# Design and Construction of a Full-Scale Traffic Simulating Apparatus Over a Soil-Geosynthetic Composite

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ABSTRACT
The increased stiffness to the soil system and overall benefits of geosynthetic stabilization in roadways has been well documented for many years. Recently, full-scale investigations have been conducted to evaluate geogrid performance under large plate load testing and simulated heavy traffic cyclic loading. An experimental apparatus has been designed and constructed to further investigate geogrid performance by traffic simulation. The apparatus accommodates four test sections approximately 1.5 m wide. These four test sections can be separated into a control section and three geosynthetic stabilized sections during each trial. A uniform and replicable subgrade is achieved by stacking blocks of Plainsman Buffstone pottery clay. This apparatus has been designed to control matric suction throughout the system. During the testing phase, a 40 kN load (0.5 ESAL) is applied over each load cycle. The load cycle automation has been programmed using OMRON automation technology, which is capable of replicating thousands of load cycles in a 24-hour period. This new testing apparatus will be able to perform full-scale traffic simulation testing in an efficient and repeatable lab environment that was previously unachievable.

RÉSUMÉ
L'effet et les avantages de la stabilisation géosynthétique dans les routes sont étudiés depuis de nombreuses années. On a constaté que les géogrilles fournissent une rigidité accrue au système du sol. Des études à grande échelle ont été menées ces dernières années pour évaluer la performance des géogrilles dans le cadre de tests de charge de grandes plaques et de charges cycliques simulées par trafic lourd. Un appareil expérimental a été conçu pour étudier plus avant les performances des géogrilles par simulation du trafic. L'appareil peut accueillir quatre sections d'essai d'environ une demi-voie de circulation en largeur. À chaque essai, ces quatre sections d'essai peuvent être séparées en une section de contrôle et trois sections stabilisées géosynthétiques. Un sous-sol uniforme et reproductible est obtenu en empilant de nombreux blocs d'argile de poterie Plainsman Buffstone. Cet appareil a été conçu pour contrôler l'aspiration matricielle dans tout le système. Pendant la phase de test, une charge de 40 kN (0,5 ESAL) est appliquée sur chaque cycle de charge. L'automatisation du cycle de charge a été programmée à l'aide de la technologie d'automatisation OMRON, capable de répliquer des milliers de cycles de charge sur une période de 24 heures. Ce nouvel appareil de test sera en mesure d'effectuer des tests de simulation de trafic à grande échelle dans un environnement de laboratoire reproductible et efficace qui était auparavant irréalisable.

## 1 INTRODUCTION

Geogrid stabilization is a well known and effective method for reducing surface distress in roadways. Significant benefit can be seen when roadways are constructed over a weak subgrade. The performance of geogrid stabilization continues to be studied as new products are produced. To accommodate the need of more efficient test methods, an apparatus was designed to simulate the impact of traffic loading on geogrid stabilized aggregate over a soft subgrade. This apparatus has been designed to apply a 0.5 ESAL load per pass at a loading rate of 15 seconds per cycle. Each loading trial will include four road sections, three stabilized with multi-axial geogrid and one control section. Load is applied using two pneumatic cylinders to extend the dual tire axle to the road surface. This apparatus was designed with a layer of rigid insulation within it to limit heat transfer with the testing environment. The apparatus was constructed in a facility capable of simulating freeze-thaw cycles from the surface down through the subgrade for future testing. The aggregate and subgrade material characterization has begun, including soil strength and hydraulic parameters, and will continued to be studied. The apparatus designed for the simulation of geosynthetic stabilized roadways is both efficient in its testing and versatile for its capabilities of observing the effects of freeze-thaw cycling in a previously unattained way.

## 2 BACKGROUND

In Saskatchewan and the Canadian Prairies, earthworks are often constructed over weak subgrades. The Prairies also face dramatic seasonal temperature changes, often from -35°C to 35°C, from Winter to Summer months. Extreme weather and poor subgrades contribute to difficult construction conditions. Geosynthetics have been well proven to provide additional support and is used for various applications such as separation control, reinforcement, stabilization, and pore-pressure control.

