Mechanical Stabilization of Unbound Layers and Incorporation of Benefits in AASHTO '93 and M-E Analysis of Flexible Pavements

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Kent Seminar Series
University of Illinois, Urbana-Champaign
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Tensar

Lecture Outline

Tensar

- Tensar International
- Stabilization Function & Confirmation Through Research
- AASHTO Empirical Approach
- Mechanistic-Empirical Approach
- New Pavement Performance Evaluation Technologies

Tensar Group Overview

Tensar Corporation is the parent company of several wholly-owned, market-leading subsidiaries including:

- Tensar International Corporation
- Geopier Foundation Company
- North American Green

Tensar International

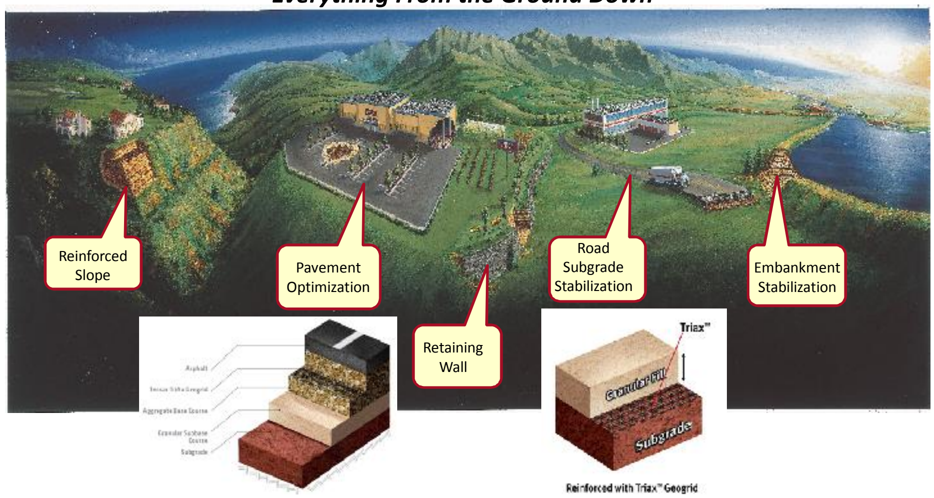





Morrow Georgia, USA	Poseyville Indiana, USA	Centre Alabama, USA	Blackburn England	Wuhan China	St. Petersburg Russia
17.9 Acres TriAx™ Geogrid BX Geogrid UX Geogrid	19.9 Acres Erosion Control Blankets	15.0 Acres HydraMatrix™ Mulch	7.7 Acres TriAx™ Geogrid BX Geogrid UX Geogrid Glasstex, Basetex	8.3 Acres TriAx™ Geogrid BX Geogrid UX Geogrid	4.0 Acres TriAx™ Geogrid UX Geogrid

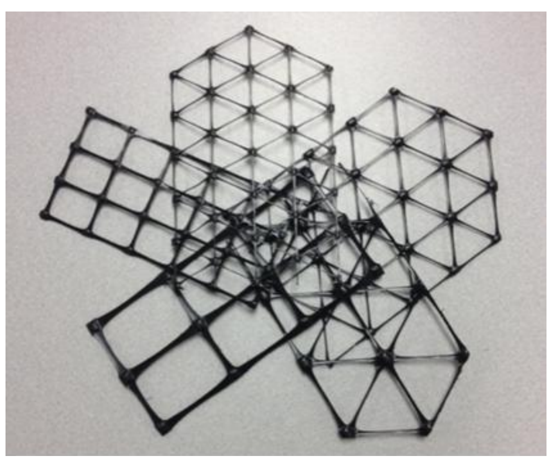
Tensar

"Everything From the Ground Down"



Manufacturing

Tensar




FAST
ACT
THE FIXING AMERICA'S SURFACE TRANSPORTATION AC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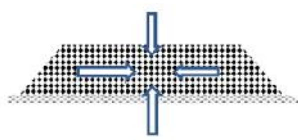
What is Stabilization?

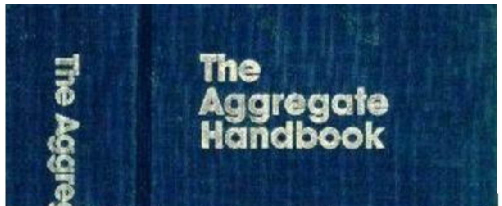
Proposed Definition by ISO TC221 - WG2



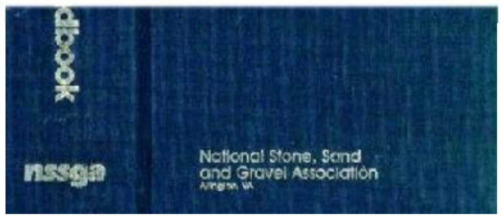
- Stabilization: Improvement of the mechanical properties of an unbound granular material by including one or more geosynthetic layers such that the deformation under applied loads is reduced by minimizing soil particle movement.

- Mechanical Stabilization is a more appropriate description – distinguishes from Chemical Stabilization, Lime Stabilization and others

Importance of Stabilization

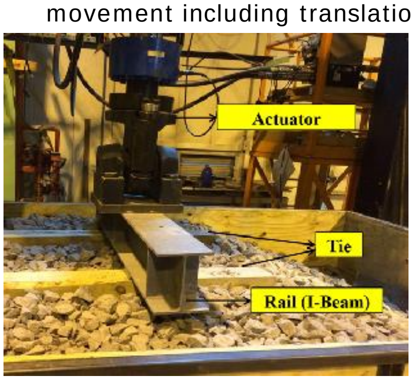


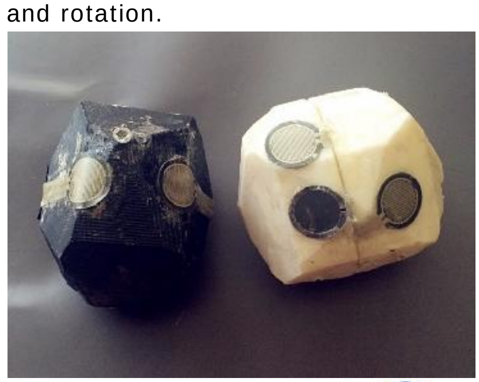
Pavements: As a pavement deflects and rebounds under dynamic loading, aggregate particles within the system also move. When this movement is relatively large, aggregate edges can be worn off, fracturing may take place, and a general degradation of the aggregate can occur. If degradation occurs, consolidation of the unstabilized aggregate layer and cracking and breakup of the upper layers of the system may result.



Particle Movement inside Railroad Ballast

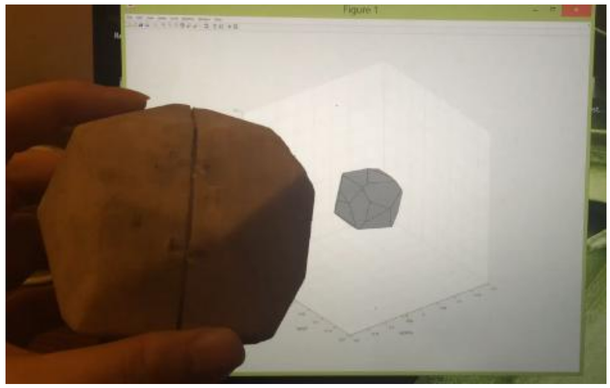
- A half section of a typical railroad track structure was constructed.
- TriAx TX190L geogrid was installed 10” below the top of the ballast.
- SmartRock is installed above geogrid and record real-time particle movement including translation and rotation.



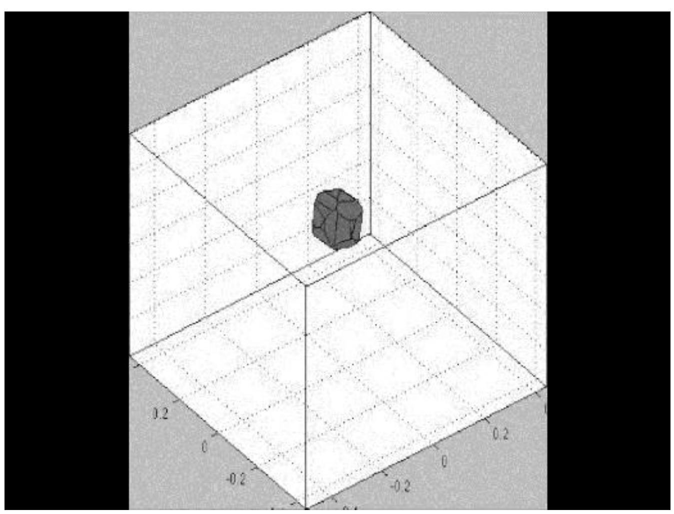


Presented at the 2016 TRB conference,
“Effect of Geogrid on Railroad Ballast Studied by SMART ROCK”
Liu, S., Huang, Hai, Qiu, T. and Kwon, J.

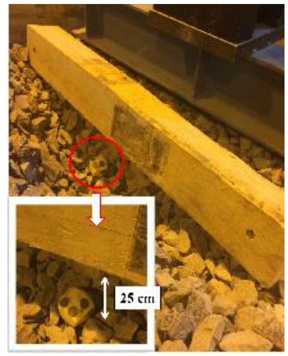
Research: Real Time Rotation



Rotation + Translation

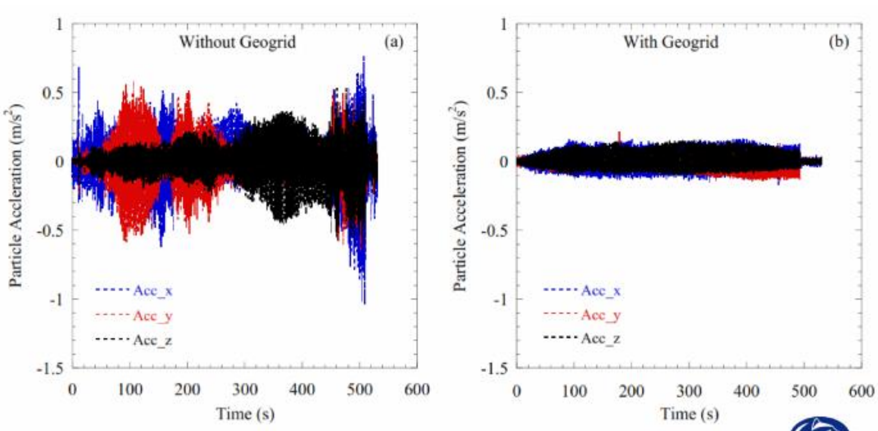


Laboratory setup



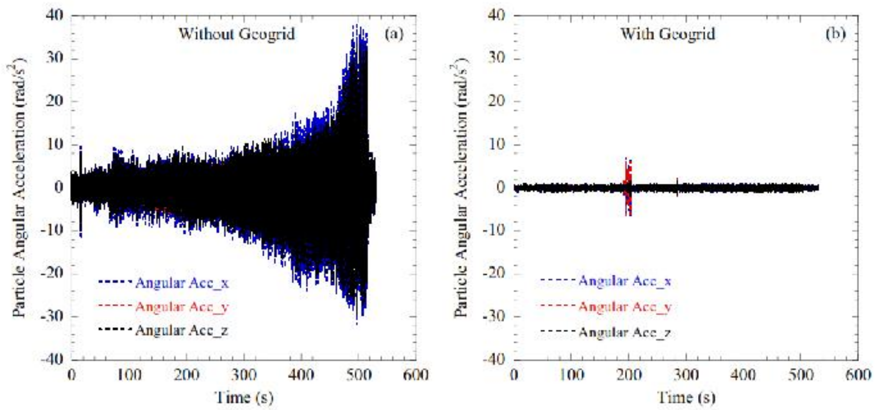
Particle Movement inside Railroad Ballast

- PARTICLE TRANSLATIONAL MOVEMENT was significantly reduced with the inclusion of TX190L geogrid.

