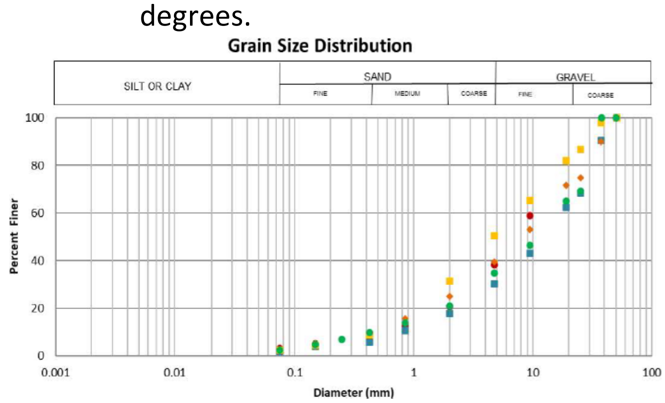


Figure 7: grading data for the well-graded crushed aggregate

Figure 8: image of the well-graded crushed aggregate

Sections & Geosynthetics:

- 0.3m thick well-graded angular crushed rock aggregate with one layer of Tensar InterAx geogrid at its base.
- 0.6m thick well-graded angular crushed rock aggregate with a layer of Tensar InterAx at its base and another at mid-height.
- 0.3m thick well-graded angular crushed concrete aggregate with one layer of Tensar InterAx geogrid at its base.
- 0.3m thick medium to coarse sub-angular natural sand with one layer of Tensar InterAx geogrid at its base.

Project site, Krakow, Poland

Here, a project site was used to carry out full scale testing using a 1.0m diameter circular steel plate to impose loading on to a working platform incorporating Tensar InterAx geogrid. The load was applied using a test set up like a pile load test with a reaction beam supported by Controlled Modulus Columns (CMC) rigid inclusions acting as anchor piles in tension. Optical levelling was used on the reaction frame to check for any movement.

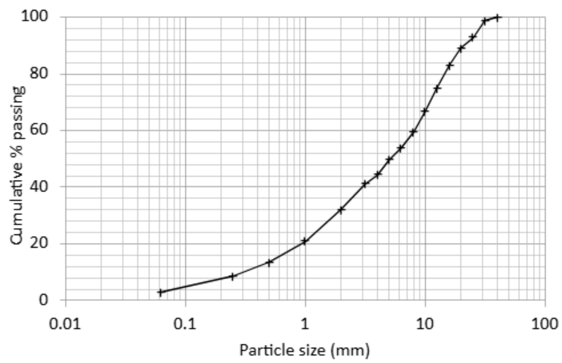
Test conditions

Subgrade:

- The material at site was a firm silty clay which when tested using a shear vane and Marchetti dilatometer at the test location on the day of the testing, gave an undrained shear strength (S_u) of 60kPa which was unform with depth in the subgrade.

Aggregate:

- The aggregate used was a well-graded angular crushed rock aggregate as shown in the image and particle size distribution chart below.
    - The aggregate had a maximum particle size of 40mm with less than 5% fines, peak secant friction angle of 51 degrees and a coefficient of uniformity greater than 5.



Section and geosynthetic

A 0.25m thick well-graded crushed rock aggregate with one layer of Tensar InterAx geogrid at its base.

<u>Project site, San Diego, USA</u>

For this site-based test, a smaller 0.6m diameter circular plate was used to impose the load on the 300mm thick working platform section. The reaction to the imposed load was provided by heavy construction plant – see images below