Geogrids are designed for two functions: stabilization and reinforcement. Geogrid stabilization uses interlocking mechanisms with aggregate material to impose lateral restraint with a coarse aggregate to primarily improve resistance against settlement.

There has previously been some comparable apparatuses that have been designed in the past for similar functions. Notably, the U.S. Corps of Engineers designed a full-scale traffic loading apparatus within an airport hangar (Robinson et al. 2017). This testing apparatus applied an equivalent single axle load (ESAL) of 2.08 per pass over test sections stabilized with multi-axial geogrid. The test section was equipped with earth pressure cells, pore-pressure sensors, moisture content sensors, strain gauges, and deflection gauges.

## 3 APPARATUS DESIGN

The apparatus was constructed inside the Multi-purpose Slope Testing facility (MOST) in Saskatoon, Saskatchewan. This apparatus was modeled after a small scale wheel loader constructed at the University of Saskatchewan. The full-scale wheel loader apparatus was conceptualized in SOLIDWORKS which is shown below in Figure 1 and Figure 2.

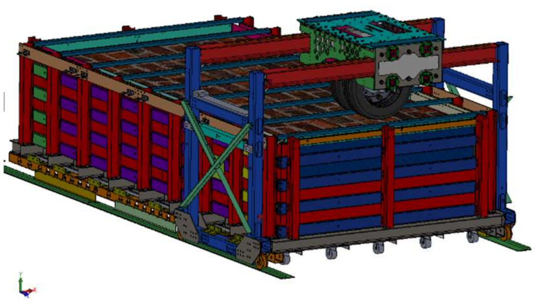

Figure 1. SOLIDWORKS Conceptual Model.

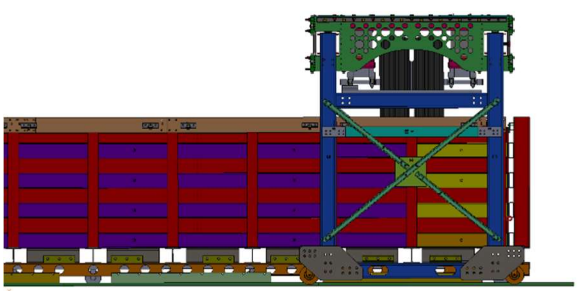

Figure 2. Side View of SOLIDWORKS Conceptual Model.

The wheel loader was constructed with over 1800 pieces of steel that were fabricated at local steel facilities for the use of precision laser cutting. Drill and tap was needed in some areas. The Engineering Shops department at the University of Saskatchewan aided with the modifications necessary for assembly. The apparatus exoskeleton rests on 40 steel casters to allow for the box to be moved outside of the testing facility for ease of removal of material. The trafficking frame, which applies the trafficking load, rests on casters that lay on a guided track to allow for the frame to be easily positioned over each testing section, as necessary. The trafficking frame is fixed at the base and at mid-height.

Figure 3. Main Steel Framing Partially Assembled.

Four layers of marine plywood are laminated together with epoxy. The epoxy used was a marine grade epoxy produced by West System. Marine grade epoxy was used, with meticulous application, to create a complete seal that prevents water from seeping through the testing box. The outer layers of plywood were laminated together with epoxy and secured with tongue and groove joints. These joints ensure a tight seal against air entry and water seepage. Butt joints are used for the inner layers of plywood. Critical joints were then reinforced with fiberglass tape. The tape acts to ensure good coverage over potential air pockets and reinforce the weak points over long-term, repeated, loading. The completed plywood epoxy-sealed box is shown below in Figure 4.

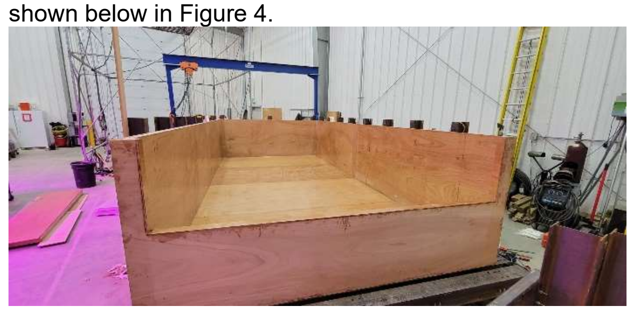

Figure 4. Completed Epoxy Sealed Plywood.