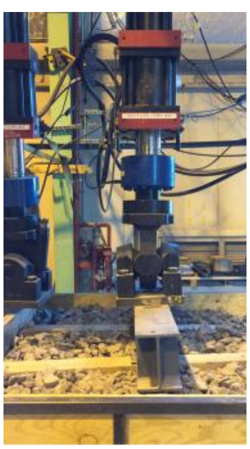


Particle Movement inside Railroad Ballast

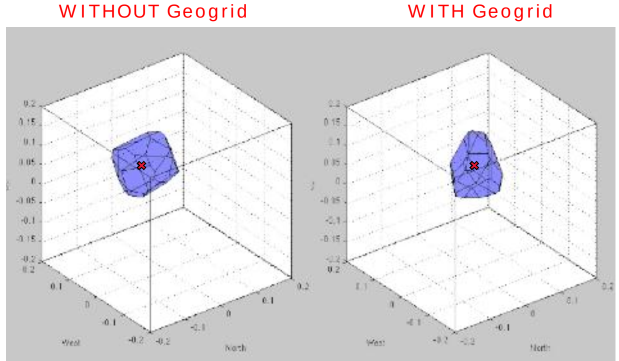
- PARTICLE ROTATION was significantly reduced with the inclusion of TX190L geogrid.



Visualized motion of SmartRock in ballast



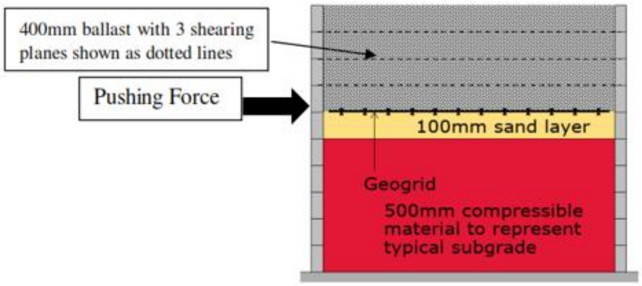
WITHOUT Geogrid WITH Geogrid



Presented at TRB2016 conference,
"Effect of Geogrid on Railroad Ballast Studied by SMART ROCK"

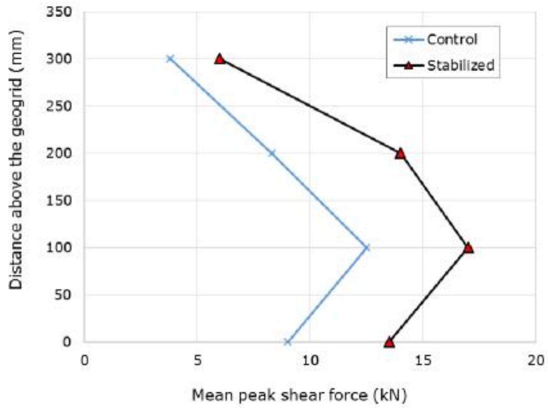
Multi-level Shear Box

- Multi-Level Shear Box Testing – with Geogrid
  - Shear plane 1 – top of the sand layer
  - Shear plane 2 – 100mm above top of the sand
  - Shear plane 3 – 200mm above top of the sand
  - Shear plane 4 – 300mm above top of the sand



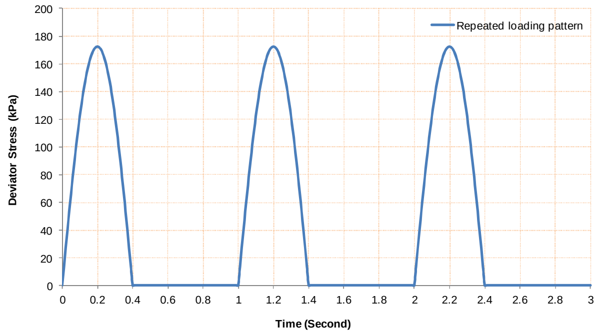
Shear Force at Various Distances

- The geogrid in the ballast layer increased the peak shear force at all of the four levels.
- The shear force increase is a true indication of the effect of aggregate confinement.



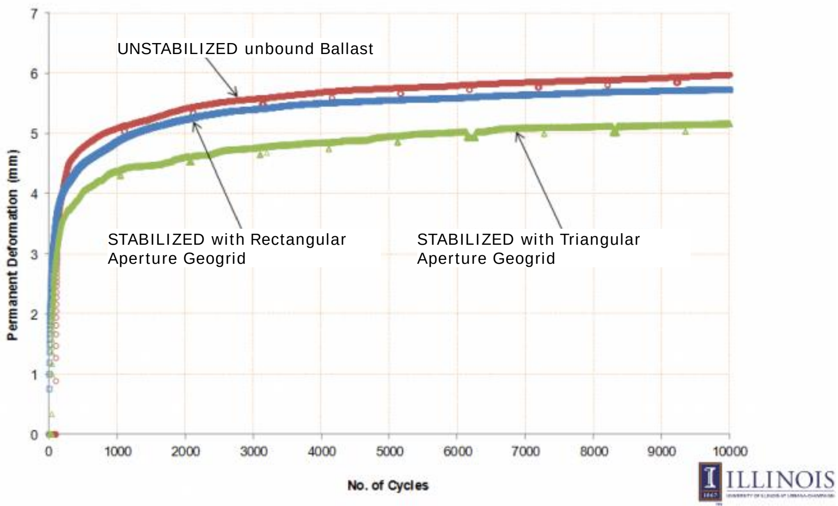
Large Scale TriAxial Testing

- The University of Illinois Triaxial Ballast Tester or TX-24
- Specimen Size: 12" x 24"



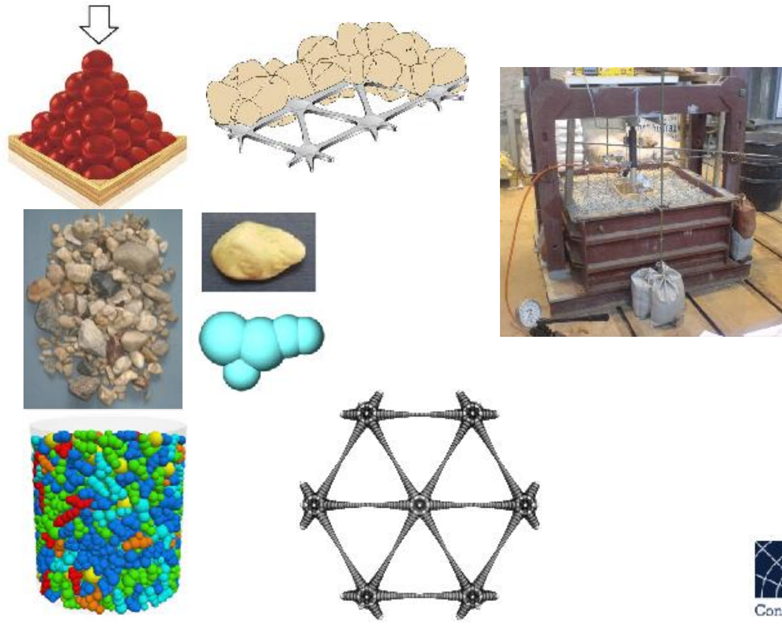
ILLINOIS

Permanent Deformation Test Results



ILLINOIS

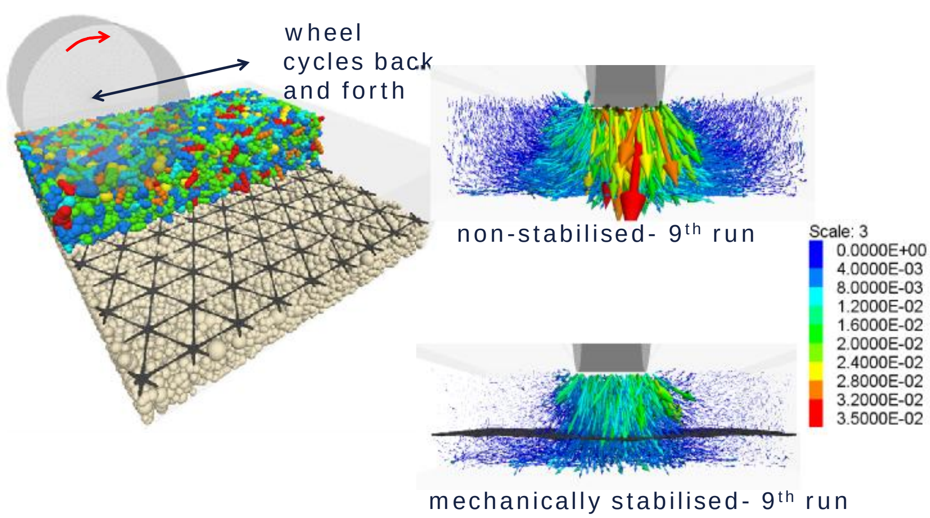
ITASCA DEM - Effect of Particle Confinement



ITASCA Consulting Group, Inc.

ITASCA DEM - Moving wheel load simulation

- 10 wheel crossings (500 N, 0.5 m/s)
  - 5 kPa normal stress is applied on load walls during the test



Wheel Load Simulation

ITASCA Consultants GmbH

Soil: 5/32 mm

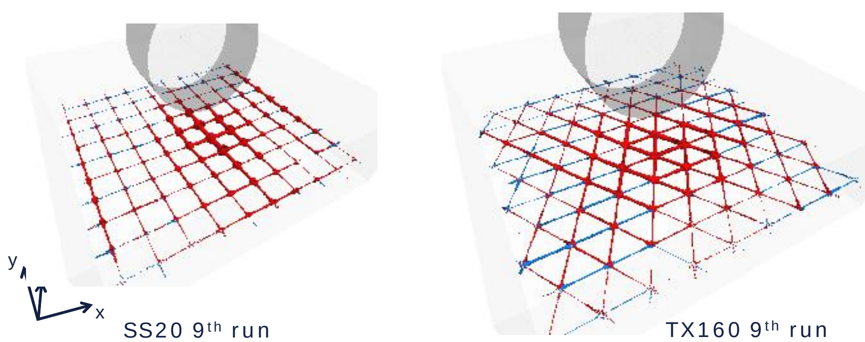
Subgrade: 2 (particles)

Relative density: DR 75

Geogrid: TX160 vs. SS20

Movie: Force between geogrid particles

Run 8-10



SS20 9th run

F_{max} = 33.6 lb/ft

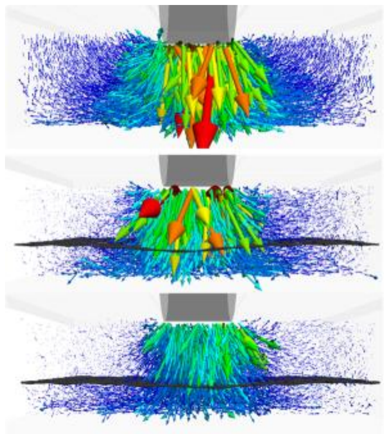
TX160 9th run

F_{max} = 18.5 lb/ft

Compression
Tension

ITASCA Consulting Group, Inc.

ITASCA DEM - Lateral and Vertical Confinement



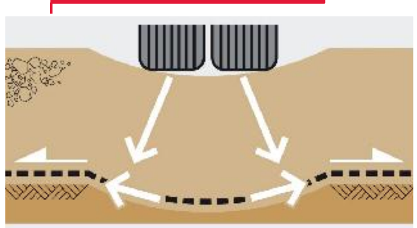
No grid - (Particle Movement Over Time! = reduction in layer stiffness over time!)