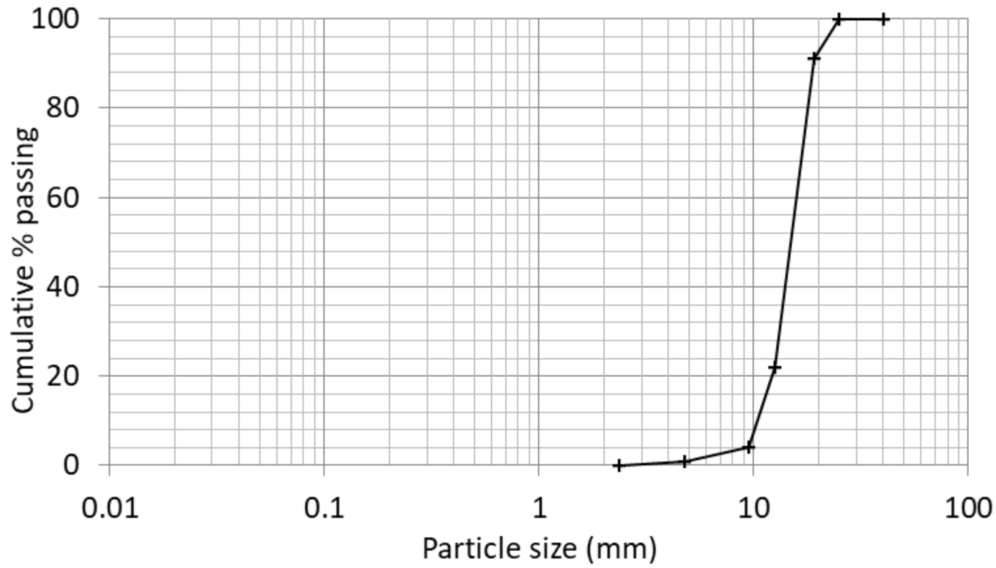
Test conditions

Subgrade:

- The material at site was a soft silty clay which when tested using borehole SPTs during site investigation and DCPs at the test location on the day of testing had an undrained shear strength of 24kPa.

Aggregate:

- The aggregate used was a uniformly graded angular crushed rock aggregate (also known as AASHTO No. 57 stone) as described in the particle size distribution chart below.
  - Maximum particle size 25mm with less than 5% fines, LA abrasion of <30 and peak secant friction angle of 50 degrees

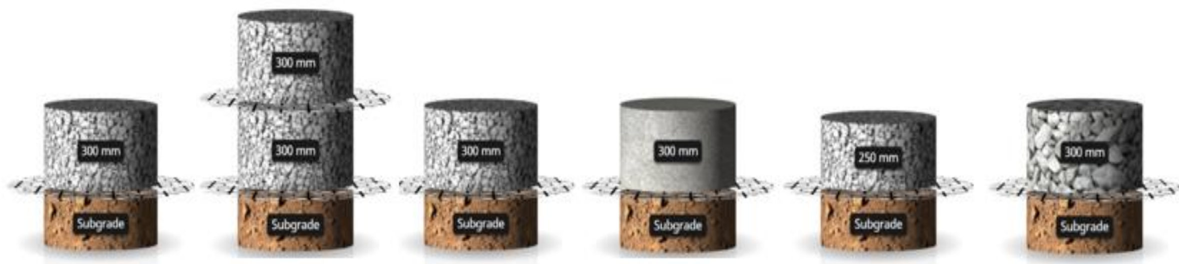

100
80
60
40
20
0
Cumulative % passing
0.01
0.1
1
10
100
Particle size (mm)

Testing results and conclusions

Tensar T-Value predictions

Table 1 below collates and summarises the 20 tests carried across the three test locations.

Table 1 – Summary of tested sections



Test location	**USASK, Canada**	**USASK, Canada**	**USASK, Canada**	**USASK, Canada**	**Krakow, Poland**	**San Diego, USA**
Granular fill type *	Well graded crushed rock **(A)**	Well graded crushed rock **(B)**	Well graded crushed concrete **(C)**	Sand **(F)**	Well graded crushed Rock **(D)**	Uniform crushed rock **(E)**
Granular platform thickness	300mm	600mm	300mm	300mm	250mm	300mm
Subgrade undrained shear strength, kPa	22 to 41	26 to 35	47 to 59	57 to 61	60	24
Maximum load at failure, kN	686	950	641	463	760	198
Number of tests	6	6	3	3	1	1
Number of layers of InterAx	1 layer of Tensar InterAx	2 layers, bottom and middle of section	1 layer of Tensar InterAx	1 layer of Tensar InterAx	1 layer of Tensar InterAx	1 layer of Tensar InterAx

(Letters in brackets refer to tests referenced in figure 9)

The graph in figure 9 collates the results carried out at the University of Saskatchewan, Krakow and San Diego and shows that the predictions made are all in close agreement with the measured values or err on the conservative side.

