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FULL-SCALE TRAFFICKING OF GEOSYNTHETIC-REINFORCED ROAD SECTIONS

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ABSTRACT

Full-scale trafficking tests have been recognized as necessary to fully characterize the complex soil-geosynthetic-aggregate interaction that is expected to produce a quantifiable benefit to a road system. The benefit – if and when it exists – must be quantifiable and clearly defined in terms of the tested road structural components. To this end, the construction of full-scale trafficking test sections must be done in such a way as to minimize variations in the strength, depth and consistency of the subgrade, compacted aggregate, and paved surface (when used). Further, the loading condition and the performance measurements must relate directly to generally recognized road design methods. This paper presents a detailed description of a trafficking facility, the test set-up, and an example of test results.

1.0 TESTING OVERVIEW

Full-scale trafficking tests have been recognized as necessary to fully characterize the complex soil-geosynthetic-aggregate interaction that is expected to produce a quantifiable benefit to a road system. The benefit – if and when it exists – must be quantifiable and clearly defined in terms of the tested road structural components. To this end, the construction of full-scale trafficking test sections must be done in such a way as to minimize variations in the strength, depth and consistency of the subgrade, compacted aggregate, and paved surface (when used). Further, the loading condition and the performance measurements must relate directly to generally recognized road design methods. The trafficking test facility and procedures used at TRI's Denver Down's Research Facility (DDRF) and described herein have been designed with these objectives in mind. This "real world" test facility was designed to simulate actual paved and unpaved road exposure conditions and variables in order to evaluate the benefits of geosynthetics relative to unreinforced sections and one another. The trafficking procedure is more severe than conditions encountered on most actual road or paved areas since traffic is channelized with no significant wander. The facility incorporates important features, including: full scale highway construction equipment and practices; exposure to weather; incorporation of local subgrade soils, aggregate and pavement; a driven trafficking vehicle capable of applying equal 80 kN axle loads to eliminate the steering axle effect; "super-single" tires, GeoKon 4800 Pressure Cells for evaluating relevant soil pressures, and laser profiling of the rutting pattern.

2.0 TEST TRACK LAYOUT AND TEST MATRIX

2.1 Test Track Layout

The “oval” layout of the test track provides a uni-directional wheel loading pattern during continuous trafficking. The test track includes inside and outside lanes and can accommodate unpaved test sections to examine subgrade stabilization and paved sections to examine base reinforcement. Only the straight sections of the test track are used as test sections making it easier to keep the wheels in the established wheel paths. Straight sections are long enough 30.5+ m (100+ ft) to accommodate multiple test sections. Each test section accommodates two wheel paths. A total of 70 m (230 ft) of test track are included in the test program. Both geosynthetic-reinforced test sections and unreinforced “control” sections are included. The test track is oval in shape and consists of two 30.5+ meter (100 foot) long by 4.6 meter (15 foot) wide straight test lanes and radius (non-tested) ends for loading vehicle turn around. As illustrated in Figure 1, the test track layout benefits from continuous one-way trafficking. Typically, each test section is divided into two equal, 2.3 meter (7.5 foot) wide test strips as shown in Figure 2.

