Inverted Pavements Synthesis

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16. Abstract Inverted pavement (IP) consists of a lower modulus layer, typically an unbound crushed stone base, sandwiched between a cement-stabilized layer at the bottom and a thin asphalt concrete (AC) surfacing. This type of pavement is extensively used in South Africa, where it has proven to be an effective, low-cost solution for high-trafficked roads. The use of IP in the United States is not widely implemented, with only a few sections identified across the country. This report provides a review of the design, current practice, use, and performance of IP, along with a compilation of US case studies. Construction and performance data for eight IP sections in United States were collected and analyzed. Most of the IP sections have performed well, except for one section, which was subjected to severe weathering that includes high levels of precipitation and freezing conditions. Life-cycle cost analysis (LCCA) and life-cycle assessment (LCA) analysis may suggest the feasibility of constructing IP to reduce costs and potentially to decrease environmental impacts compared to conventional pavements (CP). To achieve this goal, the best construction and maintenance practices must be followed. These include using appropriate AC thickness, implementing a regular maintenance program to minimize moisture penetration to the unbound layer(s), allowing the unbound layer to dry to a maximum allowed moisture content before constructing subsequent layers, and ensuring adequate drainage features throughout the IP service life.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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EXECUTIVE SUMMARY

Inverted pavement (IP) consists of a non-stabilized crushed stone base or graded unbound aggregate base (UAB) sandwiched between a cement-stabilized layer at the bottom and a thin asphalt concrete (AC) surfacing.

Although the construction of pavements using thick unbound aggregate layers is a common practice in countries such as South Africa, IP experience has been limited in the United States. The limitation of its use in the United States could be related to the following reasons: (1) limited experience with this type of pavement design and construction, (2) lack of technology transfer from other countries on this technique (e.g., South African slushing technique), and (3) Inadequate quantified field data-driven life-cycle cost analysis (LCCA) and life-cycle assessment (LCA).

Eight cases of IP in the United States, in different climatic regions, were identified, and available information was collected. Most case studies suggested that placement of unbound base layer between asphalt concrete (AC) and cement-treated base (CTB) layers in IPs is effective in delaying reflection of cracking from the CTB layer to the pavement surface. Timely crack sealing is required to control potential pavement deterioration due to water infiltration.

Most of the IP cases in the United States included relatively thicker AC layers than those in South Africa. Moreover, maximum moisture condition limits are specified for the unbound granular base in South Africa prior to allowing the application of a prime coat and constructing the following layers. Such specifications were not identified in the United States bidding documents. A regular and responsive crack sealing program was also absent in some cases.

Inverted pavement may be constructed in favorable climates. Otherwise, IP implementation in harsh winter climatic conditions, with higher precipitation and freeze-thaw conditions, could be challenging. As a result, performance of inverted pavements showed some variabilities and have not reached its maximum design potential in some of the applications.

Most of the IP case studies showed satisfactory performance. Based on the case studies, the following suggestions apply: consider IP primarily in relatively dry and warm environments, use of relatively thinner AC layers, apply a prime coat on top of the unbound granular base, implement a responsive and effective crack-sealing program, specify a maximum moisture content in the granular base course layer prior to prime coat application and AC layer construction, install adequate drainage, and possibly a chip seal following the prime coat on top of the unbound granular base. Additionally, one of the case studies in Georgia indicated that the use of the South African slushing technique could be beneficial for long-term pavement performance compared to the same pavement configuration constructed without the slushing technique.

Utilizing the limited available information, LCCA and LCA analysis were performed. It is possible to reduce costs and environmental impacts when using IPs, if optimum pavement performance is achieved.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ALF	accelerated loading facility
APT	accelerated pavement testing
ARRB	Australian Road Research Board
ATLAS	Accelerated Testing and Loading Assembly
BLI	base layer index
CBR	California bearing ratio
CI	Composite index
COTO	Committee of Transport Officials
COV	coefficient of variation
CP	conventional pavement
CTB	cement-treated base
DCP	dynamic cone penetrometer
DS	draft standard
ESAL	equivalent single axle loads
FE	finite element
FHWA	Federal Highway Administration
FWD	falling weight deflectometer
HPMS	highway performance monitoring system
HVS	heavy vehicle simulator
ICAR	International Center for Aggregates Research
ICT	Illinois Center for Transportation
IDOT	Illinois Department of Transportation

IP	inverted pavement
IRI	international roughness index
JPCP	jointed portland cement concrete pavement
LCA	life-cycle assessment
LCCA	life-cycle cost analysis
LLI	lower layer index
LTPP	long-term pavement performance
LWP	left wheel path
MDD	maximum dry density
MLI	middle layer index
NCHRP	National Cooperative Highway Research Program
NMDOT	New Mexico Department of Transportation
NMAS	nominal maximum aggregate size
OGA	open-graded asphalt
OGFC	open-graded friction course
OMC	optimum moisture content
PACES	Pavement Condition Evaluation System
PCC	portland cement concrete
PCR	pavement condition rating
PI	plasticity index
PMS	pavement management system
PSI	present serviceability index
RAP	reclaimed asphalt pavement
RoC	radius of curvature
RWP	right wheel path

