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Zigma Ground Solutions

TuffTrak® and EuroMat® Deflections

Mat Deflections by CBR Value, Applied Force and Contact Area

Report 3588/26 Issue III

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Zigma Ground Solutions
TuffTrak® and EuroMat® Deflections

SUMMARY

Zigma Ground Solutions' TuffTrak® and EuroMat® are temporary road and ground protection mats manufactured from recycled UHMWPE and recycled HDPE respectively. This report describes a study to assess the vertical deflection of the mats and the associated stresses when loaded.

The mats analysed (Reference 1) were:

- TuffTrak® (3000 x 2500 x 38 mm)
- EuroMat® (2410 x 1200 x 12 mm)

The contact areas analysed (Reference 1) were:

- Eurocode (Reference 2) (400 x 400 mm)
- As per previous studies (Reference 7) (US) (10" x 20")

The load cases analysed were:

- Single contact area in the centre of the mat
- Two contact areas with centres 1.94 m apart (Reference 3)

The analysis was performed by applying a force of 50 kN (12.5kN on quartered model) and scaling the resulting stresses and vertical displacements for other load magnitudes (100, 150, 200 and 250kN). These were then used to calculate the load capacity. In the cases with two contact areas, the load was split evenly between them.

The results show:

- The higher the CBR value of the soil, the higher the load capacity of the mat. This is because more of the stress is absorbed by the stiffness of the soil.
- Stiffer soils (higher CBR values) lead to lower deflections in the mats.
- US contact areas give higher stresses than Eurocode contact areas, in part because of the smaller contact areas.
- When the load is spread across two contact areas, the stresses are lower. However, as the contact areas are closer to the edges of the mat, the stresses are reduced to 52-66% of the typical value present with a single contact area rather than 50%, as might be expected.

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VERIFICATION CERTIFICATE

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Issue	Amendment
I	First Issue
II	Client Requested Amendments
III	Section Added to 'Discussion'

CONTENTS

1 INTRODUCTION

Zigma Ground Solutions' TuffTrak® and EuroMat® are temporary road and ground protection mats manufactured from recycled UHMWPE and recycled HDPE respectively. This report analyses the vertical deflection of the mats and the associated stresses when loaded.

The mats analysed were:

- TuffTrak® (3000 x 2500 x 38 mm)
- EuroMat® (2410 x 1200 x 12 mm)

The contact areas analysed were:

- Eurocode (400 x 400 mm)
- As per previous studies (Reference 6) (US) (10" x 20")

The load cases analysed were:

- Single contact area in the centre of the mat
- Two contact areas with centres 1.94 m apart

The analysis was performed by applying a force of 50 kN (12.5kN on quartered model) and scaling the resulting stresses and vertical displacements for other load magnitudes (100, 150, 200 and 250kN). These were then used to calculate the load capacity. In the cases with two contact areas, the load was split evenly between them.

2 SCOPE OF WORK

The scope of work is defined in proposal 3588/07 and is listed below:

1. Review information and planning.
2. Import supplied model of each mat into Solidworks and create mesh
3. Perform the minimum number of simulation runs
4. Post processing of the results including population of the provided matrix table (Reference 1) by linearly scaling the results of the FEA
5. Internal Verification
6. Reporting

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3 METHOD

Three-dimensional models of one quarter of the mats were generated using SolidWorks (Reference 4). Symmetry constraints were then applied so that the model and results were representative of the complete mat. The four loading scenarios for each mat are shown in Figures 1.1 and 1.2. The soil was modelled as a block with the same length and breadth as the mats, and 1m deep (sufficiently far from the loaded area as to not influence the results). The models are shown in Figure 2.

The TuffTrak® mat was modelled as recycled UHMWPE, and the EuroMat® mat has been modelled as recycled HDPE. The soil was modelled as solid blocks with California Bearing Ratios (CBR) of 10, 20, 30, 40 and 60. All material properties are given in Table 1.

The models were exported into SolidWorks Simulation (Reference 5) and meshed using 10 node, solid tetrahedral elements, shown in Figure 3. The fixtures are shown in green and the load locations shown in purple.

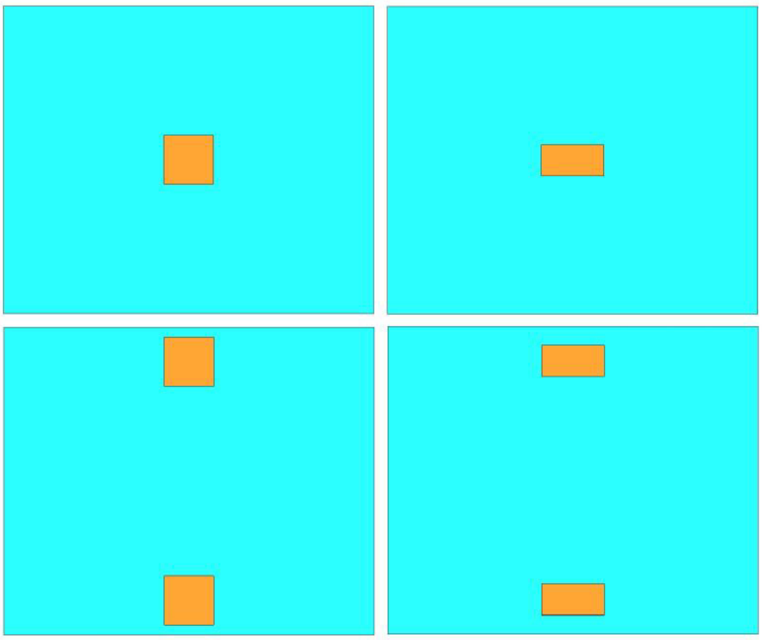

Figure 1.1 – TuffTrak® Loading Scenarios: Eurocode (400x 400 mm, Left) and as previous studies (254 x 508 mm, Right)