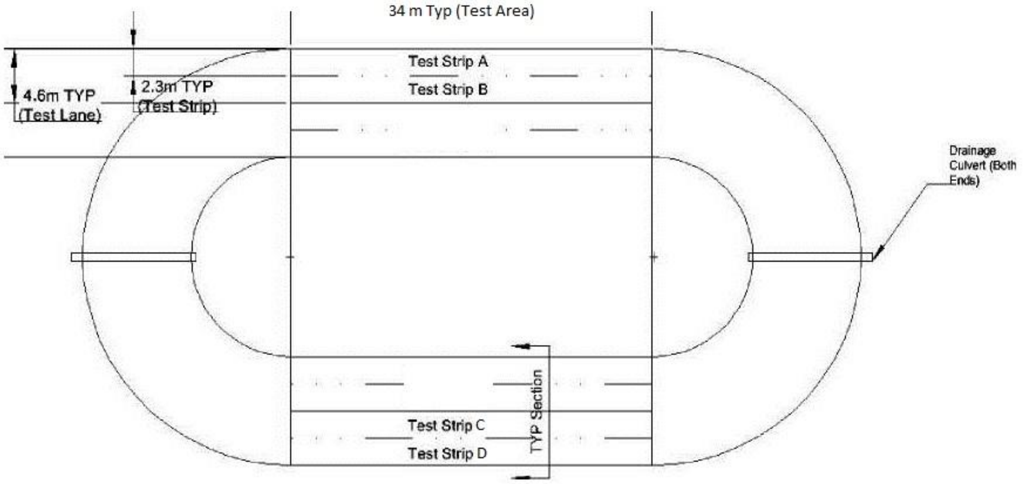

Figure 1. Test Track Layout

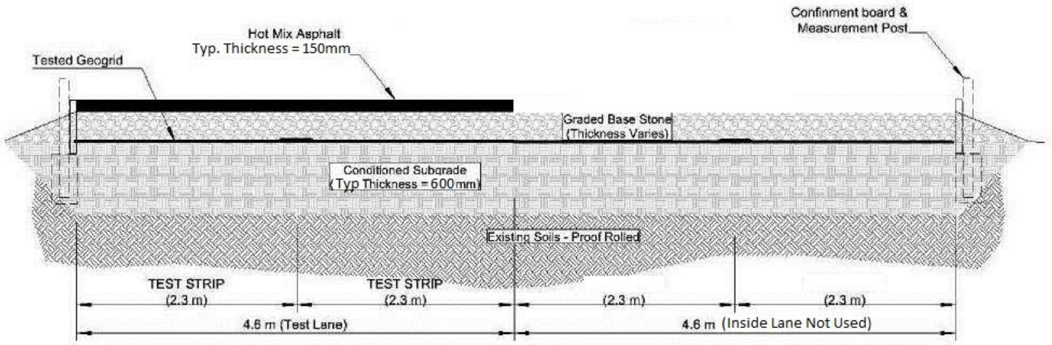

Figure 2. Typical Test Track Section

2.2 Typical Test Matrix

A typical test program is designed to provide data that can be used for both empirically demonstrating unpaved road system improvement via the calculation of a traffic benefit ratio, as well as, facilitating the theoretical derivation of associated structural numbers for paved road design. Individual test section details are provided in Table 1.

Table 1. Example Test Matrix

Station - Track	1 - C/D	2 - C/D	3 - C/D	4 - C/D	5 - C/D	6 - C/D	7 - C/D	8 - C/D	9 - C/D
Subgrade CBR	1	1	1	1	1	1	3	3	3
Asphalt Thickness, D_1, mm	0	0	0	0	0	0	0	0	0
Aggregate Thickness, D_2, mm	300	300	300	450	450	450	300	300	300
Track C Lt. Grid Style	X	Y	-	-	Y	X	X	Y	-
Track D Hvy. Grid Style	Y	X	-	-	X	Y	Y	X	-
Station - Track	1 - A/B	2 - A/B	3 - A/B	4 - A/B	5 - A/B	6 - A/B	7 - A/B	8 - A/B	9 - A/B
Subgrade CBR	5	5	5	5	5	5	25	25	25
Asphalt Thickness, D_1,mm	75	75	75	75	75	75	75	75	75
Aggregate Thickness, D_2,mm	300	300	300	450	450	450	300	300	300
Track A Lt. Grid Style	X	Y	-	-	Y	X	X	Y	-
Track B Hvy. Grid Style	Y	X	-	-	X	Y	Y	X	-

3.0 TEST TRACK CONSTRUCTION

The subgrade, instrumentation, geosynthetics, aggregate, and asphalt are important variables in the testing. Typical materials and construction procedures for each of these components is described in the following sections.