SAPEM	South African Pavement Engineering Manual
SMA	stone matrix asphalt
SMD	surface modulus differential
SN	Structural number
UAB	unbound aggregate base
UCS	unconfined compressive strength
VDOT	Virginia Department of Transportation
VTRC	Virginia Transportation Research Council

CHAPTER 1. INTRODUCTION

BACKGROUND

Inverted pavement (IP) consists of a non-stabilized crushed stone base or graded unbound aggregate base (UAB) sandwiched between a cement-stabilized layer at the bottom and a thin asphalt concrete (AC) surfacing. The use of unbound aggregate structural pavement layers in low, medium, and moderately high-volume roads can be cost effective. Unbound aggregate is recyclable and can reduce the use of relatively expensive and less environmentally friendly bound materials.

To investigate worldwide innovative programs for pavement preservation, a scanning study tour of France, South Africa, and Australia was conducted (Beatty et al. 2002). The study was sponsored by the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and the National Cooperative Highway Research Program (NCHRP). The study reported on pavement structures used by the visited countries to ensure long-lasting and well-performing pavement systems. It was noted that Australia and South Africa use thick aggregate layers surfaced with a relatively thin AC layer. The practice in Australia is using multiple unbound aggregate layers, whereas the South African practice is constructing thick crushed stone base layers over stabilized subbase layers. The superior-performing crushed stone layers used in South African IP are commonly known as G1 base (De Beer 2012, Horne et al. 1997, Jooste and Sampson 2005). These pavements are also referred to as stone interlayer pavements, G1-base pavements, inverted base pavements, sandwich pavements, and/or upside-down pavements (Lewis et al. 2012).

Conventional pavement (CP) systems rely on a combination of AC or portland cement concrete (PCC) on top of an aggregate base layer(s) to transfer load to the subgrade. All three components use aggregates as their primary constituent. Classic pavement designs call for high-modulus, more-durable layers toward the surface. Inverted pavement, on the other hand, is a composite system composed of AC top layer(s) and a well-compacted unbound crushed stone base layer(s) placed over a stiffer bound subbase that is typically cement treated. Mechanistically, this configuration (using stabilized subbase on top of subgrade) provides a relatively strong reaction platform. In addition to better load distribution, this configuration results in (1) better compaction of non-stabilized materials placed over the stabilized layers; (2) better utilization of compressive stresses induced in the granular aggregate base; (3) reduction in tensile stresses at the aggregate base course-AC interface (Barksdale and Todres 1983); and (4) economic advantages as less AC materials are required. Figure 1 illustrates a typical CP (left) and an IP (right).

In IP sections, AC layers are typically thin; therefore, their contribution to the structural capacity of the pavements is typically limited. However, they ensure ride quality and protect underlying pavement layers from water infiltration (e.g., chip seal in Australia). The unbound aggregate layer, on the other hand, is the primary load-bearing layer in IP structures. Summarizing the construction practices and layer configurations of these pavement systems, De Beer (2012) described IP as:

> A structural pavement system, where the static modulus of the unbound base layer is lower compared with the supporting (mainly lightly cementitious) subbase layers. Unbound base layer (crushed rock) of extremely high bearing capacity is typically covered with 0.47 inches (12 mm) to 1.97 inches (50 mm) asphalt layer for sealing and functional properties.

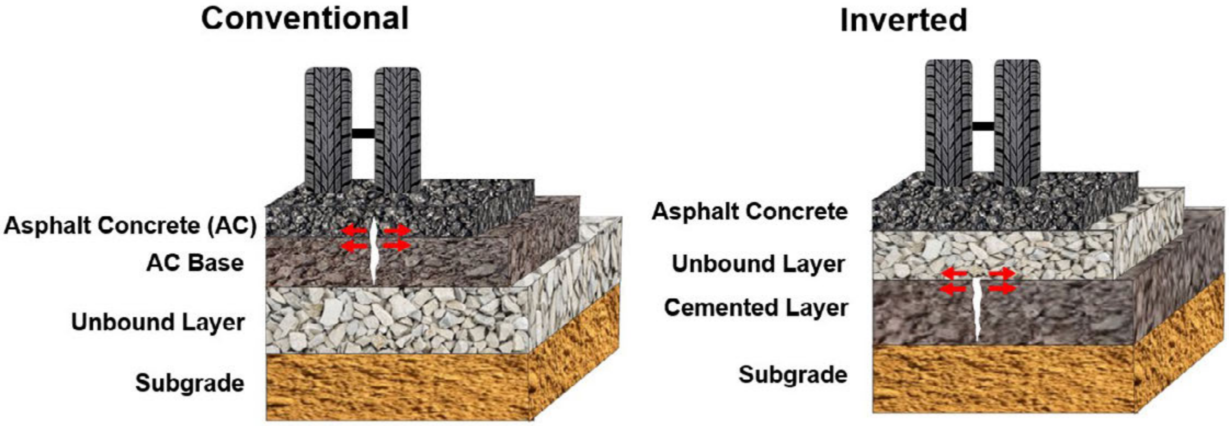


Figure 1. Illustration. Conventional pavement and inverted pavement.