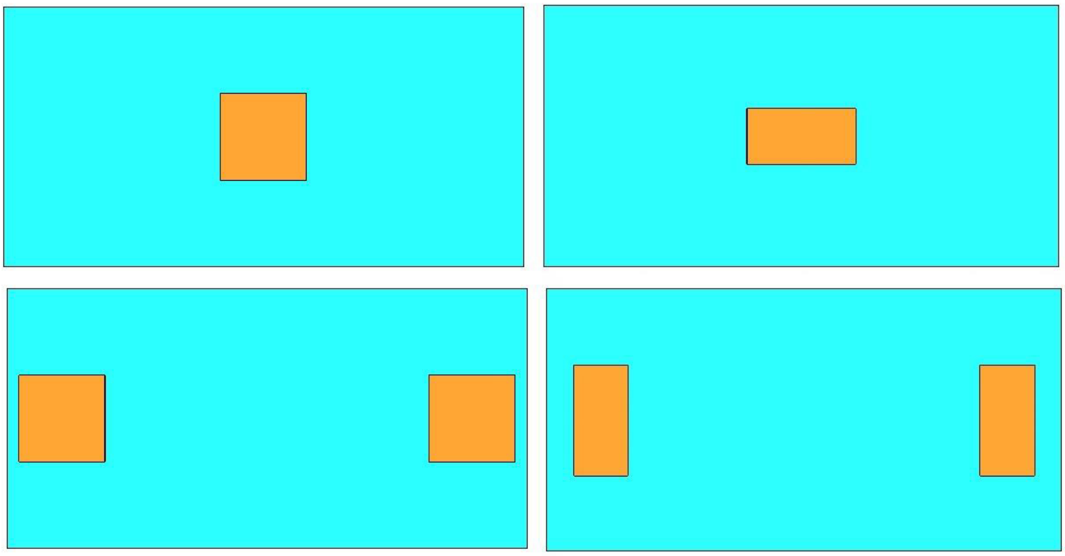

Figure 1.2 – EuroMat® Loading Scenarios: Eurocode (400x 400 mm, Left) and as previous studies (254 x 508 mm, Right)

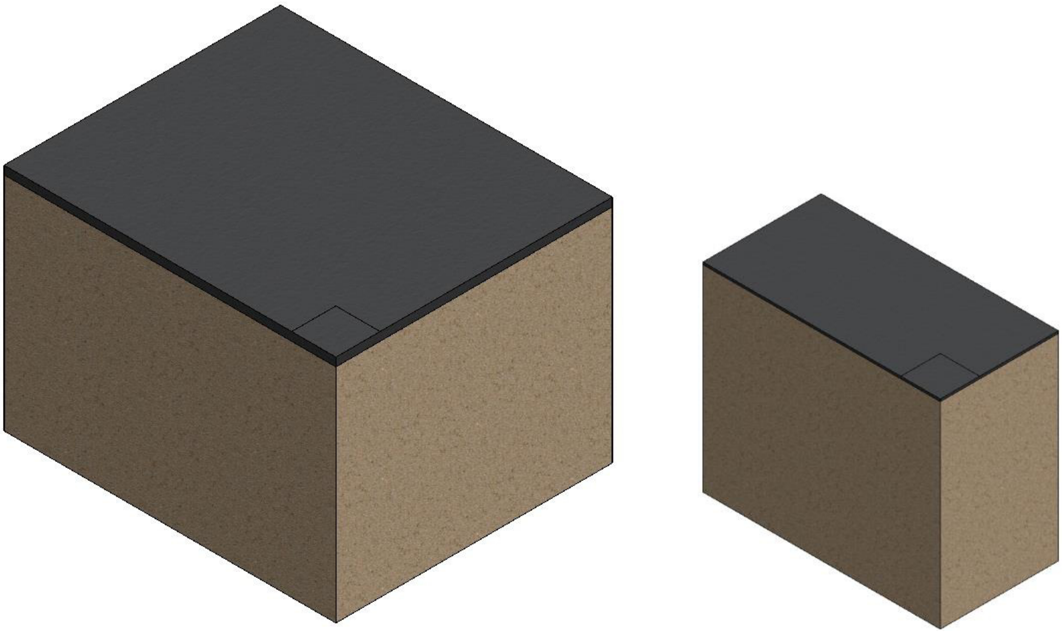

Figure 2 – Models – TuffTrak® (Left) and EuroMat® (Right)

Material Properties	Recycled UHMWPE	Recycled HDPE	Soil, 10 CBR	Soil, 20 CBR	Soil, 30 CBR	Soil, 40 CBR	Soil, 60 CBR
Young's Modulus, E (MPa)	700	850	76.9	119.9	155.4	186.8	242.2
Poisson's Ratio, ν	0.38	0.38	0.3	0.3	0.3	0.3	0.3
Shear Modulus, G (MPa)	253.6	308.0	53.8	83.9	108.8	130.7	169.5
Yield Strength (MPa)	20	24	-	-	-	-	-
Density, ρ (kg/m^3)	950	960	-	-	-	-	-

Table 1 – Material Properties at Ambient Temperature (References 6 & 7)

The soil is modelled as fully compacted and drained, and the relationship between CBR and Young's Modulus was taken to be:

$17.62 \times CBR^{0.64}$ (MPa) (Reference 8)

