Inverted Pavements

Southeastern Asphalt User/Producer Group

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Nashville, TN

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What is an Inverted Pavement

2" to 3¼" HMA

6" to 8" Unbound Aggregate Base
Compacted to 100% + Modified Proctor

6" to 10" Cement-Treated Base
(≈ 4% cement)

Prepared Subgrade

Inverted Pavement History

- Used successfully in South Africa since the 1970's

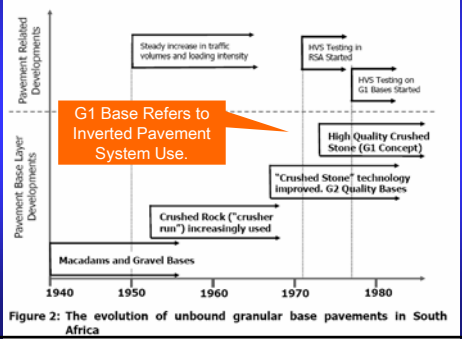


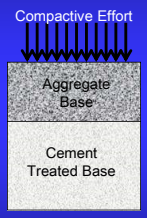
Figure 2: The evolution of unbound granular base pavements in South Africa

Inverted Pavement History

- Traffic levels increase
- US and Europe relied on thicker asphalt & increased concrete use
  - Not economically viable in South Africa
- Investigated ways to improve roads by improving the aggregate base
  - Instituted strict gradation limits
  - limited plasticity

Inverted Pavement History

- Wanted to improve/increase the density aggregate base
- Led to a cemented subbase being used as an "anvil" on which to compact the aggregate base
- Enables high level of compaction



Inverted Pavement History

- Soon discovered that this pavement
  - Could handle the highest traffic loads
  - Was impervious to water ingress
  - Performed well even when wet
- Decades of research have shown these pavements can be used on roads up to 50 to 100 million ESALs

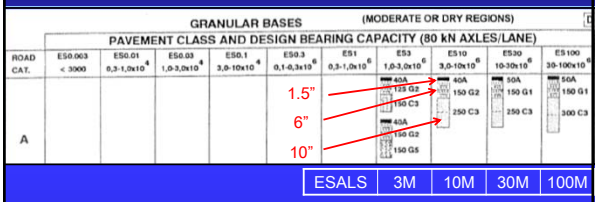
Road (Pavement) Categories
South Africa

TABLE 1
Definition of the road categories

	ROAD CATEGORY			
	A	B	C	D
Description	Major interurban freeways and major rural roads	Interurban collectors and rural roads	Lightly trafficked rural roads, strategic roads	Rural access roads
Importance	Very important	Important	Less important	Less important
Service level	Very high level of service	High level of service	Moderate level of service	Moderate to low level of service
TYPICAL PAVEMENT CHARACTERISTICS				
RISK	**Very low**	**Low**	**Medium**	**High**
Approximate Design Reliability (%) *	95	90	80	50
Total Equivalent Traffic Loading (E80/lane) **	3 - 100 x 10^6 over 20 years	0,3 - 10 x 10^6 Depending on design strategy	< 3 x 10^6 Depending on design strategy	< 1 x 10^6 Depending on design strategy

Structural Design of Flexible Pavements, Draft Technical Recommendation for Highways (TRH) 4, Pretoria, South Africa, 1996

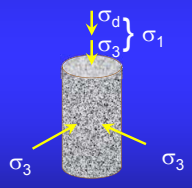
Typical Pavement Structural Designs
South Africa



ESALS	3M	10M	30M	100M

Structural Design of Flexible Pavements, Draft Technical Recommendation for Highways (TRH) 4, Pretoria, South Africa, 1996