The relatively thin AC surface typically induces considerably high-stress states within the aggregate base under wheel loading. Owing to the stress-hardening nature of unbound aggregates, these high-stress states typically lead to the aggregate layer developing very high elastic modulus values, often of the order of 100 ksi (Maree, van Zyl, and Freeme 1982; Maree et al. 1982; O'Neil, Mahoney, and Jackson 1992). Such high modulus levels will effectively dissipate traffic-induced stresses.

The unbound aggregate base is primarily a structural load-carrying component in IP sections. When properly compacted, the unbound aggregate base dissipates traffic-induced stresses laterally through interparticle contact points. The combination of stiff unbound aggregate base and cement-stabilized subbase results in a significant reduction in vertical compressive stress levels on top of the subgrade, thus minimizing the possibility of secondary rutting in the subgrade. However, attention should be given to minimize secondary rutting in the unbound base layer because of the considerably high stresses caused by axle loading. South Africa uses innovative compaction procedures (the slushing technique) to minimize secondary rutting in the base layer.

NCHRP Synthesis 445 reported consensus among surveyed researchers regarding the benefits of alternative base course applications such as the concept of a strong pavement foundation in IP (Tutumluer 2013). Appropriate use of unbound aggregate base and stabilized subbase layers as the primary structural component in pavement systems could contribute significantly to the performance of US highway systems, based on the outcome of the limited applications in the United States and extensive experience in countries such as South Africa. Performance of IP sections constructed using alternative recycled, by-product, and nontraditional aggregate materials should be quantified for feasibility, cost effectiveness, sustainability, and long-term performance.

An example of the aforementioned potential benefits was well illustrated in a recent tech brief by Ozer and Al-Qadi (2021). In the past three decades, Louisiana Department of Transportation and Development (LaDOTD) has been using semirigid pavement structures—consisting of an AC surface on a soil-cement base (or cement-stabilized base, CSB) and a lime-treated subgrade—to overcome soft soils and poor support conditions. The first application was in 1991 on LA-97. Since then, thousands of miles of highway with soil-cement bases have been paved in Louisiana, some of which have been in service for more than 40 years (Titi et al. 2003).

LaDOTD called the design a stone interlayer pavement, but it is the same as an IP. The LaDOTD application is unique because it is optimized for locally limited crushed aggregate sources, and different design configurations could be used to optimize sustainability benefits, given that good-quality crushed aggregate sources are available. Based on Ozer and Al-Qadi (2021) and Titi et al. (2003), IP performance was satisfactory, reduced greenhouse gas (GHG) emissions, and the cost was a function of aggregate availability.

In summary, IP applications appear to perform favorably, be cost effective, and have the potential to reduce GHG compared to CP structures. Although use of IP is a common practice in some countries such as South Africa, use in the United States has been limited. This could be related to the following reasons: (1) limited experience with this type of pavement design and construction, (2) lack of technology transfer from other countries (e.g., South African slushing technique), and (3) lack of accurate life-cycle cost analysis (LCCA) and life-cycle assessment (LCA) quantification.

OBJECTIVE AND SCOPE

The objective of this study was to provide a state-of-the-technology synthesis on the use of IP based on a worldwide review of available literature, along with the current practice, use, and performance of IP. To achieve the proposed objective, two main tasks were conducted: a literature review on IP best practices, and a review of IP case studies in the United States. The literature review included aspects of design, construction, and maintenance of IPs. Emphases were given to experiences in South Africa, Australia, and the United States. The review of IP cases in the United States, included collecting design, construction, maintenance and rehabilitation, and pavement performance data; conducting field visits and pavement testing; discussions with departments of transportation, academia, and industry; analysis of construction testing data, historical pavement performance, and falling weight deflectometer (FWD) data; and costs and environmental impacts assessments.

CHAPTER 2. CURRENT STATE OF KNOWLEDGE

INTERNATIONAL SCANNING TOURS

The FHWA was involved in two international scanning tours related to IP structural configuration in 1997 and 2002 (Beatty et al. 2002, FHWA 1997). The 1997 scanning tour reported that the South African IP design and construction method used an unbound crushed stone layer compacted to relatively high density and overlaid with a relatively thin AC surface (FHWA 1997). Specifically, the South African G1 base technology was highlighted and suggested as a pilot project in the United States. In the 2002 scan, the IP design in South Africa was noted as providing a strong structure with a long service life (Beatty et al. 2002). A technology transfer video developed in 1998 by the South African National Road Agency and the FHWA was presented at the 1999 Transportation Research Board annual meetings.