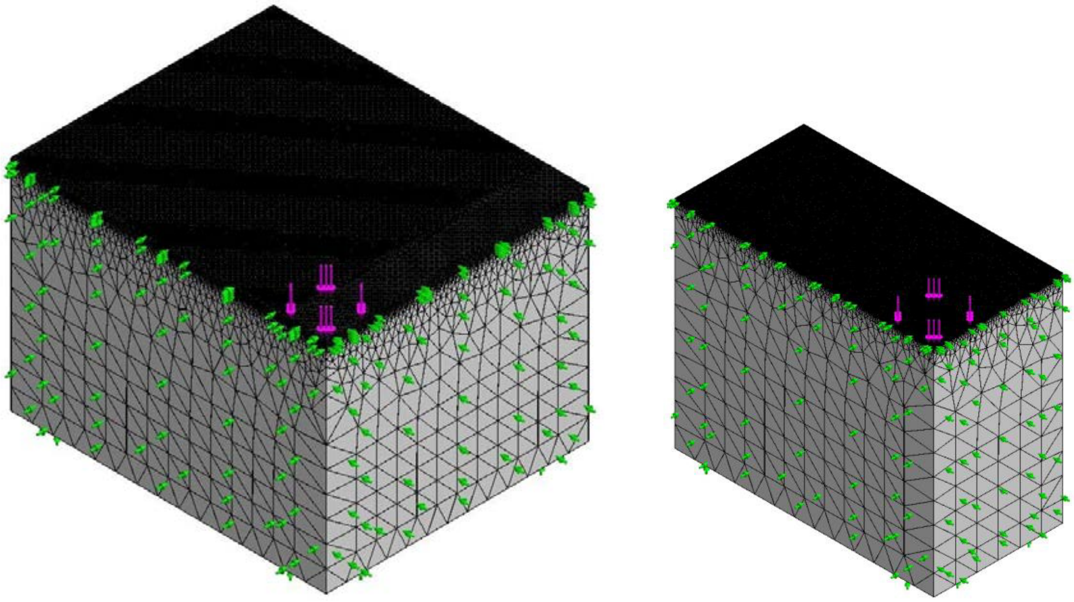

Figure 3 – Mesh Plots TuffTrak® (Left) and EuroMat® (Right)

Loading is shown in pink, symmetry is shown in green

4 RESULTS

Finite Element Analysis was used to determine the values of stress and deflection under a total load of 50kN (5 tonnef), i.e. 50kN on a single contact area and 25kN on each contact area in the double loading scenarios. As the materials are assumed not to have yielded, linear material properties allow the stresses from the analysis to be scaled to give stresses and deflections associated with loads of 100, 150, 200 and 250kN (10, 15, 20 and 25 tonnef respectively).

The 'Yield Scaling Factor' was calculated as the yield strength of the mat divided by the load conditions This factor can then be used to determine the load capacity of the mat and its deflection at yield.

All figures are stress distributions for 5 tonnes on CBR 10 soil, and can be taken as typical for each load case. The plotted deflected shapes are exaggerated for clarity by a factor which varies and is shown in each figure.

TuffTrak® - Single Eurocode Contact

	Single Eurocode Contact (400x400)												
	Load (Tonnes)												
	5		10		15		20		25			At Yield	
CBR	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Yield Scaling Factor	Load (Tonnes)	Displacement (mm)
10	0.51	1.3	1.02	2.6	1.53	3.9	2.04	5.2	2.55	6.5	39.3	196.5	51.2
20	0.34	0.8	0.67	1.7	1.01	2.5	1.35	3.4	1.69	4.2	59.3	296.7	50.1
30	0.29	0.7	0.58	1.3	0.87	2.0	1.16	2.6	1.45	3.3	69.0	344.8	45.3
40	0.27	0.6	0.54	1.2	0.82	1.8	1.09	2.4	1.36	2.9	73.5	367.6	43.3
60	0.25	0.4	0.50	0.9	0.75	1.3	1.00	1.7	1.25	2.1	80.0	400.0	34.2

Table 2.1 showing peak stresses and displacements associated with loading a TuffTrak® mat with a single Eurocode contact area