SS20 - Biaxial Geogrid = reduced vertical and horizontal displacement versus control

TX160 - TriAx = significantly less vertical and horizontal displacement versus control and biaxial geogrid. **Maintain particle shape and position = long term stiffness retention!**

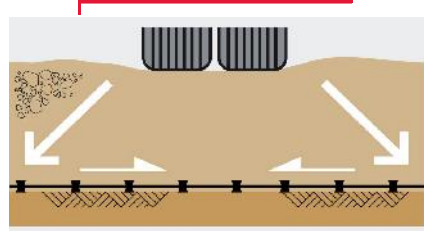
Stabilization/Reinforcement Functions

Reinforcement



Geogrid or Geosynthetic where particle confinement is not developed

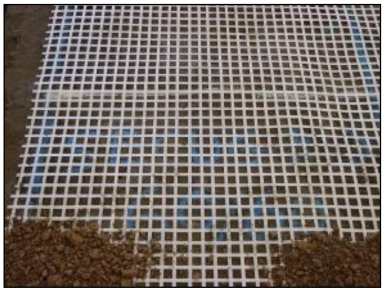
Stabilization



Geogrid where interlock results in efficient particle confinement

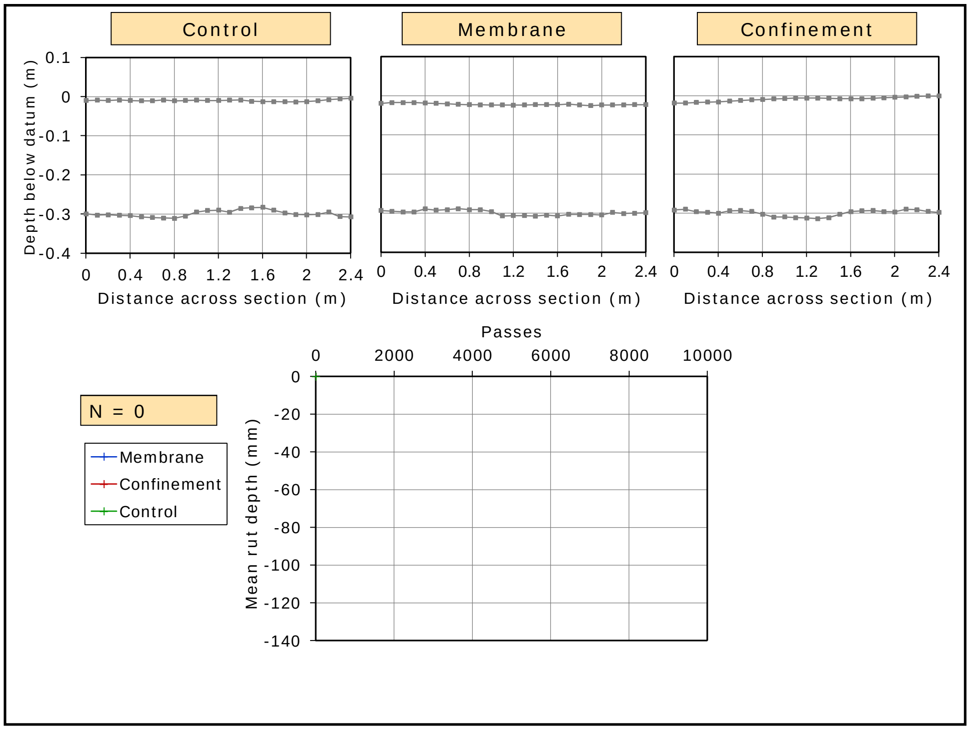
TRL Trafficking - Jenner, Watts & Blackman (2002)



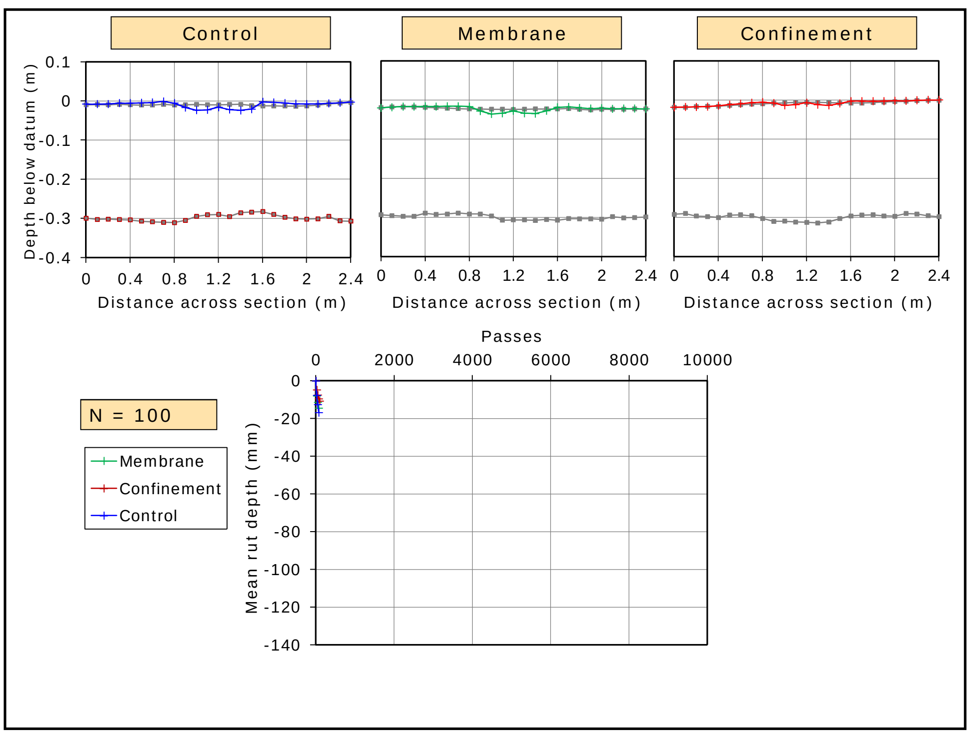



Trafficking – 10,000 passes

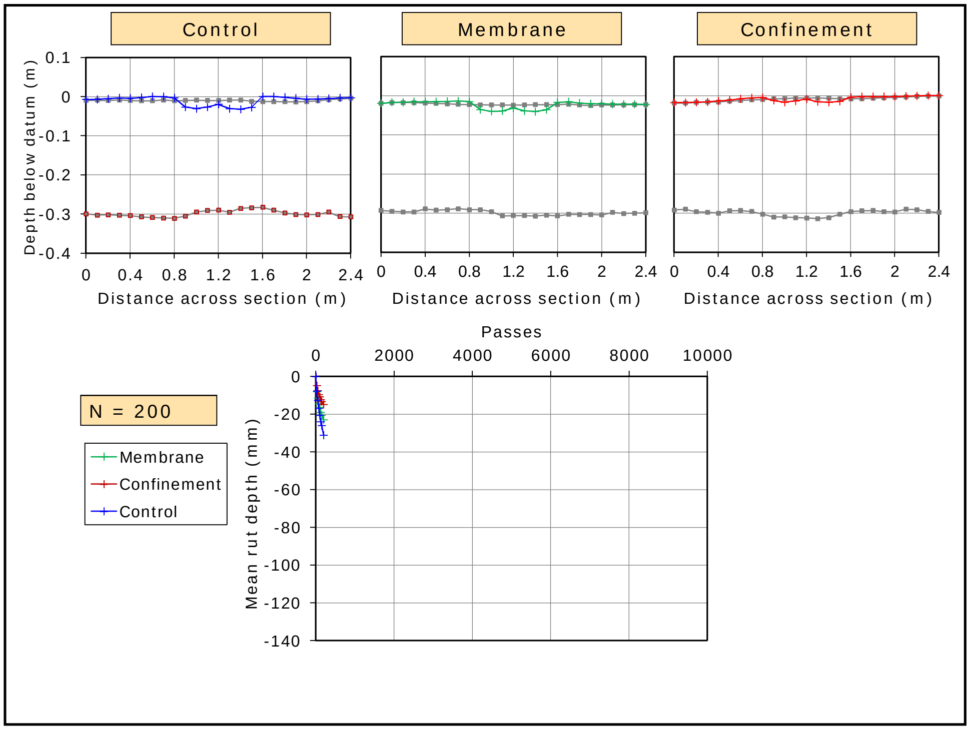
- Investigating different forms of geosynthetic
- Soft subgrade approx. 2% CBR
- 9,000 lb wheel (equal to 1 ESAL)
- Surface rut depth and deformation measured
- Subgrade profile measured after exhumation

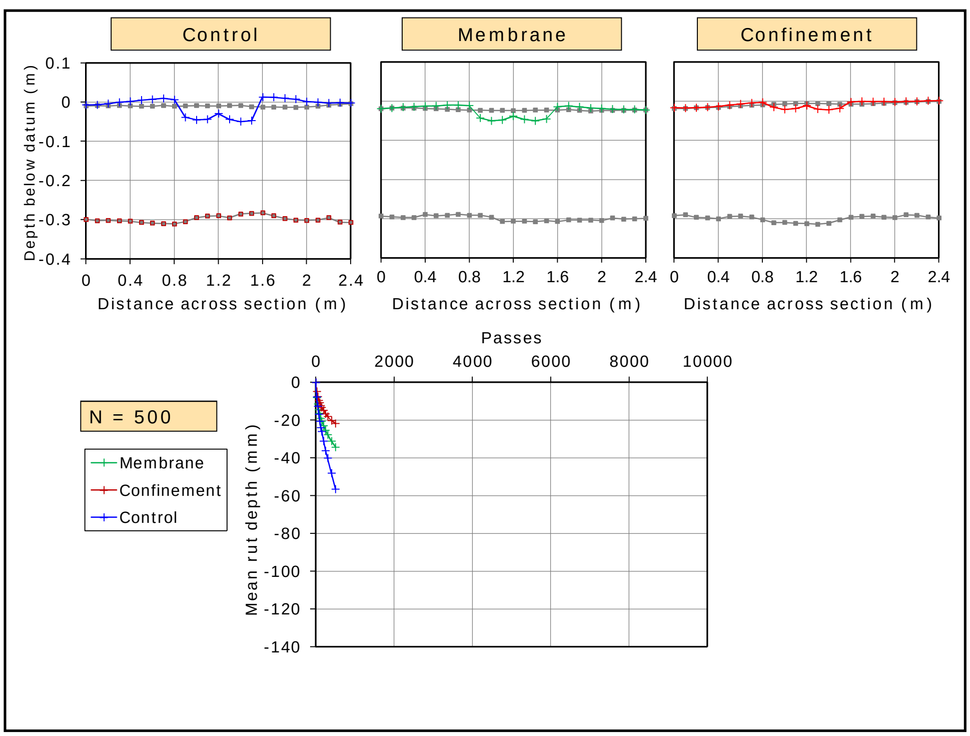



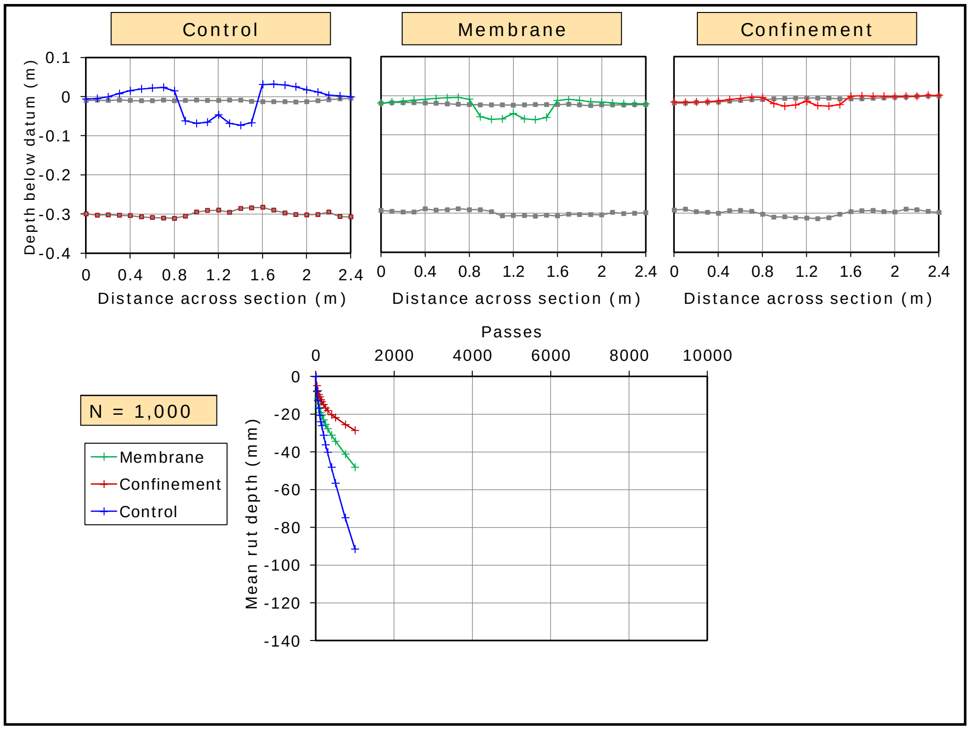
Control
Membrane
Confinement
Depth below datum (m)
Distance across section (m)
Passes
Mean rut depth (mm)
N = 0
Membrane
Confinement
Control