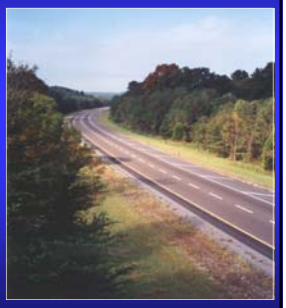
Mechanics of Inverted Pavement Systems



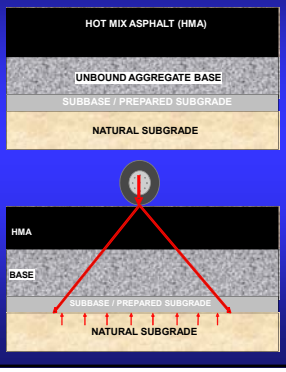
$\theta = \sigma_1 + 2\sigma_3$

Traditional Flexible Pavement System

- Successive stiffer layers from subgrade up
- Each layer "absorbs" the load as it's distributed to subgrade
- Traditional designs put unbound aggregate base on top of subgrade
- Built on the idea of protecting the layer below



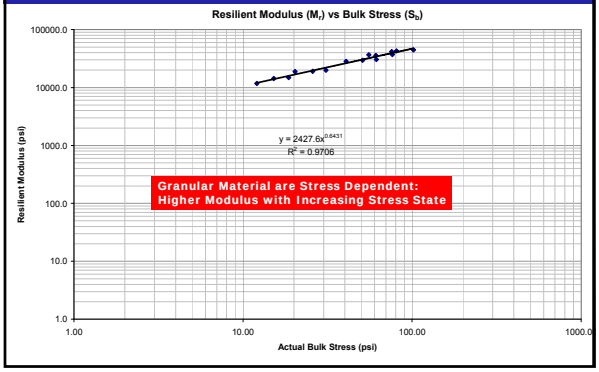
Flexible Pavement System



Inverted Pavement

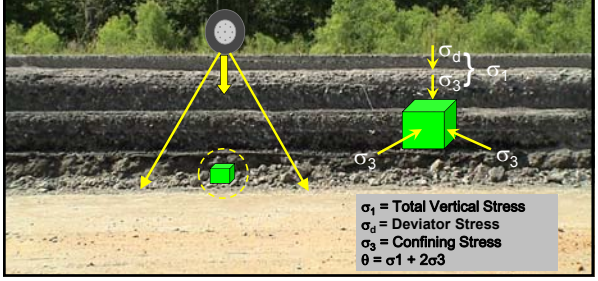
- Changes the way we think about pavement
- Utilizes the stress dependency of graded aggregate base

Resilient Modulus Stress Dependency



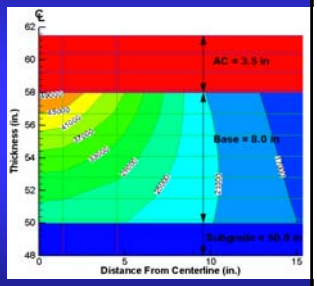
What is Bulk Stress?

- Bulk stress (θ) represents the total stress condition that a given location in the pavement experiences.
- θ is higher closer to the surface



Stress Dependency

- Higher stresses in unbound aggregate base result in increased stiffness and strength
- Value of the base is best captured when it is placed near the surface where stresses are the greatest
- Inverted pavement moves base to the top where it performs more efficiently



Credit: Erol Tutumluer

Inverted Flexible Pavement

2" to 3¼" HMA

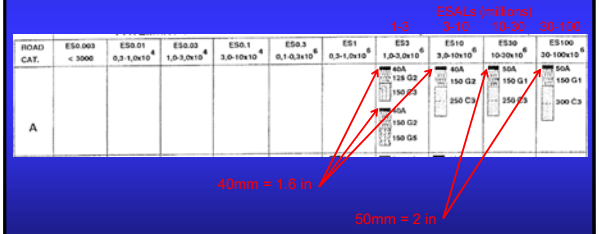
6" to 8" Unbound Aggregate Base
Compacted to 100% + Modified Proctor

6" to 10" Cement-Treated Base
(≈ 4% cement)

Prepared Subgrade

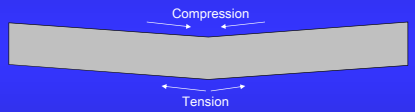
Isn't This Asphalt Too Thin?