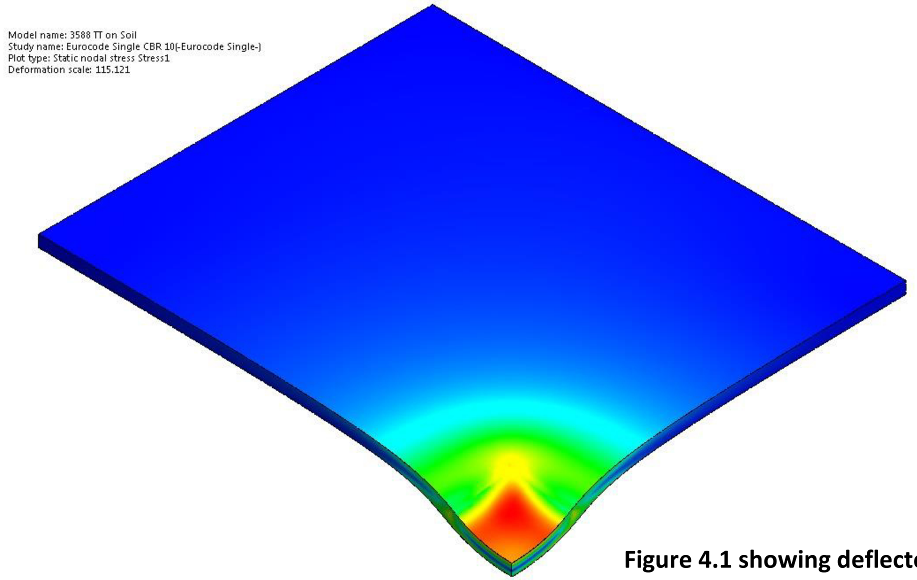

Figure 4.1 showing deflected shape

TuffTrak® - Double Eurocode Contact

	Double Eurocode Contact (400x400)												
	Load (Tonnes)												
	5		10		15		20		25			At Yield	
CBR	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Yield Scaling Factor	Load (Tonnes)	Displacement (mm)
10	0.25	0.8	0.50	1.5	0.75	2.3	1.00	3.0	1.25	3.8	80.3	401.6	60.7
20	0.19	0.5	0.38	1.0	0.57	1.5	0.76	2.0	0.96	2.5	104.7	523.6	51.8
30	0.17	0.4	0.33	0.8	0.50	1.2	0.66	1.5	0.83	1.9	120.5	602.4	46.4
40	0.15	0.3	0.30	0.6	0.45	1.0	0.60	1.3	0.76	1.6	132.5	662.3	42.9
60	0.14	0.3	0.27	0.5	0.41	0.8	0.55	1.0	0.69	1.3	146.0	729.9	37.1

Table 2.2 showing peak stresses and displacements associated with loading a TuffTrak® mat with two Eurocode contact areas

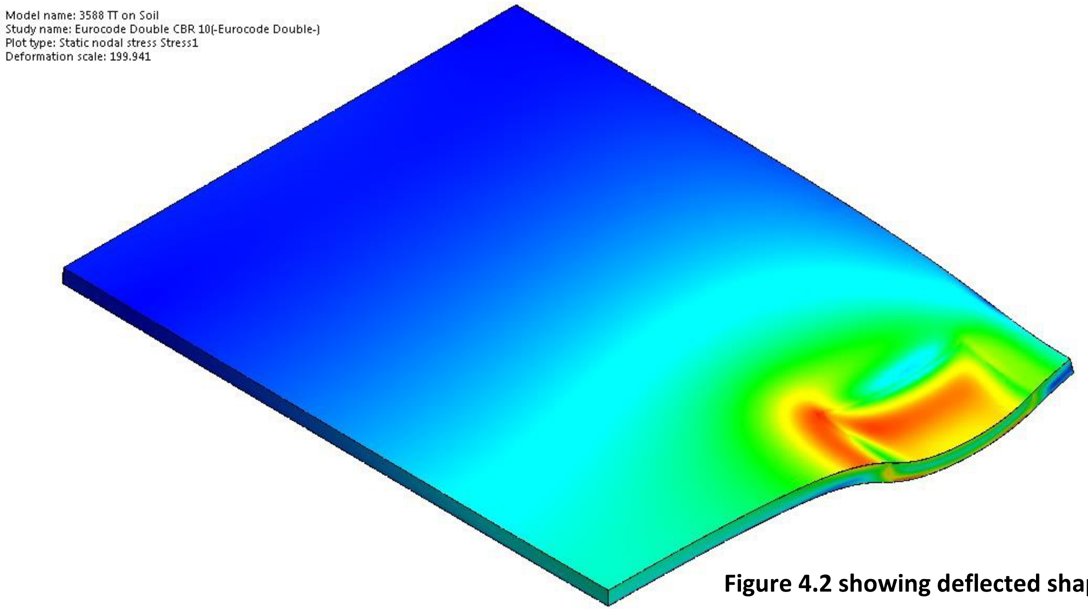

Figure 4.2 showing deflected shape

TuffTrak® - Single US Contact

	Single American Contact (254x508)												
	Load (Tonnes)											At Yield	
	5		10		15		20		25				
CBR	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Yield Scaling Factor	Load (Tonnes)	Displacement (mm)
10	0.69	1.4	1.37	2.8	2.06	4.1	2.75	5.5	3.44	6.9	29.1	145.6	40.2
20	0.44	0.9	0.88	1.8	1.32	2.7	1.76	3.6	2.20	4.5	45.6	227.8	41.0
30	0.36	0.7	0.71	1.4	1.07	2.1	1.43	2.8	1.79	3.5	56.0	280.1	39.3
40	0.34	0.6	0.67	1.2	1.01	1.8	1.34	2.3	1.68	2.9	59.7	298.5	35.0
60	0.31	0.5	0.62	0.9	0.92	1.4	1.23	1.8	1.54	2.3	64.9	324.7	29.7

Table 2.3 showing peak stresses and displacements associated with loading a TuffTrak® mat with a single US contact area