The second international scanning study was sponsored by FHWA, AASHTO, and NCHRP. The tour included France, South Africa, and Australia and focused on innovative programs for pavement preservation (Beatty et al. 2002). During the scanning tour, the team observed typical pavement structures used to ensure long-lasting and better-performing pavement systems. The road-building philosophy in Australia is to build a deep subbase and a strong unbonded base course with a thin AC wearing course. The South African practice involved the construction of IP sections. Figure 2 and figure 3 illustrate that it is a common practice in both countries to use relatively thick aggregate layers in conjunction with relatively thin AC surface layers. While the practice in Australia involved the use of multiple unbound aggregate layers in conjunction with a thin AC surface layer, the South African practice involved the construction of thick UBA layer on CTB.

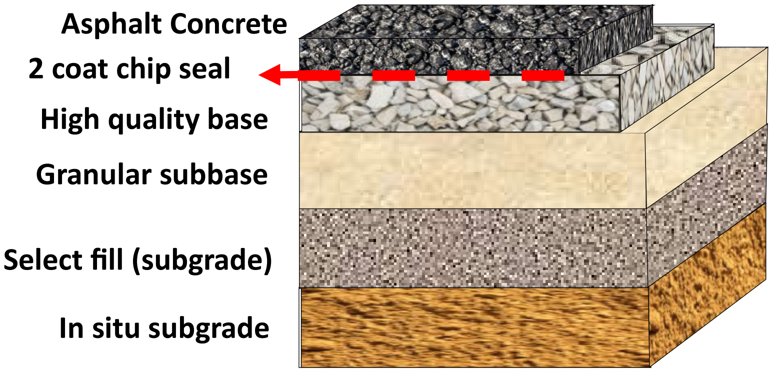


Figure 2. Illustration. Typical pavement configuration in Australia.

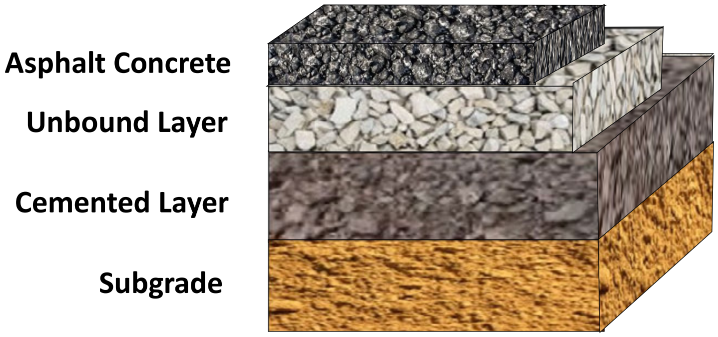


Figure 3. Illustration. Typical pavement configuration in South Africa constructed with high-quality crushed aggregate base layers.

The main goal of roadway agencies in South Africa is to build robust structural sections with a long service life into their national network. Roadway sections are constructed of cement-treated subbase covered by a high-quality crushed aggregate base course. The total thickness of these layers is typically 17.7 inches (450 mm) (subbase and base) in a total pavement structure thickness of 39.4 to 47.2 inches (1 to 1.2 m). The final layer is a thin AC of 1.2 to 2.0 inches (30 to 50 mm) (Beatty et al. 2002). In South Africa, factors critical to the success of pavement preservation treatments include a willingness to invest in quality aggregates, even if it is transported from long distances, along with paying significant attention to aggregate size and gradation. Specifications require 100 percent crushed material and 0.5 percent or less passing the number 200 sieve (smaller than 0.075 mm).

The French road-building philosophy is to build a strong base so that the AC wearing surface requires repaving only every 10 or 15 years and a structural overlay placed every 20 years (Beatty et al. 2002). Pavements are constructed with relatively thick granular layers and considerably thicker AC layers compared to practices in South Africa and Australia. Aggregate properties in France included 100 percent fully crushed materials with continuously graded to gap-graded with tight gradation bands, Los Angeles abrasion loss less than 15, micro-Deval loss less than 20, and polished stone value less than 0.5.

In the three countries visited as part of the scanning tour, the pavements consisted of deep subbase and deep base sections with a thin, high-quality AC wearing course to provide a good riding surface and moisture protection for the base. The recommendation was made to build demonstration projects with deep subbase and deep base designs in different regions of the United States to determine the effectiveness of this design strategy for 30- and 40-year pavement design lives (Beatty et al. 2002).

SOUTH AFRICA EXPERIENCE

The IP technology was developed in South Africa in the 1970s. Initially, the graded crushed stone or crushed stone method was adopted by the South African Department of Transport in their Technical Recommendations for Highways (THR) documents. A natural gravel blend with the allowance of plastic fines has also been used (Maree 1982a,b). Over time, specifications for this class of material evolved into a high-quality G1 graded crushed stone. The development of the G1 technology started when South Africa experienced a steady increase in traffic volumes and loading intensity. To achieve higher densities and strength, experiments were conducted using different crushed rock gradations. Engineers noticed that after a downpour and toward the end of compaction, the crushed rock base course would expel some of its fines, creating a tightly knit matrix (Kleyn 2012, Jooste and Sampson 2005). The G1 is a continuously graded fresh crushed rock material with a plasticity index (PI) of zero to slightly plastic. It was typically compacted in a dual-phase process, using a final slushing process to a density specification of 86 to 88 percent of solid density, equivalent to about 106 percent of modified Proctor density (AASHTO T 180).