3.1 Test Track Subgrade

The general test track area is initially constructed of silty sand (SM) compacted to greater than 90% standard Proctor compaction and graded for efficient drainage. The test track is then constructed within this area starting with the excavation and replacement of the compacted fill with the controlled subgrades to be used in the testing. Typically, test subgrades are constructed out of a fine-grained native soil that is classified as sandy fat clay (CH), as detailed in sieve analysis below, and moisture conditioned to achieve the desired strength. Very weak, weak, marginally acceptable, and moderately strong subgrades corresponding to CBRs of 1, 3, 5 and 25 have been used in testing. Subgrades having CBRs of 1, 3 and 5 were used with the unpaved sections while subgrades having CBRs of 3 and 25 were used with the paved sections.

3.2 Subgrade Construction Quality Control

The test tracks are created by first excavating existing fill to create a pit approximately 1 m deep x 10 m wide by 50 m long (3.2 ft x 32 ft x 164 ft). The bottom of the test pit is compacted using a vibratory roller to create a level surface of uniform strength. Pit bottom firmness is verified at random locations using a dynamic cone penetrometer (DCP).

A laboratory testing program is conducted to determine the relationship between moisture content and CBR strength for the subgrade soil. This relationship is then used to guide the construction of a test pad to develop the technique to be used with the full-scale equipment to place, wet, and compact the test soils. The DCP device is used to monitor in-place shear strength of the subgrade as it is being constructed. Loose and compacted lift thickness are monitored by taking vertical measurements from fixed horizontal positions maintained by pulling a string between posts set along the test track at the center of each eventual test section.

The test subgrade is prepared by dumping sandy-fat clay soil fill into the pit and spreading a loose lift of the fill using a tracked loader. The loose lift is then tilled after a predetermined amount of water is sprayed onto the lift. The moistened loose lift is then given time to equilibrate. Prior to being compacted, soil samples are taken to determine the average moisture content of the layer. Depending on the moisture content measured, water is then added using a large water truck (if too low), or the tilled surface was allowed to dry (if too wet), or the lift is compacted.

Compaction is performed with a single cylinder, smooth-drum, vibratory roller. Immediately after compaction, the DCP is used to determine in-place strength. If the strength of the test subgrade is not relatively close to the specified limits, two basic remedies are used: 1) shear strength too low—re-till the layer, allow soil to dry, and recompact the soil layer, or 2) shear strength too high—re-till the layer, add water, allow the water to penetrate the tilled soil mass, re-till the soil again, and recompact the soil layer. Once a lift is completed, DCP measurements are performed at random locations. These DCP measurements are converted to equivalent CBR values.

3.3 Instrumentation / Pressure Cells

Pressure cells having a range of 0 to 207 kPa (0 to 30 psi) are sometimes used selectively under some of the test sections to monitor the change in pressure at the subgrade interface. Pressure cells are installed on the subgrade surface beneath the unpaved test sections, in the truck wheel path approximately 300 mm (1 ft) away from the center of the test section (where the rut depth measurements were taken). To protect the cells from the angular gravel, they are covered with a thin layer of silt size material (pond fines) and the leads from the cells are run through flexible conduit to the edge of the track. Leads are then run to a data acquisition system (See Figure 3). Using these installation techniques, all pressure cells remain active and in good working condition after construction.

3.4 Geosynthetics

Both geotextiles and geogrids can be included in test sections. Samples of each geosynthetic are also collected and tested for appropriate index properties. Detailed reports presenting all index test results are included with the trafficking results to facilitate “calibration” of design models. Commonly run index tests include:

- Single Rib Tensile Properties (ASTM D6637, Method A);
- Wide Width Tensile Properties (ASTM D6637, Method B or ASTM D4595);
- Mass/Unit Area (ASTM D5261);
- Rib Thickness (Micrometer - 0.25 inch diameter base);
- Junction / Node Thickness (Micrometer - 0.25inch diameter base);
- Rib Pitch – Spacing (Calipers) and Rib Width (Micrometer - 0.25 inch diameter base);
- Carbon Black Content (ASTM D1603, Two Burn);
- Torsional Stiffness (COE Method) - (20.4 & 5.1 cm-Kg Torque);
- Flexural Rigidity (ASTM D7748)

3.5 Geosynthetic Installation Quality Control

Geosynthetics are installed in each section by carefully rolling them out in the direction of traffic making sure to orient the panel as it would typically be used in road sections. Any wrinkles are removed by gently pulling on the end of the material. The edges of the geosynthetics are secured in place using landscape staples to keep them from rolling up. Geosynthetic panels completely cover each test section. This assures that the vehicle will be centered on the material during trafficking. The geosynthetics in adjacent test sections have a small (approx. 50 mm) overlap.