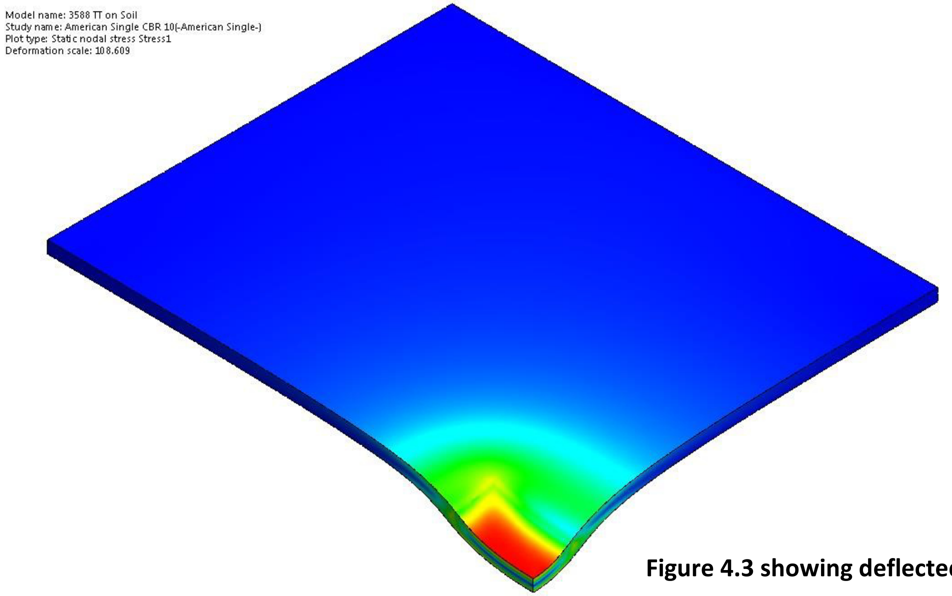

Figure 4.3 showing deflected shape

TuffTrak® - Double US Contact

	Double American Contact (254x508)												
	Load (Tonnes)											At Yield	
	5		10		15		20		25				
CBR	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Yield Scaling Factor	Load (Tonnes)	Displacement (mm)
10	0.32	0.8	0.64	1.6	0.96	2.4	1.28	3.2	1.60	4.0	62.5	312.5	49.9
20	0.24	0.5	0.47	1.0	0.71	1.6	0.94	2.1	1.18	2.6	85.1	425.5	44.6
30	0.20	0.4	0.40	0.8	0.60	1.2	0.80	1.6	1.00	2.0	100.0	500.0	40.9
40	0.18	0.3	0.36	0.7	0.54	1.0	0.72	1.4	0.91	1.7	110.5	552.5	38.0
60	0.16	0.3	0.32	0.5	0.49	0.8	0.65	1.1	0.81	1.3	123.5	617.3	33.2

Table 2.4 showing peak stresses and displacements associated with loading a TuffTrak® mat with two US contact areas

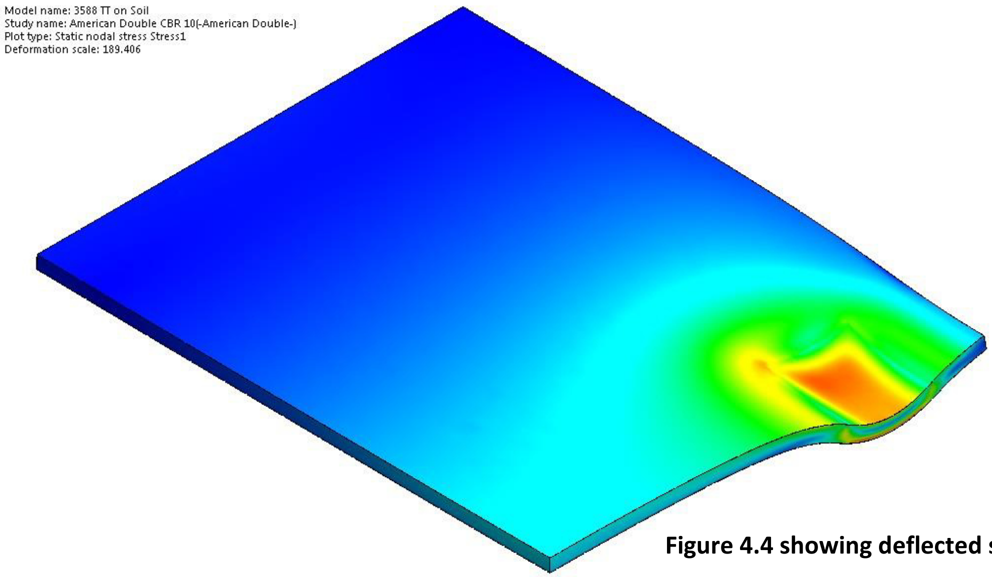

Figure 4.4 showing deflected shape

EuroMat ® - Single Eurocode Contact

Single Eurocode Contact (400x400)													
	Load (Tonnes)												
	5		10		15		20		25			At Yield	
CBR	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Yield Scaling Factor	Load (Tonnes)	Displacement (mm)
10	0.71	1.4	1.42	2.9	2.13	4.3	2.84	5.8	3.55	7.2	33.8	169.0	48.8
20	0.50	0.9	0.99	1.9	1.49	2.8	1.98	3.7	2.48	4.7	48.4	241.9	45.1
30	0.41	0.7	0.82	1.4	1.24	2.2	1.65	2.9	2.06	3.6	58.3	291.3	42.1
40	0.37	0.6	0.74	1.2	1.11	1.8	1.48	2.4	1.85	3.0	65.0	325.2	39.2
60	0.32	0.5	0.63	0.9	0.95	1.4	1.26	1.9	1.58	2.3	76.2	381.0	35.6

Table 2.5 showing peak stresses and displacements associated with loading a EuroMat® with a single Eurocode contact area