- The South African protocol uses very thin asphalt layers



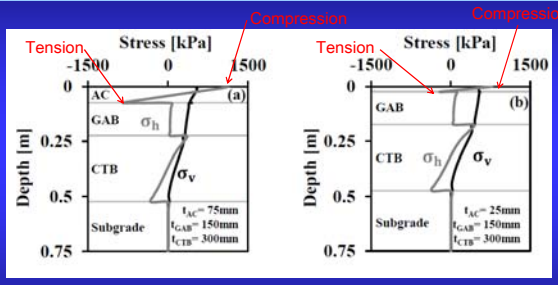
Recent Research

- Research at Georgia Tech on inverted systems
- Traditional pavement, asphalt acts like a beam



- Inverted pavement, thin asphalt performs like a membrane

Beam versus Membrane



Source: Papadopoulos, "Performance of Unbound Aggregate Bases and Implications for Inverted Base Pavements", May 2014

Inverted Pavements

- CTB used as strong foundation
  - Anvil to compact aggregate base against
- Aggregate base placed in the optimal position
  - Near the surface
  - High stress increases stiffness
- Thin asphalt protects the aggregate base
  - Acts like a membrane
  - Reduced tension

Material Specifications

Aggregate Base

Sieve Size	G1 Base	TDOT Grading D	NCDOT ABC	GDOT GAB
37.5 mm (1.5")	100	100	100	95-100
25 mm (1")	84-94	85-100	75-97	
19 mm (3/4")	71-84	60-95		60-90
12.5 mm (1/2")	59-75		55-80	
9.5 mm (3/8")		50-80		
4.75 mm (#4)	36-53	40-65	35-55	
2.00 mm (#10)	23-40		25-45	25-45
1.18 mm (#16)		20-40		
0.425 mm (#40)	11-24		14-30	
0.150 mm (#100)		9-18		
0.075 mm (#200)	4-12		4-12	4-11

Aggregate Base

- Plasticity Index < 4
- Unweathered crushed stone

Cement Treated Base

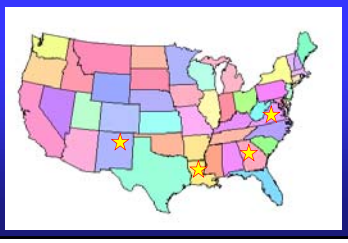
Source: Rapid International USA

- Strength: 200 to 400 psi
- Can use the same aggregate base or lower quality stone
  - Fine aggregate such as screenings
- ≈ 4% cement

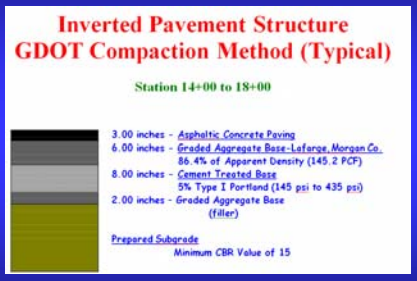
Asphalt Surfacing

- South Africa uses both gap graded and well graded
- Both modified and unmodified binders
- Georgia Tech research indicates more flexible mixes with unmodified binders may be better
  - 4.75 mm mixes may be ideal

Inverted Pavements in the U.S.



Morgan County Quarry Haul Road (GA)



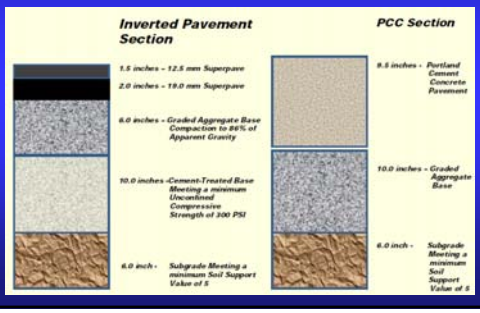
- Constructed in 2003
- Still performing well

2001 NSSGA Capstone Award

- Blue Circle (Lafarge, Martin Marietta) Morgan County, GA quarry haul road constructed in 2001.
  - December 2007 evaluation showed no rutting or cracking present.
  - Approximately 900,000 ESALs at that time.