Some of the key impacts on the G1 development process and its capabilities were achieved using the South African heavy vehicle simulator (HVS) test program during the 1980s. Kleyn (2012) reports G1 to be the only unbound road-building material found to enhance pavement bearing capacity to accommodate any increase in loading up to the point of rupture of the aggregate itself, without noticeable traffic molding.

The HVS investigations contributed to the development of the G1 technology and justified the increased use of G1 base pavements in light of improved construction practices and improved design methods for unbound materials (Jooste and Sampson 2005). Pavements with G1 bases were shown to be capable of accommodating traffic demands of up to 50 million standard axles with only a 2.0-inches-thick (50 mm) AC surface. The optimal thickness for a G1 base layer on a cemented subbase was 5.9 inches (150 mm). The best performance in pavement rutting was observed with the use of 7.9-inches-thick (200 mm) cemented subbase layers. The low sensitivity of a high-density G1 material to moisture proved that a G1 base pavement could be used in wet climate zones.

Technical impacts and benefits of HVS investigations on G1 base pavements were identified as follows:

- Suitability of G1 base pavements for 12 to 50 million equivalent single axle loads (ESALs, 18 kip, and 100 psi [62.3 kN, and 689 kPa]) design class.
- Feasibility of G1 base pavements in wet regions, given that impervious surface is maintained.
- Damage exponent (or n-value), in the power damage law equation, of pavements with a G1 base over a thick cemented subbase is close to 3 (not 4.2 as was commonly assumed).
- A 5.9-in-thick (150 mm) G1 layer is optimal for G1 base layers.

- The difference between high-quality G1 and relatively lower-quality G2 material was clearly shown.

The economic benefits of pavements with high-quality G1 crushed stone base layers, which provide a viable alternative to thicker and more expensive pavements—typically considered for heavily trafficked roads—were reported by Jooste and Sampson (2005) as follows: (1) increased use of G1 base pavements for higher design classes and wet regions, (2) use of maximum 5.9-inches-thick (150 mm) G1 base layers, and (3) improved maintenance and construction practices. The savings derived from these three benefits were assessed using a probabilistic approach. The overall savings were calculated for the South African road networks using unit cost savings. The overall savings ratio, based on total lane km of G1 base pavements constructed between 1980 and 1990, varied from 2.4 to 6.1.

Material Specifications and Construction Procedure

The G1 aggregate material used in the base course of an IP structure should be obtained from crushed hard, sound, durable, and not weathered parent rock. South African G1 base specifications require that all aggregate particle faces are fractured faces and allow the material gradation to be adjusted through the addition of fines produced from crushing of original parent rock only. The particle-size distribution and other material quality specifications for G1 are listed in table 1.A and 1.B, respectively (COTO 2020a, TRH14 1985). According to communication with Jaimes Maina of the University of Pretoria, although the G1 material with a nominal maximum aggregate size (NMAS) of 1 inch (26.5 mm) is not included in the South African Committee of Transport Officials (COTO) standard specifications, it was present in TRH14 (1985) and is still used.

Table 1. South African G1 base requirements (based on COTO 2020a, TRH14 1985).

A. Particle-size distribution.

Sieve size (mm)	Sieve size (in)	G1 percent passing	
		1.5 in (37.5 mm) NMAS	1 in (26.5 mm) NMAS
37.5	1.5	100	
26.5	~1.0	84–94	100
19.0	3/4	71–84	85–95
13.2	~1/2	59–75	71–84
4.75	#4	36–53	42–60
2.00	#10	23–40	27–45
0.425	#40	11–24	13–27
0.075	#200	4–12	5–12

B. Other material properties.

<table>
<tr><th colspan="2">Aggregate material property</th><th colspan="2">Specified threshold values</th></tr>
<tr><td colspan="2">Parent material</td><td colspan="2">Sound, clean, unweathered, high-quality rock.</td></tr>
<tr><td colspan="2">Additional fines</td><td colspan="2">Only fines crushed from the same sound parent rock may be added for grading correction, provided that added fines shall have a LL ≤ 25 and a PI ≤ 4; the quantity of fines shall not exceed 10 % by mass</td></tr>
<tr><td colspan="2" rowspan="5">Minimum 10% fines aggregate crushing value (FACT)*</td><td>Arenaceous rocks with a siliceous cementing matrix (quartzitic sandstone)</td><td>24.7 kips (110 kN)</td></tr>
<tr><td>Arenaceous rocks with nonsiliceous material</td><td>31.5 kips (140 kN)</td></tr>
<tr><td>Diamictites</td><td>24.7 kips (200 kN)</td></tr>
<tr><td>Calcrete</td><td>45.0 kips (80 kN)</td></tr>
<tr><td>All other compliant rock groups</td><td>24.7 kips (110 kN)</td></tr>
<tr><td colspan="2">Flakiness index</td><td colspan="2">≤ 35 on all individual fractions above 0.55 in (14 mm)</td></tr>
<tr><td colspan="2">Fractured faces</td><td colspan="2">All faces shall be fractured faces</td></tr>
<tr><td rowspan="3">Soil constants</td><td>Fraction smaller than</td><td>> 15 million ESALs</td><td>≤ 15 million ESALs</td></tr>
<tr><td>#40 (0.425 mm)</td><td>PI = nonplastic</td><td>LL ≤ 25
PI ≤ 6
LS ≤ 2%</td></tr>
<tr><td>#200 (0.075 mm)</td><td colspan="2">PI ≤ 8</td></tr>
<tr><td colspan="2">Durability</td><td colspan="2" rowspan="2">Refer to COTO (2020) for details.</td></tr>
<tr><td colspan="2">Deleterious minerals</td></tr>
<tr><td colspan="4">*10% FACT is the force in kN required to crush a sample of aggregate passing 1/2 in (13.2 mm) and retained on the 3/8-in (9.5 mm) sieve so that 10% of the total test sample will pass a #8 (2.36 mm) sieve.</td></tr>
</table>