The results on the graph show ultimate unfactored values for comparison at ULS without safety factors. It is important to note that in design, appropriate safety factors would be included in the platform assessment to ensure an adequate level of safety over and above the predicted bearing capacity.

The testing of Tensar mechanically stabilised working platforms including Tensar InterAx geogrid across a range of aggregate types, all at full scale with the platforms pushed to ultimate bearing capacity, has shown that the Tensar T-value approach consistently and accurately predicts the ultimate bearing capacity of working platforms on clay (undrained) subgrades with a range of shear strengths.

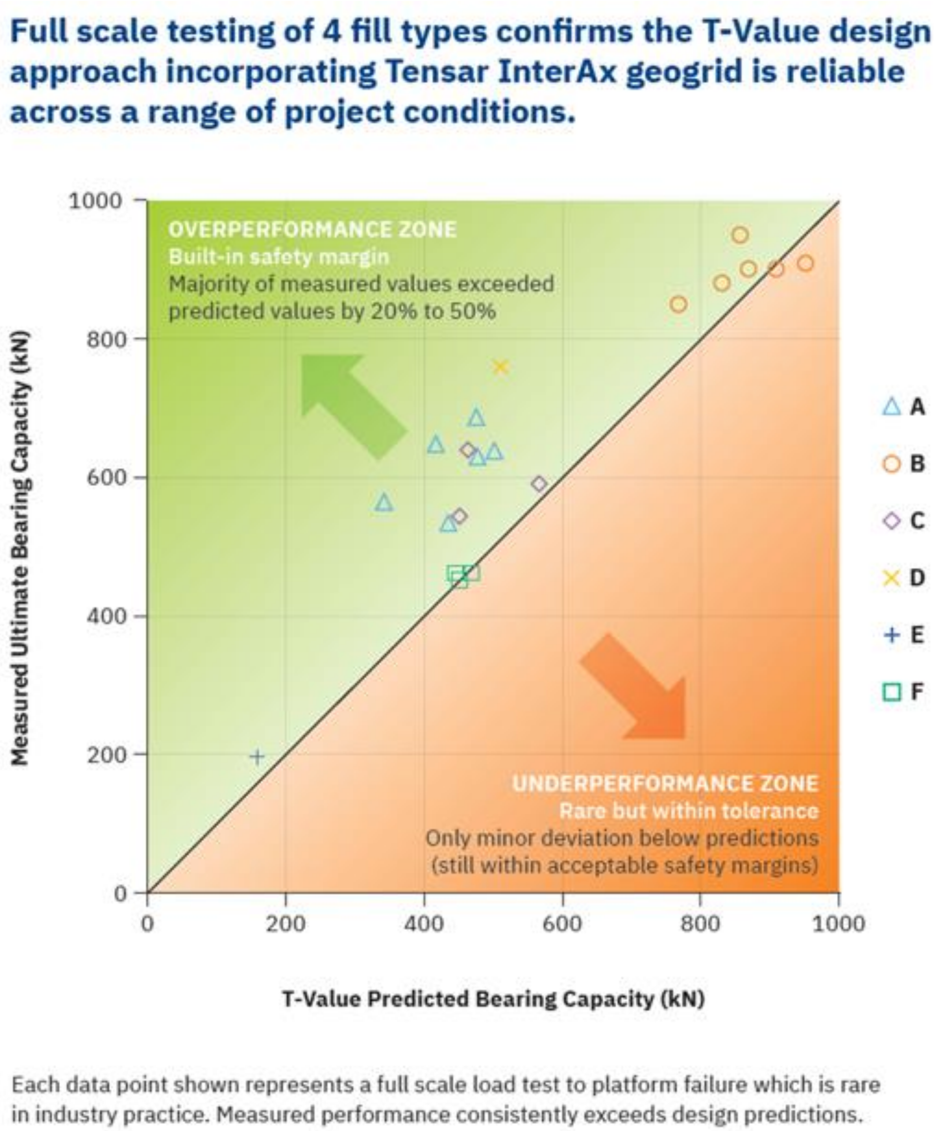


Figure 9 - predicted and measured ultimate bearing capacities across 20 full scale bearing capacity tests to failure