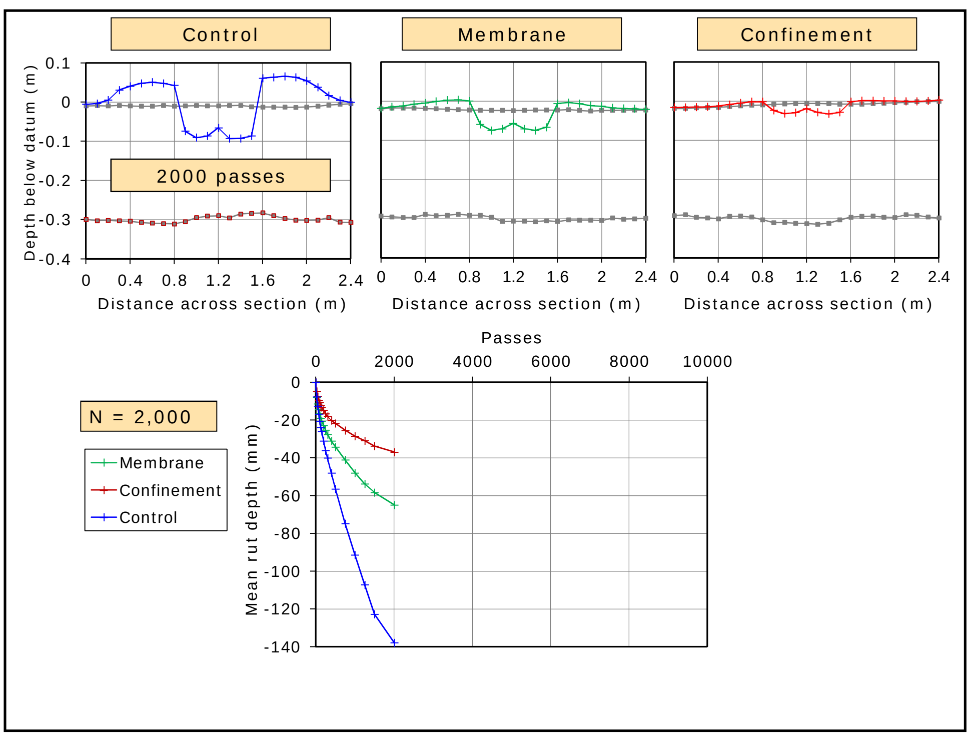


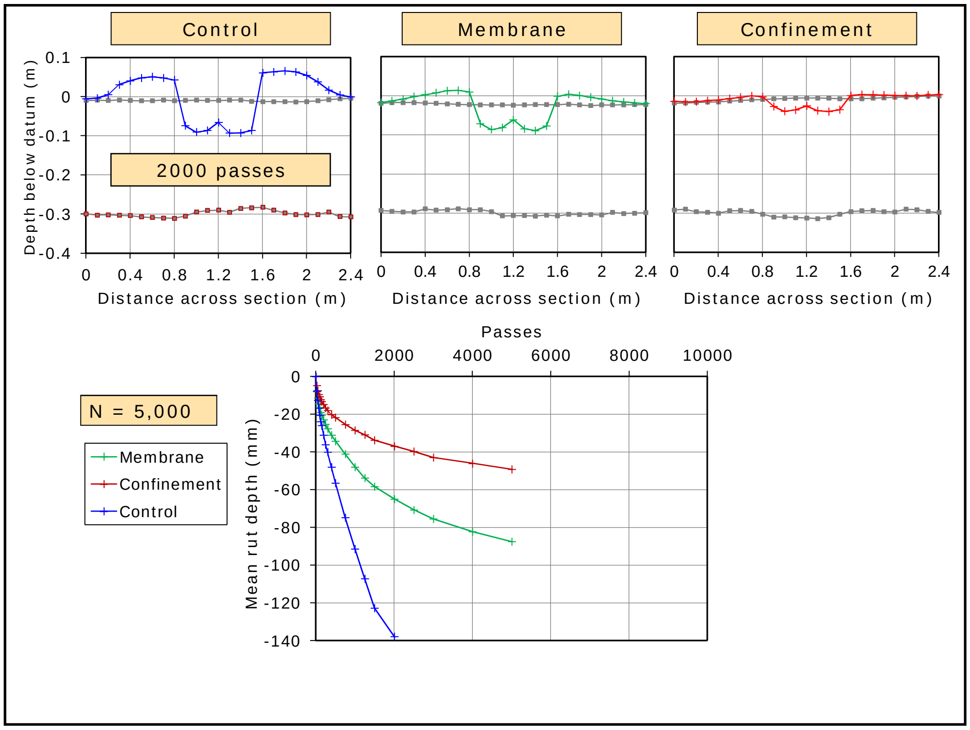
Control
Membrane
Confinement
Depth below datum (m)
Distance across section (m)
Passes
Mean rut depth (mm)
N = 100
Membrane
Confinement
Control

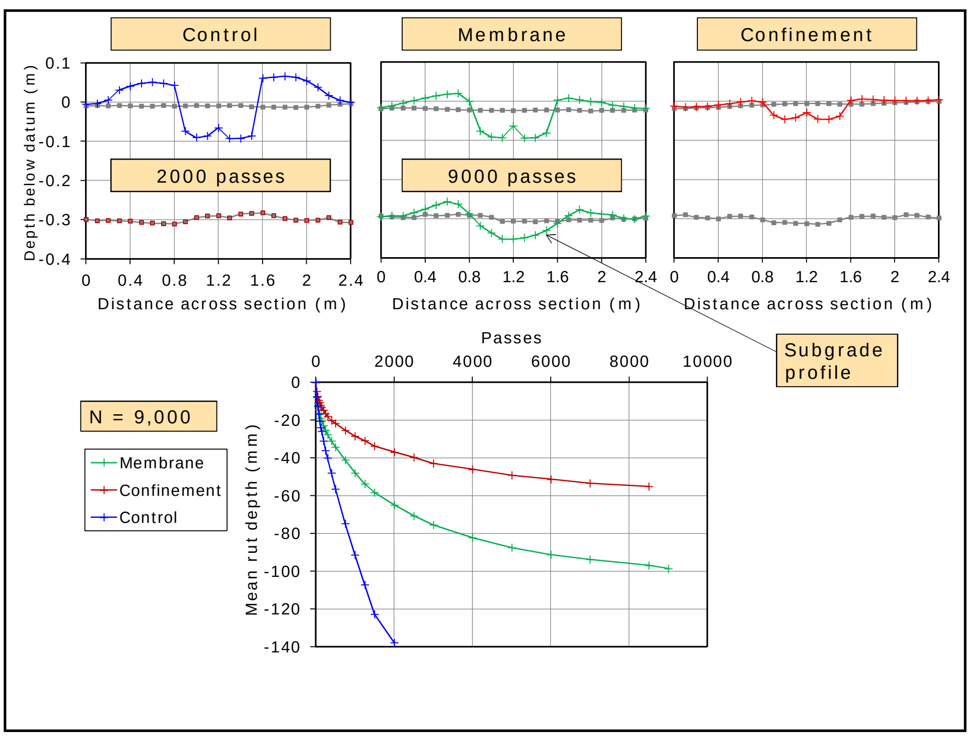

Control
Membrane
Confinement
Depth below datum (m)
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.4
0.8
1.2
1.6
2
2.4
Distance across section (m)
Distance across section (m)
Distance across section (m)
Passes
0
2000
4000
6000
8000
10000
N = 200
Membrane
Confinement
Control
Mean rut depth (mm)
0
-20
-40
-60
-80
-100
-120
-140

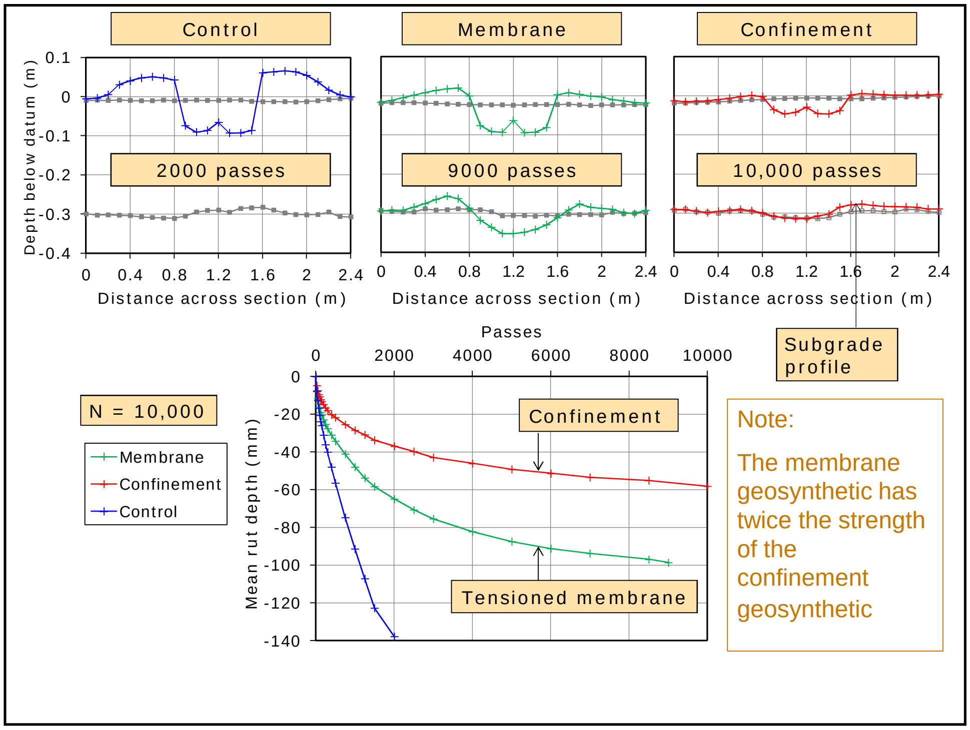

Control
Membrane
Confinement
Depth below datum (m)
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.4
0.8
1.2
1.6
2
2.4
Distance across section (m)
Distance across section (m)
Distance across section (m)
Passes
0
2000
4000
6000
8000
10000
N = 500
Membrane
Confinement
Control
Mean rut depth (mm)
0
-20
-40
-60
-80
-100
-120
-140


Control
Membrane
Confinement
Depth below datum (m)
Distance across section (m)
Passes
N = 1,000
Membrane
Confinement
Control
Mean rut depth (mm)


Control
Membrane
Confinement
2000 passes
Depth below datum (m)
Distance across section (m)
Passes
N = 2,000
Membrane
Confinement
Control
Mean rut depth (mm)


Control
Membrane
Confinement
2000 passes
Depth below datum (m)
0.1
0
-0.1
-0.2
-0.3
-0.4
0 0.4 0.8 1.2 1.6 2 2.4
Distance across section (m)
Passes
0 2000 4000 6000 8000 10000
N = 5,000
Membrane
Confinement
Control
Mean rut depth (mm)
0 -20 -40 -60 -80 -100 -120 -140


Control
Membrane
Confinement
2000 passes
9000 passes
Depth below datum (m)
0.1
0
-0.1
-0.2
-0.3
-0.4
0 0.4 0.8 1.2 1.6 2 2.4
Distance across section (m)
Subgrade profile
Passes
0 2000 4000 6000 8000 10000
N = 9,000
Membrane
Confinement
Control
Mean rut depth (mm)
0 -20 -40 -60 -80 -100 -120 -140

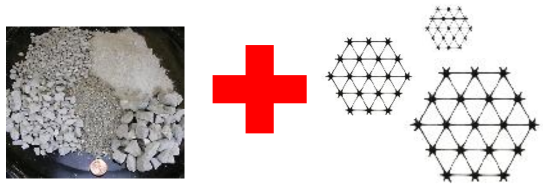


Geosynthetic Functions - Permanent Roadways

- Filtration
- Separation
- Reinforcement
- Stabilization

Stabilization

- Geogrid aperture size relative to aggregate size and grading
  - FHWA Guideline: $D_{50} \leq$ Aperture Size $\leq 2D_{85}$
    - where "D" values are for aggregate placed on the geogrid.