The G1 gradation requirements listed in table 1(a) are based on restricting the exponent n-values between 0.33 and 0.50 in Fuller's or Talbot's equation (figure 4).

$$P(\%) = \left(\frac{d}{D}\right)^{n}$$

Figure 4. Equation. Fuller's or Talbot's equation.

where:

P = percentage (%) of material by weight finer than the sieve size being considered.
d = sieve size being considered.
D = maximum aggregate particle size in the current matrix.
n = parameter that adjusts the gradation curve for fineness or coarseness.

Compaction of the unbound aggregate base layer in an IP structure is the most critical step during its construction to ensure that individual layers perform as desired. The unbound aggregate base is constructed on top of a stabilized subbase, which provides a solid construction platform for the placement and compaction of the unbound aggregate base layer and ensures that an adequate density level is achieved. According to Kleyn (2012), a clean, dampened, well-stabilized, and leveled subbase serves as an anvil upon which to construct the G1 base course. The G1 layer requires relatively large amounts of water and high compaction energy to compact and interlock. The degree of compaction achieved in the unbound aggregate base layer is therefore dependent on the energy applied, as well as the initial and final G1 gradation.

Figure 5 shows the high-quality G1 base course material provided from a crusher onto a prepared site without the danger of being contaminated/degraded and stockpiled directly along the road (Kleyn 2012). Varying truck sizes, which may cause variations in dump spacing and material movement, should be avoided to control potential aggregate segregation and layer thickness variation. Spreading of damp material on the day of construction is done with a motor grader by gently moving successive, fully laden blade-sized loads off the stockpiles to the subbase across the full width of the available cement-stabilized subbase. The layer should be shaped, excess material should be removed, and all layer corrections should be done just prior to compaction. The aggregate should be watered while fines are well distributed to ensure proper material placement and compaction and achieve optimum moisture content (OMC).

A. Loose G1 unbound aggregate base course material.

B. G1 material stockpiled along the road.

Figure 5. Photo. G1 base course material (Kleyn 2012).

The strength of the layer material depends on the level of interlock of particles, strength of particles, and the micro and macro texture of particles (figure 6). The compaction of unbound aggregate layers in the South African IP structures involves two phases: (1) standard compaction and (2) particle interlocking or slushing (Kleyn 2012). The standard compaction phase is carried out using a combination of grid rollers, vibratory rollers, and pneumatic tire rollers. The initial compaction phase is concluded with the application of a pneumatic tire roller (weighing up to 18.7 tons) in combination with heavy, static steel-tire rollers. It is important to lead with the driven wheels of the roller, especially initially, to avoid formation of a bow wave of material in front of the roller drum.