LaGrange Bypass, GA

- Constructed in 2009



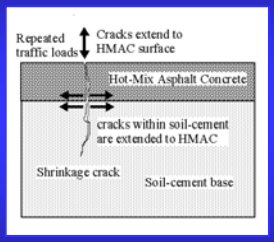
Luck Stone, Bull Run Quarry, VA

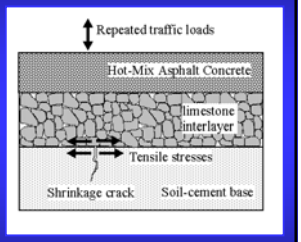
- Constructed in 2011
- FHWA participating
  - Installed pressure and strain gauges
- Still gathering data

I-25 in Northern New Mexico

- Interstate 25, Raton, NM
- 54+ inches of snow per year
- Constructed in 2012

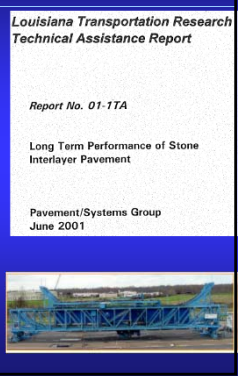
Louisiana DOT Stone Interlayer Pavements





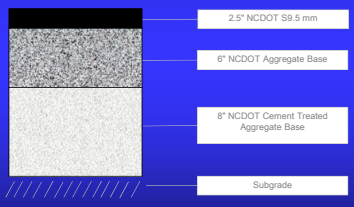
Inverted Pavement Performance

- Louisiana DOTD Field Evaluation Project 97 constructed in 1991
  - Inverted: 3.5" HMA / 4" crushed limestone / 6" of soil cement base
  - Control: 3.5" HMA / 8.5" soil cement base
  - 10 year evaluation showed almost 50 percent reduction in cracking versus typical flexible section
- Accelerated pavement testing
  - Stone interlayer (inverted) pavement carried over four times the ESALs of the conventional pavement lane before failure.
- Louisiana DOTD adopted stone interlayer base course (inverted) design as a standard option.



Vulcan Materials

- Planned for 2015
- Road relocation in a Charlotte, NC Quarry



Cost Comparisons

- Georgia quarry haul road (2001)
  - 22% savings compared to typical structure
- Georgia DOT LaGrange Bypass
  - Estimated life cycle cost analysis (LCCA) savings of $131k per lane mile
- Virginia DOT Highway 569 Relocation near Bull Run
  - 20 to 30% estimated savings

Inverted Pavement Key Points

- Uses thin-lift asphalt surface
  - Allows for "mill and fill" surface maintenance
- Less cracking and improved fatigue life due to lower tensile stresses at bottom of the asphalt layer
- 6"- 8" optimal thickness for unbound base to maintain increased bulk stress state condition
- Low cement content on cement treated base (~4 percent)
- Cement treated base can be made of cost-effective materials

Inverted Pavement Performance
South Africa

- *"The Economic Benefits of HVS Development Work on G1 Base Pavements," July 2005*
  - "Pavements with high quality Crushed Stone bases are capable of accommodating traffic demands of up to 50 million standard axles." [1.8" asphalt]
  - "The optimum thickness for a G1 base layer on a cemented subbase is 150 mm [6"]."
  - "If a pavement with a Crushed Stone base is maintained with resurfacings at appropriate intervals, the pavement can provide service for an indefinite time."
  - "The high quality, high density Crushed Stone (G1), placed on a thick cemented subbase (200 mm [8"] or more), showed the least permanent deformation under loading and was also the least sensitive to moisture."

Inverted Pavement Summary

Inverted Pavement Summary

- Inverted Pavements consist of
  - Thin HMA layer
  - Base
  - Cement Treated Base
  - Subgrade
- Nothing new, just changing the order from a typical flexible system
- Layers placed in their optimal position to perform
- Potential cost savings compared to traditional pavements

Questions…