  - Separation Check
    - Piping Ratio = $D_{15fill}/D_{85subgrade} < 5$
    - Average Size Ratio = $D_{50fill}/D_{50subgrade} < 25$

Lecture Outline

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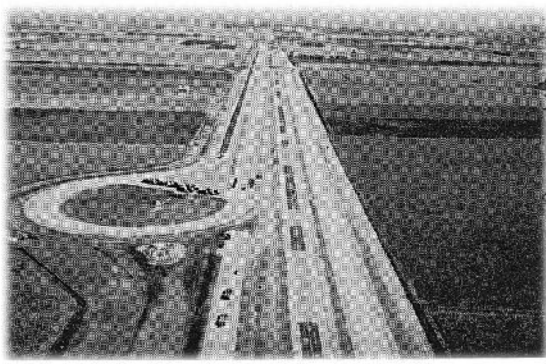
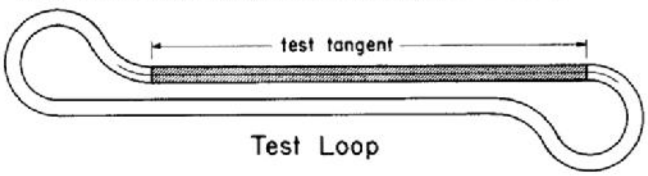
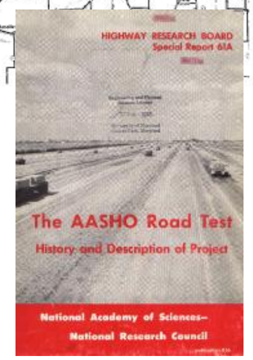
- Stabilization Function & Confirmation Through Research
- AASHTO Empirical Approach

AASHO Road Test (late 1950's)

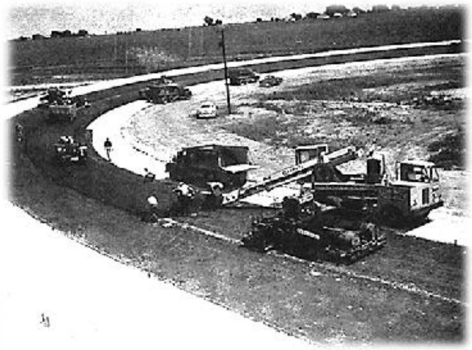






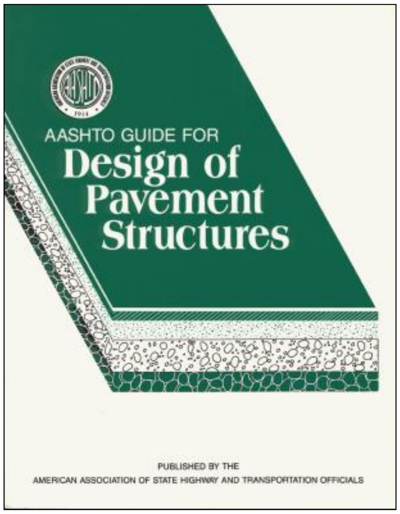
One Subgrade Type…

Controlled Construction Methods...



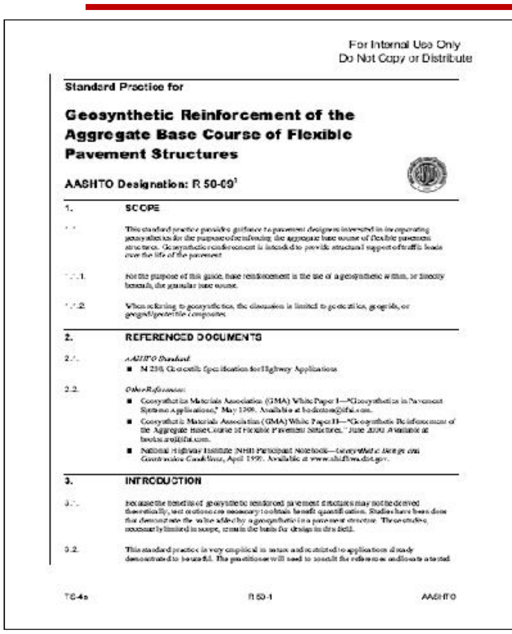
1950s' Vehicle Loads...

AASHTO Pavement Design Guide



- Empirical methodology
- Based on AASHO Road Test
- Several versions:
  - 1961 (Interim Guide), 1972, 1986, 1993
  - 1986 Guide highlights need for mechanistic design

AASHTO: R50-09



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Standard Practice for

Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures

AASHTO Designation: R 50-09[1]

1. SCOPE

[illegible]

2. REFERENCED DOCUMENTS

[illegible]

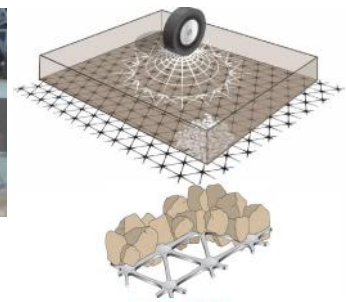
3. INTRODUCTION

[illegible]

TS-4a R 50-1 AASHTO

- Benefit of including geosynthetics in pavement is recognised to:
  - Improved life
  - Reduced thickness
- Benefits cannot be derived theoretically
- Designs not easily translated to other geosynthetics
- Test sections are necessary to obtain benefit quantification
- Users are encouraged to affirm their designs with field verification

Full Scale Evaluation

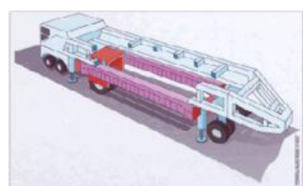


USCOE Full Scale APT Studies

Accelerated Pavement Testing:

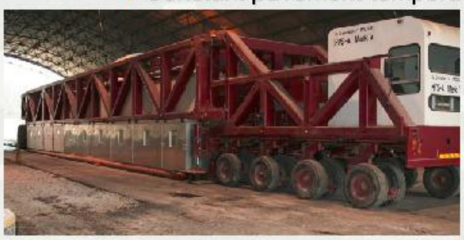
- Provide full-scale pavement performance data for TriAx for base enhancement design following AASHTO ’93 and/or M-E approaches.

- Project in 2 phases.
  - Phase 1: CBR=3% (31 MPa)
  - Phase 2: CBR=6% (62 MPa)

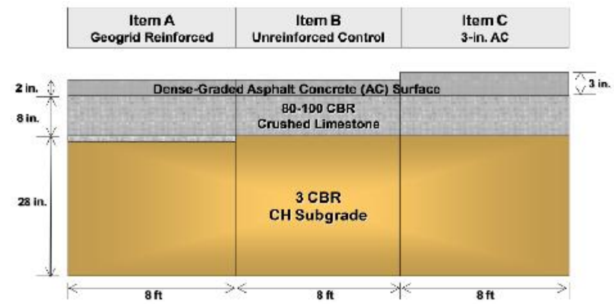


Accelerated Pavement Testing (APT)

- Traffic HMA lanes with the HVS-A
  - Dual wheel tandem axle
    - 20,000 lbs on HVS carriage (= 40,000 lbs on tandem axle)
      - Equivalent axle load factor = 2.08
    - 120 psi tire pressure
    - 32" wander pattern normally distributed
  - Constant pavement temperature of 77° F



APT Variation in Asphalt thickness



APT Variation in Asphalt thickness

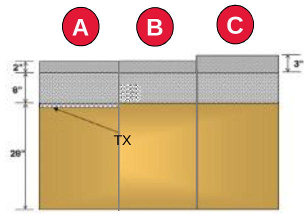
Geogrid Stabilized Section With 2-inch AC After 100,000 ESAL's

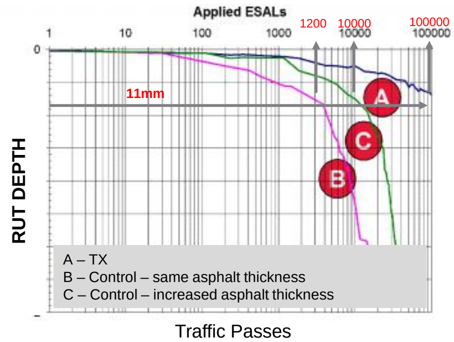
Control Section with 2-inch AC After 24,000 ESAL's

APT Variation in Asphalt thickness

- Accelerated pavement testing carried out by US Corps of engineers - Independently verified as accurate
- Three trial sections – A,B,C
- Full size loaded wheel is trafficked back and forth and the surface is rutted.
- The section A with TX in the base layer showed significantly reduced rutting compared to the control B
- Section A with TriAx even outperformed section C with 25mm more asphalt.
- ✓ TriAx is PROVEN to increase pavement life
- ✓ Alternatively, the pavement layer thickness can be reduced for a given pavement life

✓ 100,000 standard axle passes

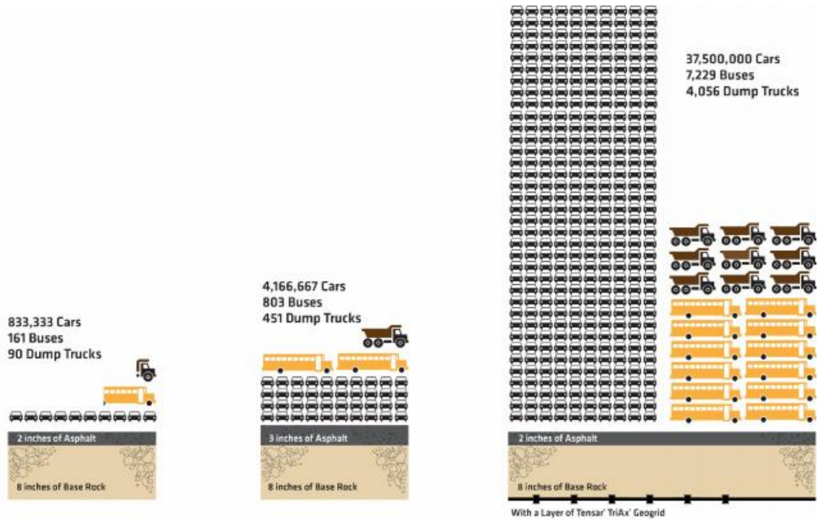




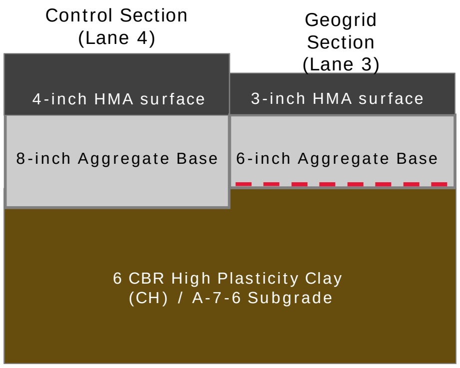
APT Variation in Asphalt thickness

Pavement Section			ESAL'S at Surface Deformation			
Asphalt Thickness (in)	Crushed lime stone (in)	Geogrid	0.25 in.	0.50 in.	0.75 in.	1.0 in.
2	8	Yes (TriAxial)	19,300	100,000+	100,000+	100,000+
2	8	No	1,800	8,100	9,500	13,000
3	8	No	4,220	16,300	24,500	27,870