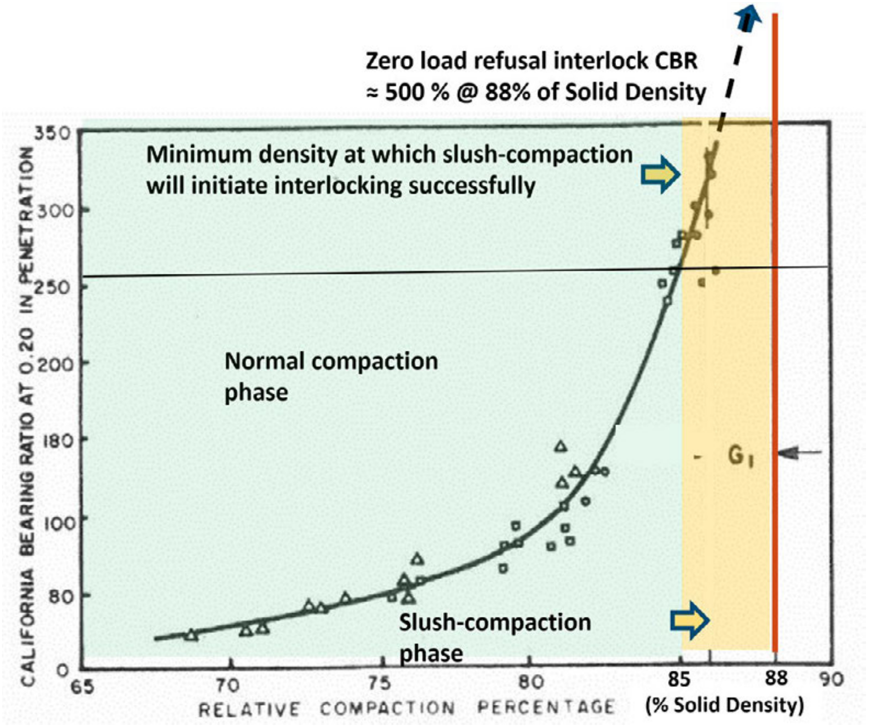


Figure 6. Graph. Effect of interlock on G1 aggregate base (Steyn and Kleyn 2016).

Commonly, two or three passes of the grid roller are used to gently knead the aggregate layer into shape. Subsequently, a vibratory roller is used to compact the layer to 85 percent of apparent solid density (figure 6). When the compaction process is being initiated with a vibratory roller, the first pass should be applied in a static mode. This can be followed by two passes with vibration at relatively low frequency and high amplitude at a speed of 1.9 to 2.5 mph (3 to 4 km/h). The amplitude and frequency of vibration need to be strictly monitored during this phase. Rolling should continue until the layer exhibits no (or little) movement under the wheels of a heavy roller before the slushing process may begin.

Too much vibration can easily lead to "de-densification" of the aggregate matrix. Moreover, extreme care should be exercised to prevent breakage of individual aggregate particles under the vibratory roller. The aggregate moisture content is typically maintained near optimal condition during this phase of compaction to aid the rearrangement of individual aggregate particles into a densely packed matrix. The fines fraction in the aggregate matrix plays a critical role during this phase by lubricating the aggregate contact points. It is therefore imperative that the aggregate material used should contain an adequate amount of fines. A rule of thumb used in the construction of South African G1 base course layers is that OMC values less than 4 percent are indicative of too few fines in the aggregate matrix, whereas OMC values higher than 6 percent are indicative of too many fines (De Beer 2012).

The second phase of compaction involves consolidating the material under saturated conditions by expelling or "slushing" out the excess fines from the matrix, allowing the larger particles to interlock into a superdense matrix. According to Kleyn (2012), the slushing process is initiated by thoroughly wetting and rolling 131- to 197-ft (40 to 60 m) sections of the layer at a time with heavy static rollers (figure 7). The water should be applied at the highest points of the cross section or gradient and used as it runs down to the lower points. The fines (passing number 200 sieve, or less than 0.075 mm) expelled should be broomed to areas deficient in fines—and eventually off the road (figure 7).

A. Excess fines being expelled as slush from layer.

B. Brooming and spreading initial slush/fines to deficient areas.

Figure 7. Photo. Slushing technique (Steyn and Kleyn 2016).

Finally, all slush/fines should be removed from the road with heavy-duty hand brooms or light mechanical brooms before they dry out and harden to a crust. This "washing out" of the fines accompanied by compaction is continued until the water draining of the pavement becomes colorless and does not contain any trace of excess fines (De Beer 2012). A pneumatic tire roller passing over the aggregate layer without leaving any indentations is used as an indicator of the achievement of adequate compaction. South African specifications require achieved density to be greater than 88 percent of solid particle density (assuming solid rock for the equal volume with no voids) for a G1 base compacted over cement-stabilized subbase, as illustrated with a zero load refusal interlock state (figure 6). Density/quality control should be conducted within 24 hours, preferably using a nuclear density gauge. Quality control should be performed when the material is still damp (moisture content of about 50 percent OMC in the upper portion of the layer) and the possibility of disturbance is minimized (Kleyn 2012).

Steyn and Kleyn (2016) recommended observing the following signs that suggest optimal interlock has been reached: (1) no air bubbles escaping during slushing, (2) expelled water clearing up substantially, (3) well-knit mosaic visible through surface water, (4) road surface does not heave under heavy roller, and (5) confirmation through an interlock and density acceptance control. The final mosaic surface should look like that shown in figure 8. According to Kleyn (2012), the particle interlock should result in an aggregate matrix that when tapped with a geological pick or similar object results in a "ringing" sound.

A. Slush compacted G1 layer at an HVS site.

B. Constructed G1 base layer cut like concrete.

Figure 8. Photo. Final mosaic surface (Kleyn 2012).

While a G1 base layer is being constructed, if the 88 percent solid density zero load refusal interlock, illustrated in figure 6, is not achieved, the following may have to be investigated (Steyn and Kleyn 2016): (1) support value of subbase not sufficient, (2) deflection of pavement too high, (3) grading of aggregate not continuous, (4) aggregate too soft, (5) moisture content of aggregate not at OMC, (6) material not slush compacted, (7) roller(s) not heavy enough, (8) over vibrating of material, (9) material altered during compaction, and (10) slush compaction stopped too soon.