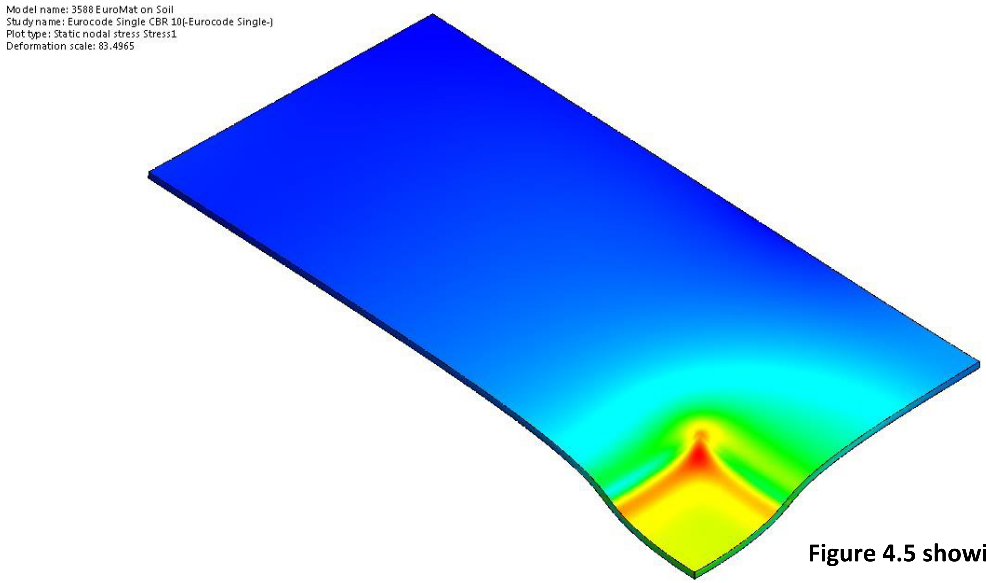

Figure 4.5 showing deflected shape

EuroMat® - Double Eurocode Contact

Double Eurocode Contact (400x400)													
	Load (Tonnes)												
	5		10		15		20		25			At Yield	
CBR	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Yield Scaling Factor	Load (Tonnes)	Displacement (mm)
10	0.43	1.0	0.87	1.9	1.30	2.9	1.73	3.9	2.17	4.8	55.4	277.1	53.4
20	0.32	0.6	0.65	1.3	0.97	1.9	1.30	2.5	1.62	3.2	74.1	370.4	46.9
30	0.27	0.5	0.54	1.0	0.82	1.5	1.09	2.0	1.36	2.5	88.2	441.2	43.8
40	0.24	0.4	0.48	0.8	0.72	1.2	0.96	1.7	1.21	2.1	99.6	497.9	41.4
60	0.20	0.3	0.41	0.6	0.61	1.0	0.81	1.3	1.02	1.6	118.2	591.1	38.3

Table 2.6 showing peak stresses and displacements associated with loading a EuroMat® with two Eurocode contact areas

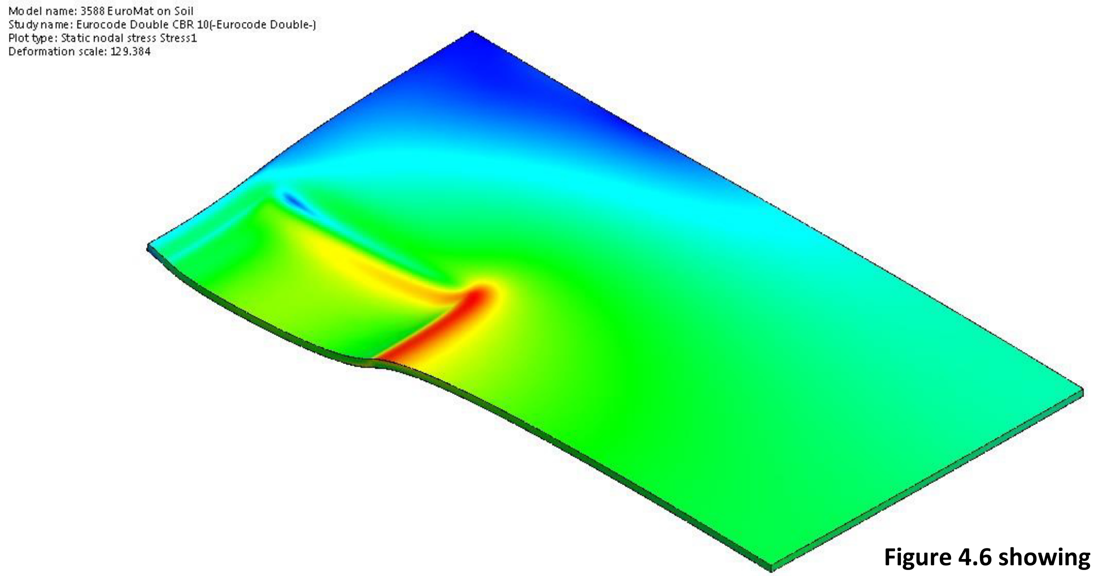

Figure 4.6 showing deflected shape

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EuroMat® - Single US Contact

	Single American Contact (254x508)												
	Load (Tonnes)												
	5		10		15		20		25			At Yield	
CBR	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Yield Scaling Factor	Load (Tonnes)	Displacement (mm)
10	0.86	1.6	1.71	3.1	2.57	4.7	3.42	6.2	4.28	7.8	28.1	140.4	43.5
20	0.60	1.0	1.19	2.0	1.79	3.0	2.38	4.0	2.98	5.0	40.3	201.7	40.4
30	0.49	0.8	0.97	1.6	1.46	2.3	1.94	3.1	2.43	3.9	49.4	246.9	38.3
40	0.43	0.6	0.87	1.3	1.30	1.9	1.73	2.6	2.17	3.2	55.4	277.1	35.9
60	0.37	0.5	0.73	1.0	1.10	1.5	1.47	2.0	1.84	2.5	65.4	327.0	32.8

Table 2.7 showing peak stresses and displacements associated with loading a EuroMat® with a single US contact area