APT Variation in Asphalt thickness



APT Variation in Asphalt & Base thickness



- Sections designed to validate "equal performance" between a conventional control and an optimized TX5 section

Permanent Surface Deformation Measurements

Test Item	Pavement Structure	ESAL's				
		832	5200	52,000	104,000	200,000
Item 1	4-inch AC 8-inch Base Unstabilized	0.00	0.05"	0.09"	0.17"	0.25"
Item 2	3-inch AC 6-inch Base Stabilized	0.00	0.00	0.13"	0.21"	0.25"

APT Variation in Asphalt & Base thickness

Geogrid Stabilized Section With
3-inch AC and 6-inch Aggregate Base

Control Section with
4-inch AC and 8-inch Aggregate Base

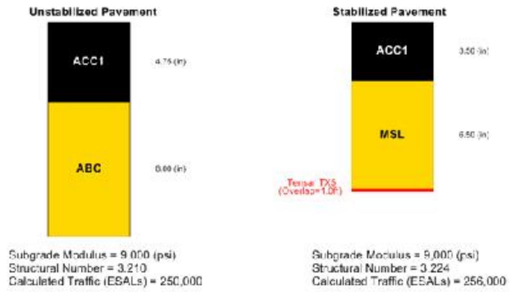
APT Variation in Asphalt & Base thickness

- SpectraPave4-PRO

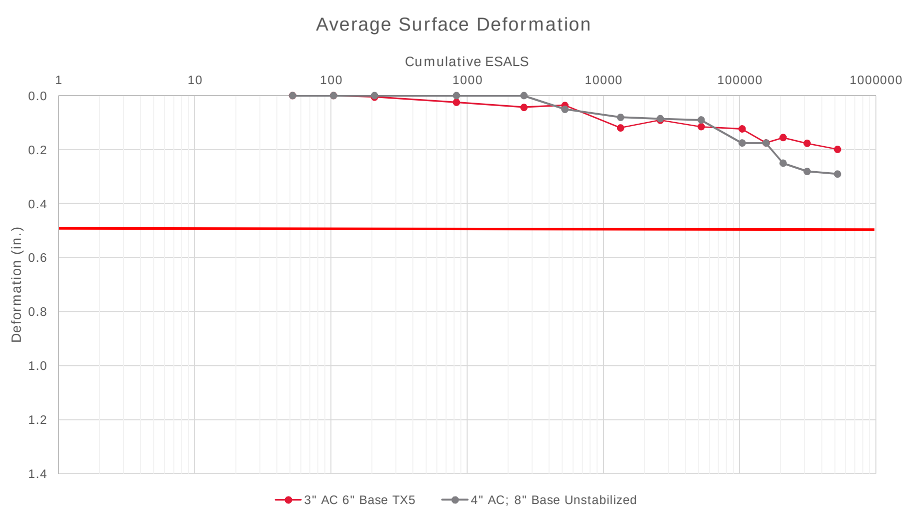
Test Item	Pavement Structure	Permanent Surface Deformation (in.)				
		832 ESAL	5,200 ESAL	52,000 ESAL	104,000 ESAL	200,000 ESAL
Item 1	Control	0.00	0.05	0.09	0.17	0.25
Item 2	Stabilized	0.00	0.00	0.13	0.21	0.28

Table 1. Permanent surface deformation measurements.

Figure 1 demonstrate a good correlation between full scale research and the Tensar SpectraPave4PRO software



Repeat Performance at 500,000 ESALs



Review of Tensar Geogrid Benefit

ARA

- Authors of DARWin 3.1
- Considered experts in the industry of pavement design.
- Developed AASHTOWare Pavement ME design software being
- Consultant for many state DOTs

Ryan R Berg & Associates

- Authored GMA White Paper II – utilized by AASHTO for the development of R50-09.
- Expert in the field of Pavement Design.
- Consultant for FHWA and other groups.

ARA AASHTO '93 Design Verification

- Third party verification of AASHTO '93 pavement design using Tensar TriAx geogrids
- Verified design methodologies used in SpectraPave4-PRO software


INDEPENDENT REVIEW AND VALIDATION OF
TENSAR'S MODIFIED 1993 AASHTO PAVEMENT DESIGN PROCEDURE AND
VERIFICATION OF SPECTRAPAVE4-PRO™ SOFTWARE

Tensar

By

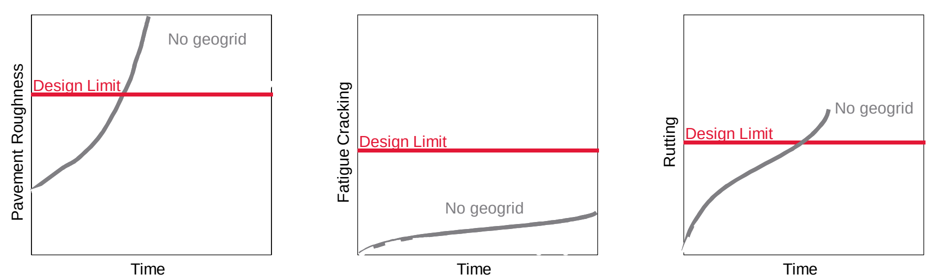
Applied Research Associates, Inc.

April 12, 2013

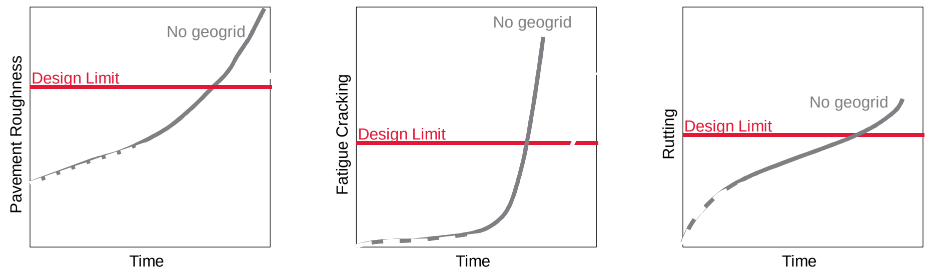
‘93 AASHTO - Pavement Serviceability

- Serviceability is a composite measure
  - Pavement roughness
  - Pavement cracking
  - Pavement rutting
  - Pavement surface distress
- Asphalt thickness drives primary distress mechanism
- SN = $a_1 d_1 + a_2 d_2 m_2 + a_3 d_3 m_3$
  - Tensar geogrid stabilized base course leads to an enhanced “a” value

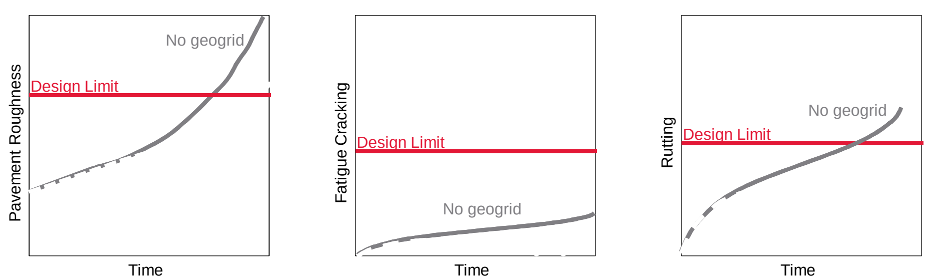
Thin Pavement Primary Distress Roughness & Base/Subgrade Rutting (<3-inch)



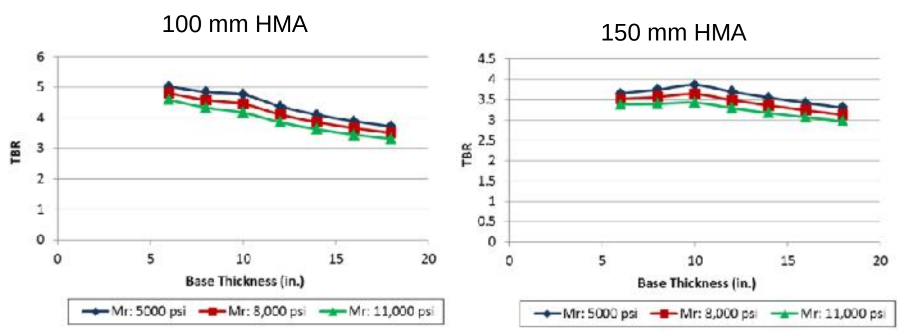
Standard Pavement Primary Distress Fatigue (3-6 inch)



Thick Pavement Primary Distress Roughness & Asphalt Rutting (>6-inch)



Traffic Benefit Ratio (TBR)



34.5 / 55 / 76 MPa

Reliability	90%
Overall standard deviation	0.49
Initial Serviceability Rating	4.2
Terminal Serviceability rating	2.5

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Adoption of the geogrid benefit in AASHTO

Option	Modulus		Traffic
Conventional	a ⇨	AASHTO calculation ⇨	Ns
MSL	Mr ⟶ a* ⇨	AASHTO calculation ⇨	Ns*

$SN = a_1 d_1 + a_2 d_2 m_2 + a_3 d_3 m_3$

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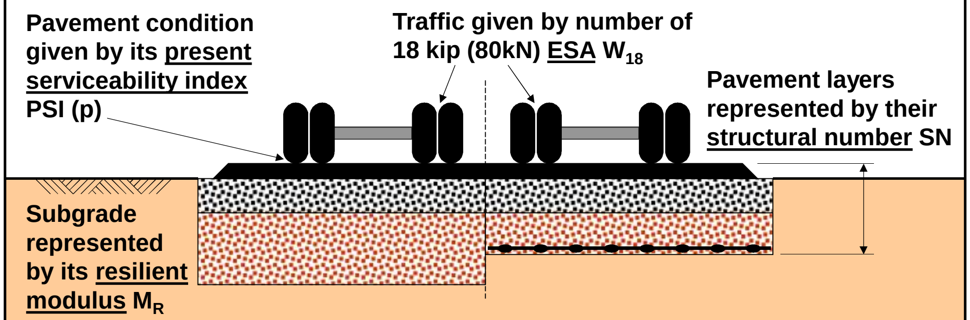
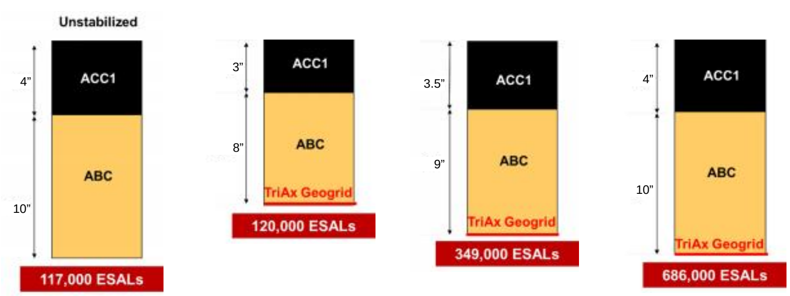
Design with a Mechanically Stabilised Layer



$$\log_{10} W_{18} = Z_R S_0 + 9.36\log_{10}(SN^{msl}+1) - 0.2 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.4+\frac{1094}{(SN^{msl}+1)^{5.19}}} + 2.32\log_{10} M_R - 8.07$$

Tensar.