In the middle of the plywood layers, a 1” layer of rigid insulation was installed in between the marine plywood. The extruded polystyrene rigid insultation has a compressive strength of 20 psi (140 kPa), ensuring that the insulated layer does not crush under load. The partially constructed layer of insulation can be seen below in Figure 5. To prevent the creation of air pockets in the insulation layer, sonotubes were cut to proper lengths to function as a mode of compression against the insulation.

Figure 5. Construction of Insulation Layer.

The trafficking carriage, as shown in Figure 6, is based on a linear slide. The carriage rolls across two W8X31 beams supported by the main trafficking frame. A chain drive system was designed for motion control. Chain tighteners were designed with threaded rod and compression springs. These springs act to mitigate the shock force caused by rapid deceleration at the end of each directional movement. The single axle assembly was fabricated at the Engineering Shops at the University of Saskatchewan. The tire set is made up of two 255/70R22.5 semi tires which are inflated to a tire pressure of 90 psi. In combination with the tire pressure, two 8” bore by 10” stroke pneumatic cylinders generate the application of one-half ESAL. These pneumatic cylinders require three air compressors for efficient application of load. The current load application has been minimized to 15 seconds per cycle. This drive system is programmed through an automated programmable logic controller (PLC).

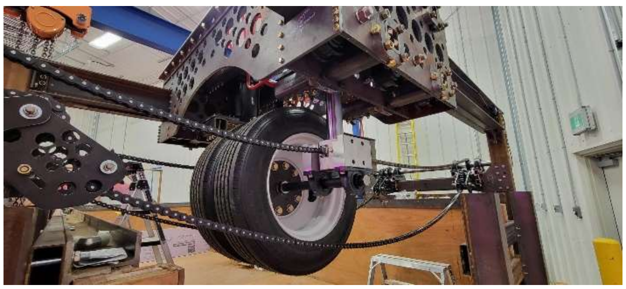

Figure 6. Trafficking Carriage.

An OMRON Automation PLC is programmed to run the wheel loader. This PLC controls the speed of the wheel loader, cycle count, and timing for each load application. Wheel load is only applied in a single direction for a constant simulated traffic flow direction. This automation system uses a 7.5kW (10 HP) servo-drive which powers the chain drive system that controls the motion of the wheel loader. A 500W braking resistor was installed to supply the braking power to the drive system. Status monitoring of the PLC through the human-machine interface (HMI) produces information on velocity, torque, and position output over time. The HMI allows for users to change 9 program parameters instantaneously to improve efficiency of traffic simulation. Programmable parameters include load application timing, rest times, peak acceleration and deceleration, and maximum velocity. The final constructed wheel loader exoskeleton is shown below in Figure 7.

Figure 7. Constructed wheel loader apparatus.

## 4 TEST SECTION DESIGN

### 4.1 General Section Setup

This apparatus is constructed to accommodate four test sections. The four lanes are each 1.5 m wide with a trafficking length of 2.8 m. A test section 1.5 m wide provides nearly half the width of a standard traffic lane, generally 3.6 m wide. Using a lane width of 1.5 m optimized the number of lanes within the allowable footprint in the MOST Facility. Any effects of constraint will be considered by the results of ongoing research. A 600 mm thick layer of weak subgrade is overlain by a 300 mm thick layer of aggregate. An adjustable reservoir is used to ensure partially saturated conditions are maintained throughout the experiment. A processed drainage material and three layers of 8 oz./sq. ft non-woven geotextile ensures a constant distribution of head at the bottom of the substrate. The non-woven geotextile also acts to prevent clogging of the reservoir system drains. A profile view of a section of the apparatus can be seen in Figure 8.

The adjustable reservoir is connected to one end of the apparatus through two drainage ports. This reservoir is fed by a peristaltic pump from the sump tank inside the facility. An outflow port was installed to keep the constant application of head to the system.