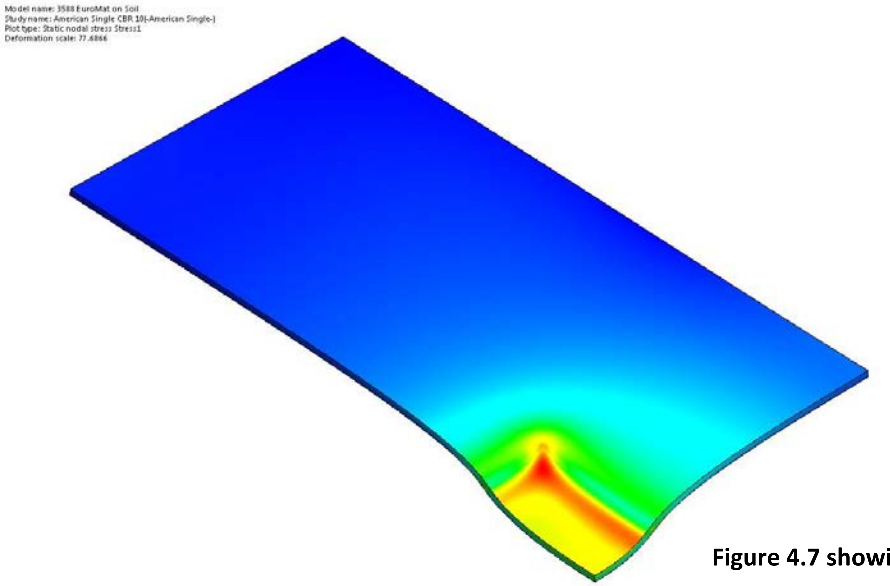

Figure 4.7 showing deflected shape

EuroMat® - Double US Contact

Double American Contact (254x508)													
	Load (Tonnes)											At Yield	
	5		10		15		20		25				
CBR	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Peak Stress (MPa)	Displacement (mm)	Yield Scaling Factor	Load (Tonnes)	Displacement (mm)
10	0.45	1.0	0.89	1.9	1.34	2.9	1.78	3.8	2.23	4.8	53.9	269.7	51.7
20	0.34	0.6	0.68	1.3	1.01	1.9	1.35	2.5	1.69	3.1	71.0	355.0	44.4
30	0.29	0.5	0.57	1.0	0.86	1.5	1.15	1.9	1.44	2.4	83.6	418.1	40.7
40	0.26	0.4	0.51	0.8	0.77	1.2	1.02	1.6	1.28	2.0	94.1	470.6	38.3
60	0.22	0.3	0.43	0.6	0.65	0.9	0.87	1.3	1.09	1.6	110.6	553.0	34.9

Table 2.8 showing peak stresses and displacements associated with loading a EuroMat® with two US contact areas

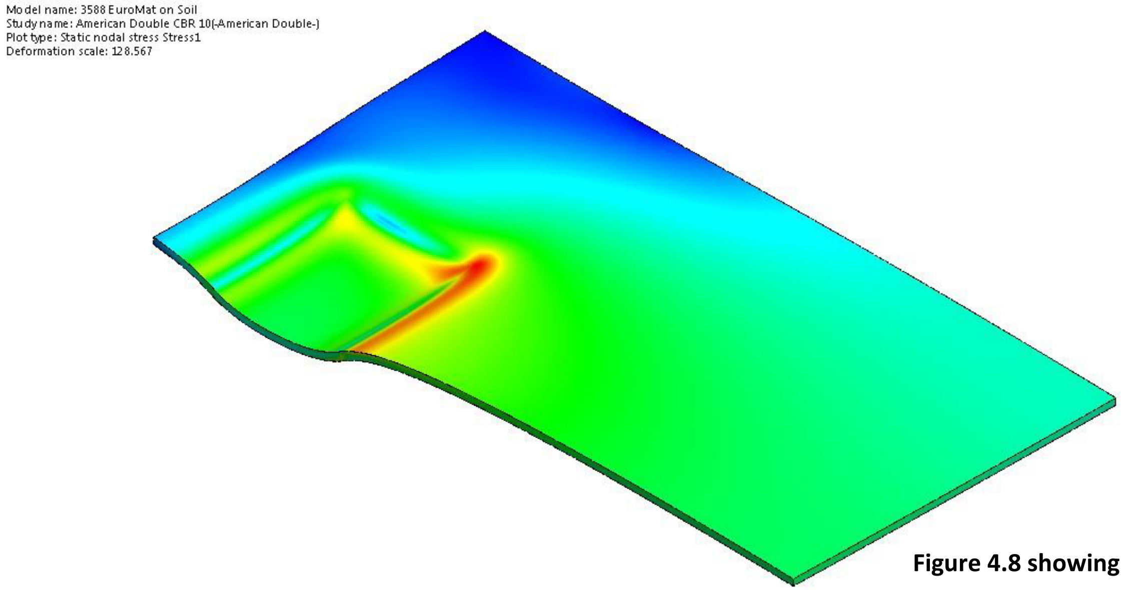

Figure 4.8 showing deflected shape

5 DISCUSSION

All of the material properties given in Table 1 are properties at ambient temperature. At temperatures below 0°C, the surface of the ground will freeze and result in a higher CBR value, which is favourable. The results provided are therefore only indicative of loading on the specified soils at ambient temperature.

Different temperatures affect the mats considerably. Figure 5 shows that UHMWPE is approximately twice as stiff at -30°C as 23°C, increasing the effect of any non-uniformity in the soil as the mat cannot conform as easily.