Pavement Optimization Summary



Original Design Life

Original Design Life, Lowest First Cost

3 X Original Design Life, Same Cost

6 X Original Design Life

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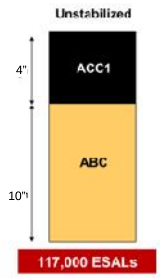
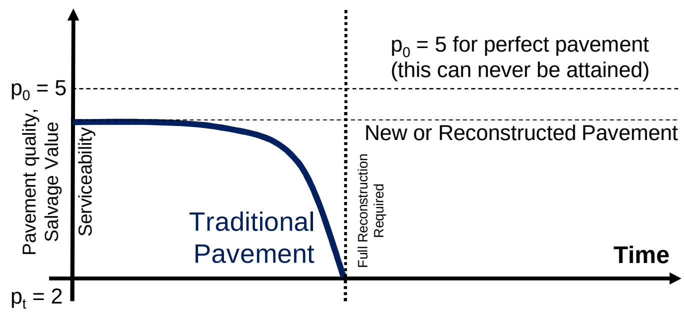
The Development of a Value Proposition

Tensar

Pavement Optimisation – an existing proposal prior to optimisation



Original Design Life



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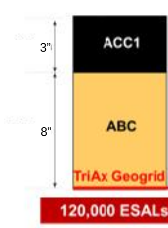
The Development of a Value Proposition

Tensar

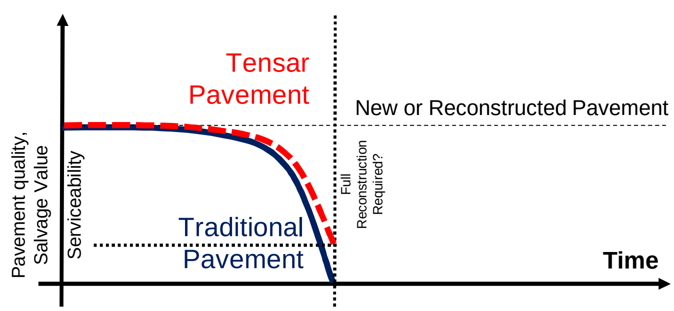
Pavement Optimisation – a short term value proposition approach

- **focus on the construction phase**

Reduce the pavement to its optimum (thinnest) thickness, whilst retaining existing capacity



Original Design Life, Lowest First Cost



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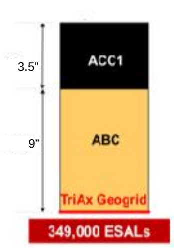
The Development of a Value Proposition

Tensar

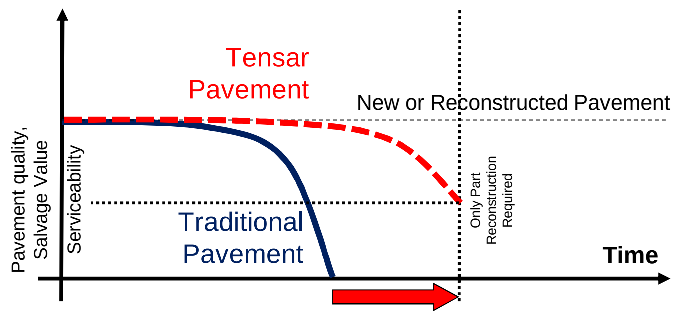
Pavement Optimisation – a medium term value proposition approach

- **focus on the construction phase along with enhanced risk management benefits**

Reduce the pavement thickness, whilst increasing the performance



3 X Original Design Life, Same Cost



Extended life = Reduced Costs

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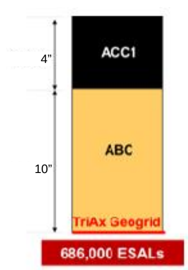
The Development of a Value Proposition

Tensar

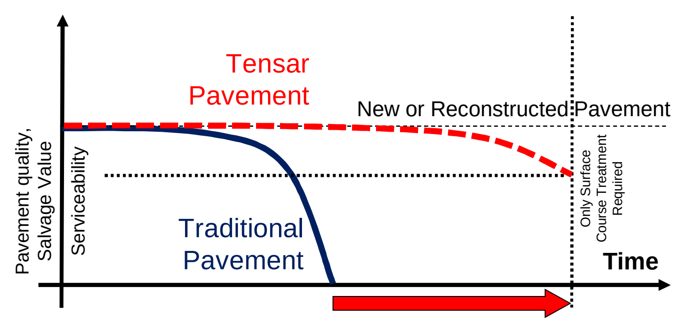
Pavement Optimisation – a long term value proposition approach

- **focus on the whole life cycle for the whole pavement structure**

Maintain the pavement thickness, whilst increasing the whole life design capacity



6 X Original Design Life



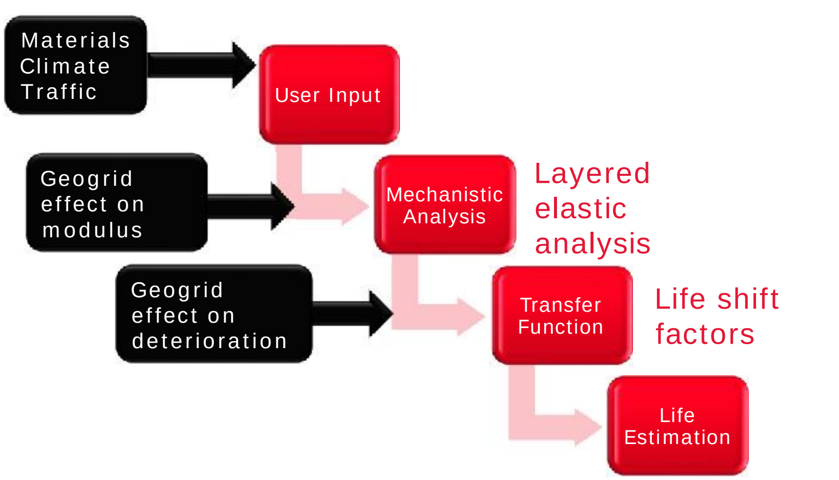
Extended life = Reduced Costs

Tensar. THE COMPANY YOU CAN BUILD ON

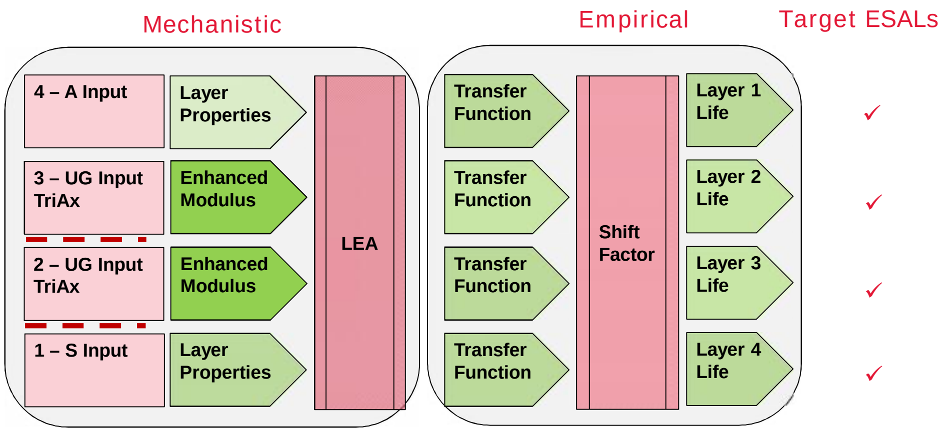
Lecture Outline

- Tensar International
- Stabilization Function & Confirmation Through Research
- AASHTO Empirical Approach
- Mechanistic-Empirical Approach

Incorporating the geogrid effect into M-E Analysis



Incorporating the geogrid effect into M-E Analysis



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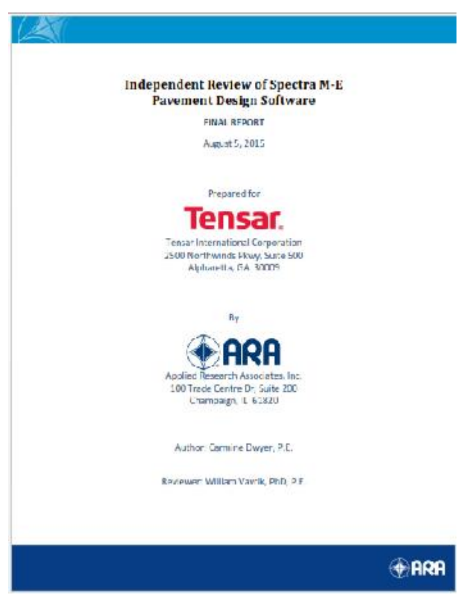
Mechanistic-Empirical Analysis

ARA

- Experts in the industry of pavement design.
- Developed AASHTOWare Pavement ME design software used throughout North America today
- Currently Perform M-E Validation and Calibration for numerous State Department of Transportation



Independent Review of Spectra M-E Pavement Design Software

FINAL REPORT

August 5, 2015

Prepared for

Tensar

Tensar International Corporation
2500 Northwinds Pkwy, Suite 500
Alpharetta, GA 30009

By

ARA

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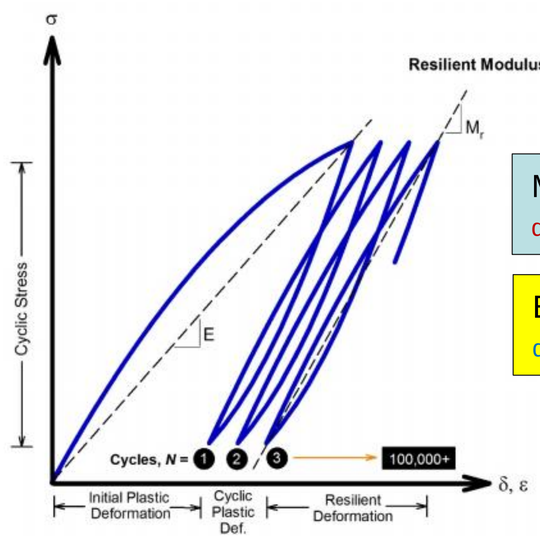
ARA

Lecture Outline

Tensar

- Tensar International
- Stabilization Function & Confirmation Through Research
- AASHTO Empirical Approach
- Mechanistic-Empirical Approach
- New Pavement Performance Evaluation Technologies

Elastic versus *resilient* modulus



$M_r = (1-v^2)\ f\ \sigma_o\ (a / d_r)$

d_r = ***recoverable*** deformation

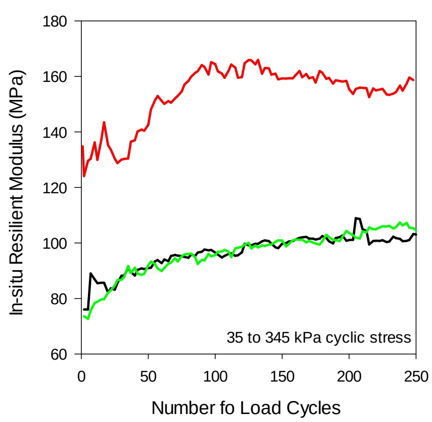
$E = (1-v^2)\ f\ \sigma_o\ (a / d_0)$

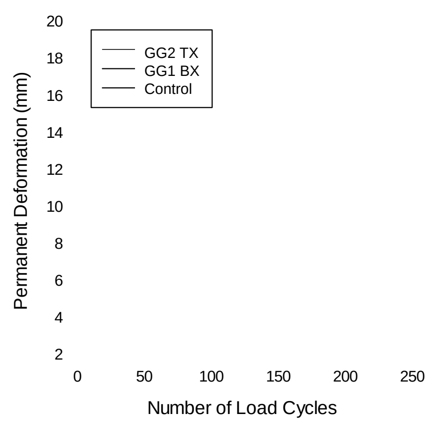
d_o = ***Elastic*** deformation

Assessment of Pavement Foundation Stiffness using Cyclic Plate Load Test, Presented by Mark H. Wayne