Figure 3. Installation of Pressure Cells

Figure 4. Geogrids Positioned and Covered with Based Aggregate

3.6 Base Course Aggregate

The base course aggregate used in testing is a typical DOT crushed gravel, such as that described in Table 2.

Table 2. Aggregate Base Course Target Gradation

Sieve Size (Opening)	Percentage Passing (%)
1.5 in.	95 – 100
1 in.	70 – 100
1/2 in.	48 – 75
No. 4 (4.75 mm)	30 – 60
No. 30 (600 mm)	11 – 30
No. 200 (75 mm)	0 – 20
LL max	25
PI max	6

3.7 Base Course Aggregate Construction Quality Control

The test aggregate is delivered and stockpiled adjacent to the test track. After placement of the geosynthetics and preparation (moisturizing) of the aggregate, a single layer of aggregate 20 cm (8 in) thick is placed on top of the geosynthetics from the end using a tracked skid loader (see Figure 4). The installation of the aggregate is carefully monitored to prevent damage to the geosynthetics during construction. Driving directly on the geosynthetic is not allowed. Final grading of the surface of the aggregate is done with the skid loader. The skid loader is light enough to assure that no construction damage is inflicted on the geosynthetics and that little, if any, rutting deformation occurs before trafficking is initiated.

The same single-drum vibratory roller used to construct the test subgrade is used to compact the aggregate. As with the subgrade, loose and compacted lift thicknesses are monitored by taking vertical measurements from fixed horizontal positions maintained by pulling a string between posts set along the test track at the center of each eventual test section. Equal compactive effort is applied to all sections. The DCP is used to estimate the as-placed base course CBR after placement and compaction of aggregate on each section.

3.8 Asphalt Pavement

The asphalt commonly used for the paved surface is an HMA surface course such as that described in Table 3.

Table 3. Hot-Mix Asphalt Material Properties

Aggregate Sieve Requirement	
Sieve Size (Opening)	Percentage Passing (%)
3/4 in.	100.0
1/2 in.	97 - 100
3/8 in.	83 - 100
No. 4 (4.75 mm)	58 - 80
No. 8 (2.00 mm)	42 - 62
No. 30 (850 mm)	20 - 40
No. 100 (150 mm)	5 – 20
No. 200 (75 mm)	2 - 9
Binder Requirements	
Binder Limits, %	5.0 – 6.8
Binder Grade	PG 64-22
Air Voids	3.5 – 4.5

3.9 Test Pavement Construction Quality Control

The paved surface is placed and compacted using standard paving equipment and techniques. As with the subgrade and aggregate, asphalt lift thicknesses are monitored by taking vertical measurements from fixed horizontal positions maintained by pulling a string between posts set along the test track at the center of each eventual test section. Compacted asphalt densities are accepted as-is after eight passes of the compactor.

4 TRAFFICKING AND MONITORING

4.1 Trafficking Vehicle

A two axle commercial truck has been modified for use as a loading vehicle for trafficking of the test sections. Modifications include adding carefully distributed weight to the vehicle such that each axle applies an equal, equivalent single axle load (ESAL) of 80 kN (9000 lbs). In addition, all tires (steering and rear dual) are equal sized, super single tires inflated to a pressure of 690 kPa (100 psi). Weight distribution and tire pressure is checked and adjusted as necessary throughout the trafficking process. These modifications ensure that each passage of the loading vehicle applies two identical ESALs to the test sections thereby negating the complicating effects of a steering/load axle combination often associated with full scale testing. This is shown in Figure 5.