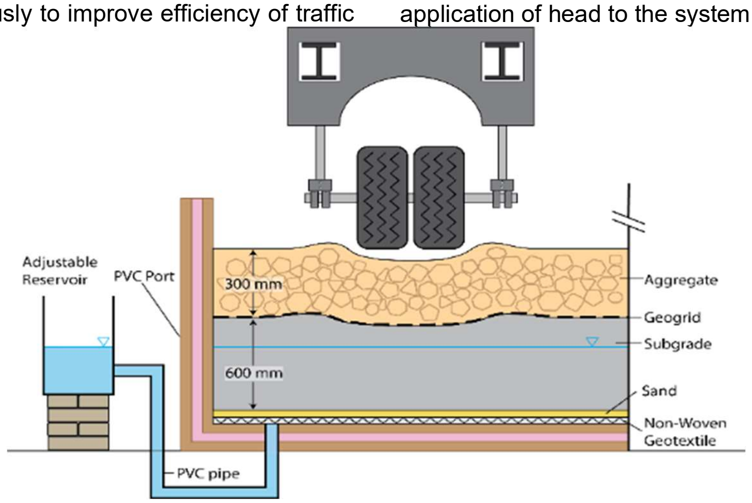


Figure 8. Profile view of test section.

4.2 Instrumentation Plan

During the testing phase, load and pore-pressure response will be monitored. To monitor load, earth pressure cells have been embedded at the bottom of the apparatus, underneath the subgrade material. Four load cells were used in the initial implementation of this research, two positioned under the center of the trafficking land and two at the interface between lanes. The placement and installation of the earth pressure cells are shown in Figure 9. Boussinesq's load distribution theory will be applied to calculate stress levels with respect to depth. The location and depth of earth pressure cells may change based on the monitored response of ongoing research.

Figure 9. Non-Woven Geotextile and Earth Pressure Cells in Place.

Pore-pressure conditions will be checked using tensiometers. Six tensiometers have been installed thus far. Access tubes have been installed for the tensiometers through the sidewall of the apparatus. These tubes have been epoxy sealed to negate any moisture loss, as well have a threaded end to produce a tight seal. To prevent damage to the tensiometers during testing due to the deformation of the material, these ports have been installed at the lane interface. The instrumentation plan is shown below in Figure 10.

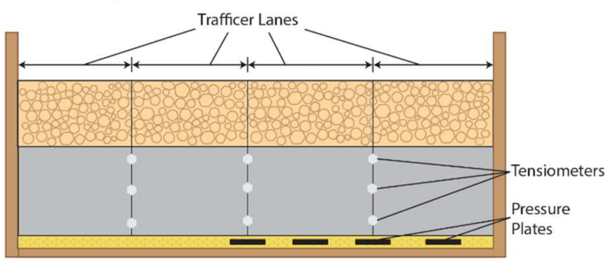


Figure 10. Instrumentation Plan.

4.3 Materials

4.3.1 Drainage Material

A uniform sand was utilized for a drainage material. This sand is used to ensure a constant application of head throughout the bottom of the subgrade. This sand was combined at a 4:1 ratio from the processed material larger than 0.075 mm and less than 0.15 mm to 0.425 mm and 0.15 mm in particle size. The use of fine sand ensures the air entry value (AEV) would be sufficiently high to maintain saturation throughout the layer, while still allowing fluctuation by water being pulled into the subgrade. This sand was placed at with a layer thickness of approximately 1".

4.3.2 Subgrade

A low plasticity kaolinite clay was chosen as a subgrade for this research. This clay was purchased from Plainsman Clays in Medicine Hat, AB and was delivered as many individual blocks of clay. Some initial material characterization was done on this subgrade. The relationship of undrained shear strength with water content was evaluated, following ASTM D4318 (ASTM 2017), as well as Atterberg limits. These results are summarized in Table 1.The clay was placed together in four lifts. The clay was periodically packed together and wetted to ensure desiccation of the subgrade did not occur, as seen in Figure 11.

Table 1. Subgrade Characterization.

| Characteristics | Values |
|---|---|
| Liquid Limit (%) | 34.5 |
| Plastic Limit (%) | 16.9-17.7 |
| Water Content (%) | 20.8-24.7 |
| Undrained Shear Strength, $S_u$ (kPa) | 22-43 |

Figure 11. Placement of Clay.