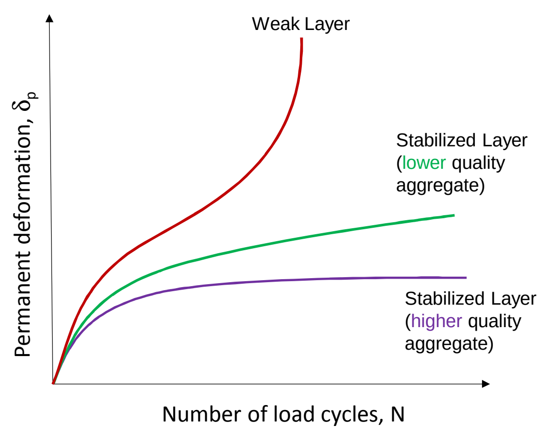
In-situ Resilient Modulus

- **Influence of load cycles**





A power model describes the permanent deformation versus load cycles response to provide deformation forecasting comparisons.



$$d_p = CN^d$$

f (material type, physical state, and stress conditions, Li and Selig 1994)

f (shear stress magnitude, aggregate abrasion resistance, resiliency of stabilizer)

Monismith et al. (1975) described the power model relationship for relating permanent strain to cycle loadings.

Post-compaction permanent strain is a function of the shear stress magnitude and can reach an equilibrium state following the “shakedown” concept (see Dawson and Feller 1999).

Ingios 2-layer testing to determine base and subgrade layer moduli values

Two-Layered Analysis using Odemark's method of equivalent thickness concept

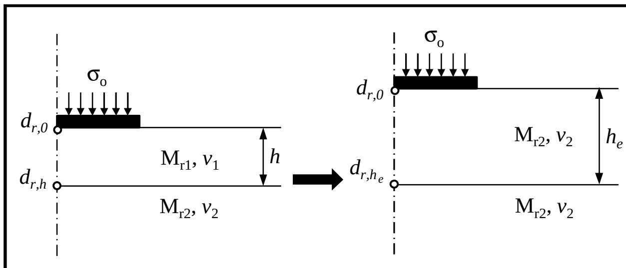


Illustration of Odemark's Method of Equivalent Thickness (MET) concept.

$$h_e = h \times \sqrt[3]{\frac{M_{r1}(1-v_1^2)}{M_{r2}(1-v_2^2)}}$$

Calculating Base and Subgrade Layer Modulus – (AASHTO 1993)

$$M_{r(sg)} = \frac{(1-¬^2)\cdot P}{®\cdot r' \cdot ¢_{r,r'}}$$

← Subgrade Layer Modulus

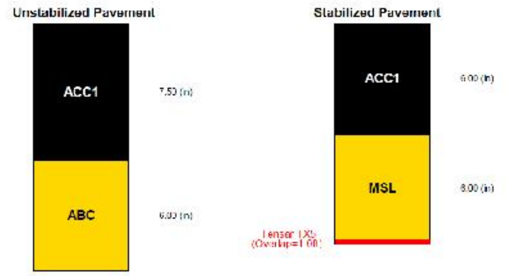
$$¢_c = (1-¬^2)±_0 rf \left[\frac{1}{M_{r(sg)}\sqrt{1+\left(\frac{h}{r}\times\sqrt[3]{\frac{M_{r(base)}(1-v_1^2)}{M_{r(sg)}(1-v_2^2)}}\right)^2}} + \frac{\left(1-\frac{1}{\sqrt{1+\left(\frac{h}{r}\right)^2}}\right)}{M_{r(base)}} \right]$$

Base Layer Modulus using an iterative solution

Automated Plate Load Testing Summary
Hunt Highway, Arizona

Tensar

Pavement Design Options



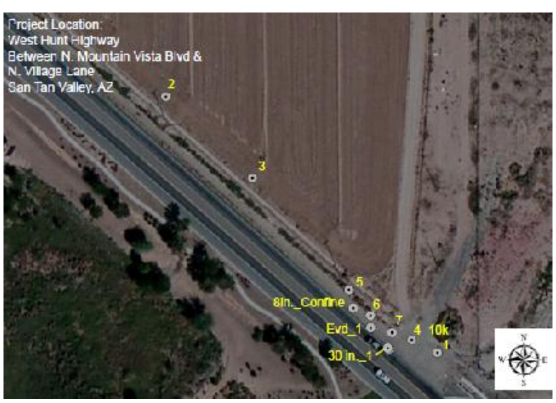
Subgrade Modulus = 15,271 (psi)
Structural Number = 3.870
Calculated Traffic (ESALs) = 8,476,000

Subgrade Modulus = 15,271 (psi)
Structural Number = 3.882
Calculated Traffic (ESALs) = 8,634,000

Savings >$118,000

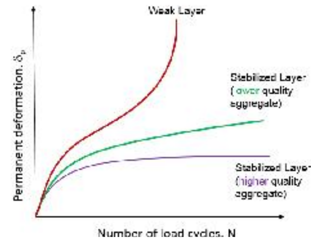
Automated Plate Load Testing Summary
Hunt Highway, Arizona

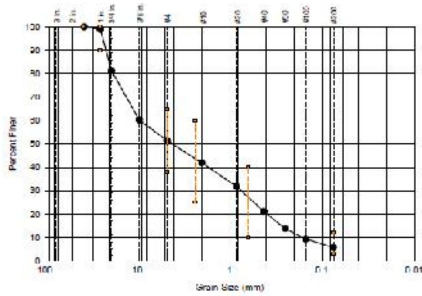
Tensar

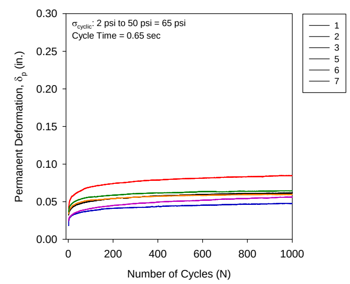


Automated Plate Load Testing Summary
Hunt Highway, Arizona

Tensar



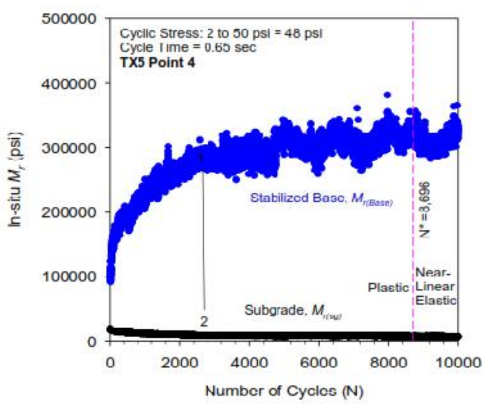




Automated Plate Load Testing Summary
Hunt Highway, Arizona

Tensar

"For the 10,000 cycle test, the in-situ resilient modulus rapidly increased in the aggregate base layer for the first ~3000 cycles and then continued to increase at a slower rate. Based on a permanent deformation rate of 0.0001in./cycle the transition from plastic deformation accumulation to near-linear elastic occurs at N* = 8,696 cycles. At N*, the in-situ Mr was about 321,881 psi (2x higher than the average value from the 1000 cycle tests)."



Automated Plate Load Testing Summary
Hunt Highway, Arizona

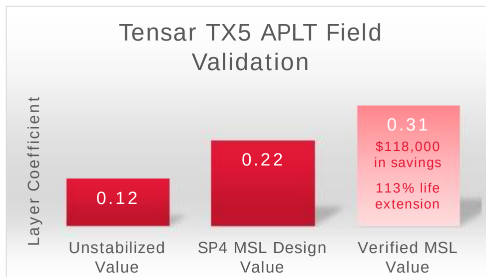
Tensar

Research Organization
Ingios Geotechics, Inc.

Section Tested
6-inches of base over TX5

Testing Conducted
Mr of the mechanically stabilized base course
Mr of the subgrade
Mr composite modulus
Modulus of subgrade reaction (k)
Ev1 and Ev2 strain modulus testing
Resilient deflections (scaling exponent)

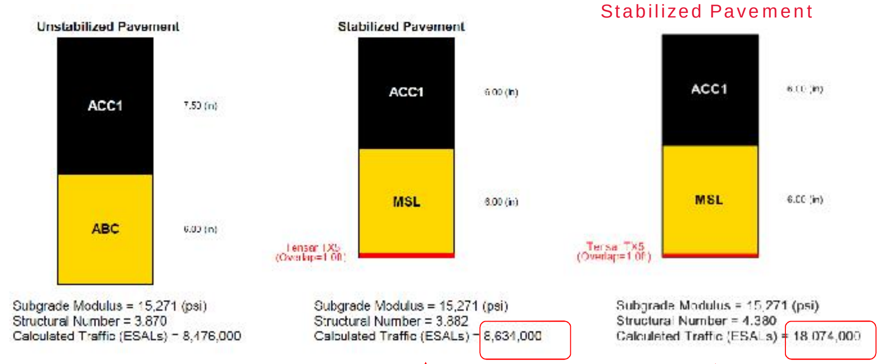
Mr (Ave) base	155,694 psi
Mr (Ave) subgrade	16,144 psi
Mr (Ave) composite	34,251 psi
Ev2 (top of stabilized base)	15.23 ksi
Ev2/Ev1 Ratio	1.60
K-value (stabilized)	392 pci



Automated Plate Load Testing Summary
Hunt Highway, Arizona

Tensar

Actual Tested Values of the Stabilized Pavement



Savings >$118,000 for both sections.
Actual APLT results showed a layer coefficient of 0.31 – providing 113% greater anticipated design life.

PaVision

- **PaVision is low cost, high quality data collection system**
  - Low cost, easy to install in use, highly mobile
- **Allows agencies to collect & analyze pavement distress**
  - Cracking & surface distresses
  - Roughness
- **Reports pavement condition index, roughness, and distress**
  - Data analysis is fully automated
  - Data ready for import to MicroPAVER & other systems

A Disruptive Innovation in Pavement Data Collection

PaVision Equipment

PaVision Data Collection

- Integrated with Google Maps

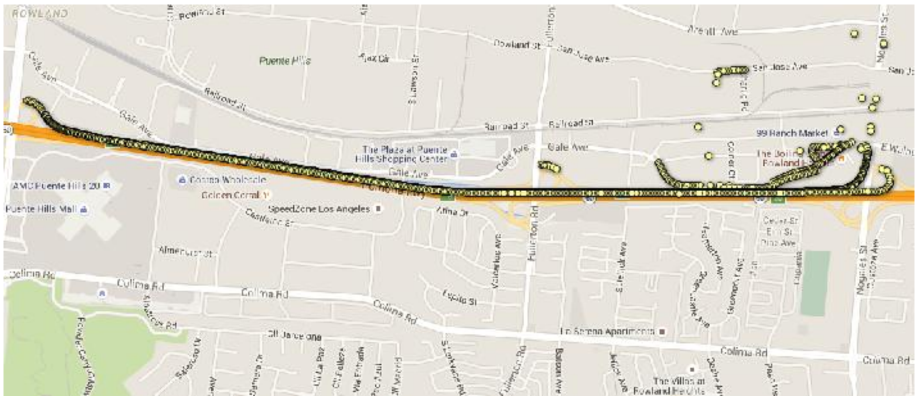


Image File Tagged to Collection Point

Questions

Tensar