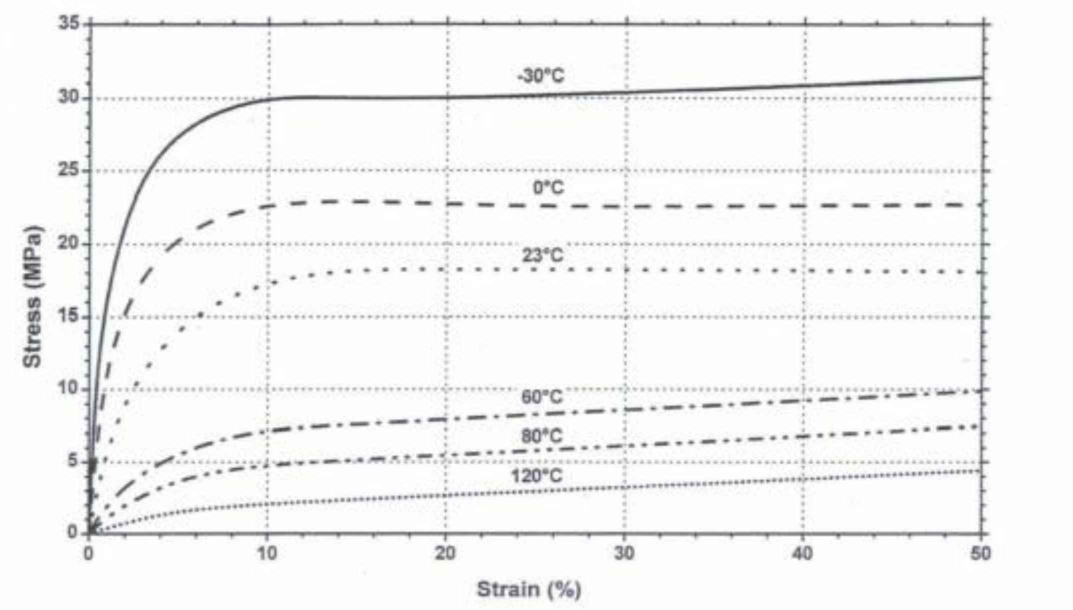

Figure 5 – Stress vs. strain at various temperatures of UHMWPE (Reference 9)

If the supporting soil has significant undulations when it freezes, a scenario could arise where the mat has barely any support from the soil, and therefore the load could induce stresses within the mat greater than its yield strength. An illustration of this is given in Figure 6.

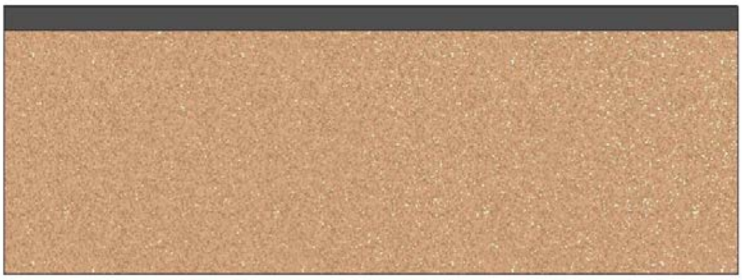

Figure 6.1 – Mat is placed on soil at ambient temperature

Figure 6.2 – Soil and mat deform under tyre load

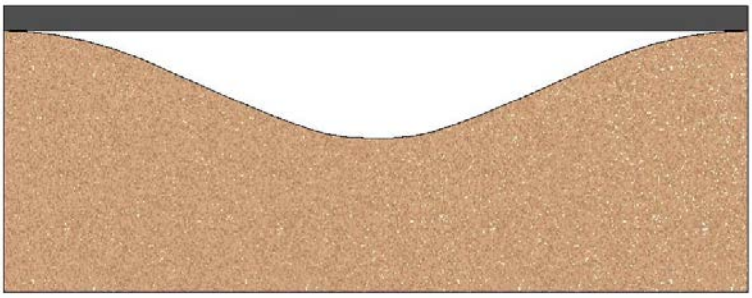

Figure 6.3 – On unloading, a permanent deformation is left in the soil

Figure 6.4 – At much lower temperatures, the ground no longer deforms when the load is reapplied. The mat experiences much higher stresses

6 CONCLUSIONS

A series of analyses have been performed to evaluate the load capacities and deflections of Zigma Ground Solutions' TuffTrak® and EuroMat® products on a variety of contact areas, number of contact areas and soils of different bearing capacities.

The results show:

- The higher the CBR value of the soil, the higher the load capacity of the mat. This is because more of the stress is absorbed by the stiffness of the soil.
- Stiffer soils (higher CBR values) lead to lower deflections in the mats.
- US contact areas give higher stresses than Eurocode contact areas, in part because of the smaller contact areas.
- When the load is spread across two contact areas, the stresses are lower. However, as the contact areas are closer to the edges of the mat, the stresses are reduced to 52-66% of the typical value present with a single contact area rather than 50%, as might be expected.

7 REFERENCES

1. Initial enquiry from Zigma Ground Solutions 8/10/2014, 3588/04

2. BS EN 1991-2:2003, Eurocode 1, 4.3.2

3. Information Requests 3588/14 & 3588/16

4. SolidWorks ® 2014 SP4, SolidWorks Corporation, Dassault Systèmes SolidWorks Corporation, 175 Wyman Street, Waltham, MA 02451

5. SolidWorks Simulation® 2014 SP4, SolidWorks Corporation, Dassault Systèmes SolidWorks Corporation, 175 Wyman Street, Waltham, MA 02451

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7. DC White CE, Job #3311, TuffTrak MkII FEA Technical Note Issue IV, 12/8/13, E. Hirons

8. Black, W.P.M. (1961), "The calculation of laboratory and in-situ values of California Bearing Ratio from bearing capacity data," Geotechnique, Vol. 11, pp. 14-21.

9. Image supplied by Zigma Ground Solutions 19/12/2014, 3588/25