Figure 5. Loaded truck used for trafficking

Figure 6. Centerline Deflection and Rut Measurement

4.2 Trafficking Procedure

Lines are painted on the road surface prior to trafficking so that the truck is properly positioned on the test sections, so as to be centered over the geosynthetics (and pressure cells). No attempt is made to introduce or control wander of the trafficking vehicle. Therefore, testing is indicative of typical channelized traffic. The truck traverses the test sections for a predetermined number of passes before stopping for rut depth measurements.

The typical test plan is to traffic the test sections until each of the individual test sections reaches an average of 75 mm (3 in.) (unpaved sections) or 25 mm (1 in.) (paved sections) of rut as measured by changes in elevation. Test sections that fail early are repaired to allow the truck to pass over them without getting stuck. This repair is accomplished by adding extra base course aggregate in the rutted areas and smoothing the area out with a skid-steer tractor.

4.3 Data Collection

Wheel centerline and transverse profile rut data is collected on the surface of each test section using a stiff beam placed on the measurement posts shown in Figure 6. A laser distance measuring device accurate to 1.0 mm (0.04 in.) is placed at predetermined points along the measurement beam to gather these measurements. A full transverse surface profile is collected on each test section before trafficking and at various intervals during trafficking.

5.0 DATA ANALYSIS AND PERFORMANCE RATIOS

5.1 Summary of Test Section Characteristics

A typical cross section of the test sections is illustrated in Figure 7. The thickness and strength of each layer is integral to any performance evaluation. Since it is commonly used in design methods for flexible pavements, all strength data gathered from the test sections is reported in terms of CBR. As noted earlier, CBR values are determined from measurements made with a Dynamic Cone Penetrometer (DCP) before and during testing. Base course CBR measurements are averaged over the entire thickness of the base course.

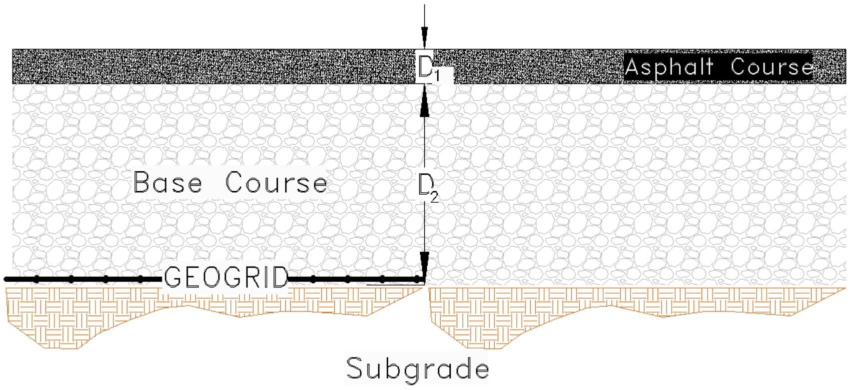

Figure 7. Typical Test Sections

5.2 Analysis of Performance

Test section characteristics are chosen by the client to be characteristic of road structures to be designed based on the results. The goal is to apply trafficking until the total rutting failure criteria (25mm paved / 75mm unpaved) is achieved or until load/deflection trends are reasonably apparent. Results of total rut depth verses single axle loadings for each section are summarized and used for performance analysis.

A common analysis approach is to plot total rut depth measurements vs. associated cumulative single axle loading. "Best fit" regression curves are then applied to the data to facilitate (via regression equations) accurate comparison of the performance of the test sections. The equations also make it possible to extrapolate, as required, when failure criteria had not been achieved prior to the end of trafficking. The data may be used by designers to analyze and design reinforced flexible pavements using the tested geosynthetics. In general accordance with the AASHTO R50 Standard Practice (AASHTO, 2010), the design procedure may be summarized as follows.

- Design the thickness of an unreinforced pavement section based on representative material parameters for a pavement design unreinforced by geosynthetics. The designer may use whatever design method he normally uses to design pavements in this step, for example AASHTO (1993).

- Determine the desired benefits of incorporating a geosynthetic. According to AASHTO (2010), "The geosynthetic is expected to provide one or both of these benefits: (1) improved or extended service life of the pavement, or (2) reduced thickness of the structural section". In addition, some designers choose to partially include both of these benefits.
- Apply an appropriate "performance factor" derived from comparing pavements reinforced with a specific geosynthetic to unreinforced pavements, preferably tested under full-scale trafficking conditions.