All but two of the 20 tests sit to the left or on the "No difference/0% error line" where the measured equals the predicted, demonstrating a consistent overachievement of the Tensar mechanically stabilised working platforms when compared with predicted values.

The range of loading imposed on the platforms is from 198kN up to 950kN which represents a realistic spectrum of loading that needs to be catered for in working platform design.

Not only does this work validate the calculation method, it also validates the whole process to derive the T-value parameters. [(2), (3)]

Users of the T-value approach to calculate ultimate bearing capacity of working platforms can do so with the confidence and knowledge of the extensive full-scale testing undertaken by Tensar.

Bearing capacity factor improvements

Across the series of 20 full-scale plate load tests, five different granular materials were tested over soft to firm silty clay with undrained shear strengths of 22 to 61 kPa (see table 1) The performance of Tensar InterAx geogrid-stabilised platforms was evaluated by calculating the bearing capacity factor (Nc), which is the ratio of the ultimate bearing load to the undrained shear strength of the subgrade. The results showed significant increases in the bearing capacity factor for all of the platform sections tested and are summarised in Table 2.

It is interesting to note that the bearing capacities measured for the thicker sections used for the tests labelled "B" at the University of Saskatchewan were around double those measured for thinner platforms with a single layer of geogrid. These thicker platforms had two layers of geogrid to maintain the stabilisation effect of the Tensar InterAx geogrid throughout the thickness of the resulting Tensar MSL.

In layman's terms, the bearing capacity factor is crucial for designers and engineers because it indicates how much load a foundation can support before failing. A higher bearing capacity factor means the foundation material can support more weight, making it essential for ensuring the stability and safety of structures. By understanding and optimising this value, engineers can design more efficient and reliable foundations, reducing the risk of unacceptable settlement.

Table 2 – summary of bearing capacity improvements

Test location	**USASK, Canada**	**USASK, Canada**	**USASK, Canada**	**USASK, Canada**	**Krakow, Poland**	**San Diego, USA**
Granular fill type	Well graded crushed rock	Well graded crushed rock	Well graded crushed concrete	Sand	Well graded crushed rock	Uniform crushed rock
Granular platform thickness	300mm	600mm	300mm	300mm	250mm	300mm
Bearing Capacity Factors improvement with InterAx	246% to 283%	418 to 561%	117%	42%	147%	61%

Summary

By extending the scope of previously completed full scale platform testing, Tensar have demonstrated with this work that even under extreme loading conditions, a Tensar mechanically stabilised working platform can improve platform performance.

This is shown to be the case not just for the higher quality well graded crushed rock materials often expected for use in working platforms but also for lower quality fill with recycled content, where grading is more uniform and for sand. By testing a range of granular fill types in this programme of work, it can be seen that the benefits of including a Tensar InterAx geogrid in a working platform will offer technical benefits in terms of increased bearing capacity of the result platform but also commercial benefits where lower quality fill material become available where previously that may have been rejected.

These results have been included in the validation work carried out for the Tensar “T-Value” approach adopted in Tensar’s platform design methodology. By pushing these platforms to failure, knowledge on expected platform behaviour has been advanced as well as understanding how Tensar’s InterAx geogrids behave all the way up to platform failure.

References:

1. The strength Envelope of granular soil stabilised by multi-axial geogrid in triaxial tests: Lees. A, Clausen, J: Canadian Geotechnical Journal
2. The design of mechanically stabilised working platforms: Lees.A, Kawalec, J: EuroGeo7
3. Bearing capacity of a geogrid stabilised granular layer on clay, Ground Engineering magazine, UK, 2019 – Lees & Matthias

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