Over a period of weeks, the clay subgrade was dried by exposing the surface of the subgrade. Drying the surface was done to ensure that deformations do not occur once the aggregate is placed. During this period, tensiometers were installed to monitor the suction. Continuous observation of the clay surface was done to ensure desiccation did not occur throughout this process. The in-place clay surface as it dries is shown below in Figure 12.

Figure 12. Subgrade Surface After Placement.

To create a flat subgrade surface and fill miscellaneous voids, various packing and smoothing techniques were employed. Compaction of the clay was done initially by sizing plywood boards for weight distribution. Appropriate sizes were made to not exceed bearing capacity of the clay subgrade (Figure 13. After compaction, a lawn roller was used to smooth out any discontinuities in the subgrade surface (Figure 14. Surveying was done to ensure a level surface. To finalize the clay surface, some scraping and patching was necessary

Figure 13. Bodyweight Compaction.

Figure 14. Smoothing the Clay Surface with a Lawn Roller.

4.3.3 Aggregate

Several local materials were considered for this research. Three from local pits and one material (S7 Special Blend) from another research project locally. The interlocking effect of particles with the geogrid produces the desired stabilization for good performance. The interlocking of particles with the geogrid has better performance based on the grain size distribution (GSD). The considered materials are shown below in Figure 15.

The Type 32 Special Blend was chosen for this research. This material has a 90% one face fracture and a 60% two face fracture. The Type 31, Type 32, and Type 33 all conform to provincial specifications (Government of Saskatchewan 1996). The aggregate will be placed in multiple lifts and packed with a plate tamper. Aggregate density will be checked using a nuclear densometer and an electrical impedance spectroscopy soil density gauge.

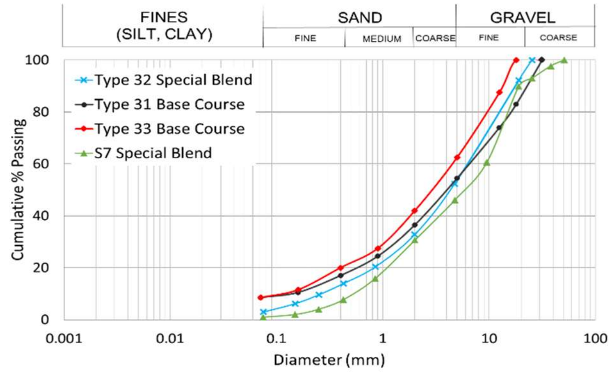


Figure 15. GSD of Available Materials.

5 CONCLUSIONS

Geogrid stabilization continues to be studied for new applications and testing conditions. A new apparatus has been designed and constructed to evaluate the performance of geogrid stabilized roadways over a weak subgrade. This apparatus was built with a steel exoskeleton and marine plywood. This plywood is sealed with epoxy and contains a 1” layer of rigid insulation to prevent both leakage and heat loss does not occur. The prevention of heat loss provides versatility to test the influence of freeze-thaw cycling on geogrid stabilized sections in future research. The wheel assembly applies a load of one-half ESAL to the surface through two pneumatic cylinders. The trafficking carriage is automated through a PLC and can be tuned instantaneously at the HMI for improved efficiency. The current HMI setup produces a cycle time of 15 seconds per load application. Future improvements to reduce cycle time will be attempted.

This new apparatus has been constructed to accommodate four 1.5 m wide test sections. Each loading trial will accommodate three geogrid stabilized sections and one control section, without geogrid. Matric suction is controlled throughout the system by applying a constant head at the bottom of the subgrade with an adjustable reservoir. Tensiometers have been instrumented to monitor the suction at various locations of the subgrade. Load is monitored during the testing phase with earth pressure cells instrumented at the base of the apparatus underneath the subgrade. The materials used in this research include a processed sand for drainage material, a kaolinite clay imported from Plainsman Clays, and a local type 32 aggregate. Results from ongoing research and interaction of the soil-geosynthetic composite will dictate future implications for design.

6 ACKNOLEWDGEMENTS
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## 7 REFERENCES


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