Traffic Benefit Ratio (TBR), Base Course Reduction percentage (BCR), and Layer Coefficient Ratio (LCR) are recognized "performance factors" used to incorporate experimental evidence of geosynthetic benefits into flexible pavement designs. Derivation of these factors based on the test results derived from full-scale trafficking is briefly discussed in the following sections.

5.2.1 Traffic Benefit Ratio (TBR)

The TBR is defined as the "ratio of the number of load cycles of a reinforced pavement structure to reach a defined failure state to the number of loads for the same unreinforced section to reach the same defined failure state" (AASHTO, 2010). The ESALs to achieve 75 mm of rut depth are used to calculate TBRs for unpaved sections and 25 mm of rut depth are used to calculate the TBRs for paved sections.

The typical TBR results shown in Table 4 demonstrate that geosynthetics lead to improved pavement performance. The ranges of TBR values are very reasonable when compared to nearly 30 years of historical data on similar products trafficked under similar conditions (GMA, 2000). Additional testing with replicate sections would give a better view of the range of performance available from these products. More importantly, the fact that data in the current study was gathered from a long-term, outdoor trafficking trial subjected to real world elements lends reassurance that the performance is a conservative indicator of the true benefit of geosynthetic reinforcement.

5.2.2 Base Course Reduction Percentage (BCR)

The BCR factor can be used to compare the base course thickness between reinforced and unreinforced test sections that perform equally. To perform the BCR analysis, unreinforced test sections of the same strength but different thicknesses must be composited to create reference curves that relate base course thickness and axle loads to specific rut depths. The base course thickness for unreinforced "controls" at a specific rut response is then compared to the base thickness of the reinforced test section for the same level of rutting. The difference in base course thickness between the reinforced test section and the unreinforced test section ($D_{\Delta} = D_{unreinforced} – D_{reinforced}$) divided by the thickness of the unreinforced test section and multiplying by 100 to express the result in percent yields a BCR. Typical BCR results are also shown in Table 4.

5.2.3 Layer Coefficent Ratio (LCR)

More recently, designers and leading geosynthetic manufacturers favor the use of the LCR to incorporate the benefits of geosynthetic reinforcement into pavement design. This approach is sensible and more technically correct. The

LCR applies and limits the geosynthetic benefit derived from tests to the specific layer improved by inclusion of reinforcement (base course layer) whereas the TBR applies to the whole pavement section. Therefore, extrapolation of TBRs derived from a limited set of trafficking trials to general pavement design may or may not be valid. On the other hand, the limited focus of the LCR is more robust. Table 4 also summarizes a typical range of LCR values obtained from the full-scale trafficking described herein.

Table 4. Typical Performance Factors Derived from Testing Geogrids at DDRF (*Valero, et al, 2013)

Surface	Target Subgrade Strength	TBR*	BCR	LCR*
Unpaved	CBR = 3	1.5 – 7.4	31 – 65%	-
Paved	CBR = 3	-	18 – 34%	1.16 – 1.85

6.0 SUMMARY AND CONCLUSIONS

The procedure described herein is a “real world” simulation of actual paved and unpaved road exposure conditions and variables used to evaluate the benefits of geosynthetics relative to unreinforced sections and to one another. The trafficking procedure is more severe than conditions encountered on most actual road areas since traffic is channelized with no significant wander. The facility incorporates important features, including: full scale highway construction equipment and practices; exposure to weather; incorporation of local subgrade soils, aggregate and pavement; a driven trafficking vehicle capable of applying equal 80 kN (18 kip) axle loads to eliminate the steering axle effect; “super-single” tires, pressure cells for evaluating soil pressures and, laser profiling of the rutting pattern. The results to-date (an example is shown in Table 4) support the premise that practical and relevant performance trials may be conducted in a simple, outdoor facility using materials, construction methods and equipment commonly used in pavement building and that the resulting data is relevant to quantifying the geosynthetic benefit to a road system.

7 REFERENCES

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