The granular base surface should dry out sufficiently before a prime coat and AC surfacing layer are placed. When the material has dried off to below 50 percent of OMC, the surface should be swept clean to remove loose surface fines and other material that may have been deposited (COTO 2020a). The prime coat applied to the granular base consists of a low-viscosity bituminous product applied in a single application and allowed to dry prior to construction of any other layers. The prime coat's role is to seal and protect the surface of the granular base (COTO 2020c).

The AC surfacing layer thickness in South African IPs varies from 1.2 to 2.0 inches (30 to 50 mm), with the higher values corresponding to sections of higher volume of traffic loading. The mixes are generally gap-graded, with NMAS varying from 0.28 to 0.55 inches (7.1 to 14 mm); larger sizes are used for thicker layers. It is also the practice in South Africa to use rolled-in chippings on AC surfacing layers. This technique consists of spreading precoated chippings with a mechanical spreader that straddles the paved width immediately behind the paver. The chippings are rolled into the AC during compaction, with steel-wheeled and rubber-tire rollers, to produce a final surface texture not less than 0.03 inches (0.8 mm). This technique is used to achieve good surface friction. However, some researchers believe that the action of rolling in chips can lead to micro cracks in the AC, potentially leading to areas of high permeability in that layer (Horak et al. 2019). The authors reported good performance for this technique in Illinois (Son et al. 2013). Construction acceptance criteria include visual assessment of cracking, bleeding, and surface raveling; deflection; rutting; roughness; mean profile depth; air permeability; water permeability; and Marvil permeability.

Maintenance

Maintenance is a key aspect in ensuring adequate performance of IPs in South Africa. Defects observed in these pavements are mainly reflective cracks that propagate from the cemented layer to the surface. These cracks appear roughly 5 to 10 years following construction. Linear cracks of 0.12 inches (3.0 mm) are crack sealed with rubber-modified bitumen to ensure that these cracks do not develop further and allow water infiltration. Crack sealing should be done every year once cracks start to appear, with wider cracks being targeted.

Prior to application of the seal, the cracks should be blown out with heated ("hot air lance") or cold compressed air to remove all dirt, grit, and other foreign matter from the cracks and road surface. If deemed necessary, an herbicide and/or prime is applied in the cracks prior to sealing. In some instances, the surface is heated along the length of the crack and rolled until an even surface is achieved. The crack sealant is required to penetrate the crack rather than just cover it (COTO 2020b).

The thin AC surfacing layer typically lasts for approximately 12 to 15 years before it needs to be replaced.

AUSTRALIAN EXPERIENCE

In Australia, the term "upside-down pavement" is used for IP. Austroads (2015) defines upside-down pavement as "a pavement in which a stronger layer underlies a weaker layer; for example, a cement-stabilized subbase overlain by an unstabilized granular base."

The use of IP in Australia is not as common as it is in South Africa, but Australia has experience designing and constructing granular pavements with thin AC surfacing for relatively heavy-trafficked roads.

In rural areas, granular pavements are typically constructed using natural gravel surfaced with a prime and two-coat chip seal. In locations where horizontal loading poses a risk to the performance of chip seals, such as areas of heavy braking or turning traffic, as well as in urban areas where the noise generated by the tire–pavement interaction needs to be minimized, a thin AC surfacing is constructed on top of a chip-sealed granular pavement. The thin AC layer is typically 1.2 to 3.0-inches-thick (30 to 75 mm), comprising one or two AC layers. If high volumes of traffic are expected, high-standard crushed rock is required as a base course to ensure adequate support of the thin AC layer.

Granular pavements with thin AC have been shown to be adequate for traffic volumes of up to about 30 million ESALs. Above that, pavements with greater structural capacity are commonly used, such as full-depth AC pavements, concrete pavements, or composite pavements.

In locations with soft subgrades, a lightly bound layer may be constructed below granular pavements. This layer is typically referred to as a working platform, construction platform, or improved subgrade layer. For pavement design purposes, this layer is not considered part of the pavement. Hence, the term “upside-down pavement” (or “inverted pavement”) is not commonly used to refer to pavements that incorporate a lightly bound working platform.

One potential issue identified in Australia with the use of IP is the risk of water buildup caused by a less-permeable material (CTB) being underneath a more permeable layer (granular base course). This can result in reduced pavement strength and poor performance. This behavior has been observed in the Kiama Bypass in Wollongong, New South Wales. The constructed upside-down pavement failed prematurely because the base course became saturated (RTA 2004).

To avoid this issue, Austroads (2019) recommends designing pavements with increasing permeability of materials with depth from the surface. Where a pavement with permeability reversal is used, Austroads (2019) recommends designing a subsurface drainage system to allow water to drain the less-permeable material.

Nevertheless, in relatively low rainfall area, RTA (2004) reported a satisfactory performance of IP on Hume Highway in Holbrook, New South Wales after more than two decades.

Australian Pavement Design Considerations

Granular pavements with a chip-seal surface (and no AC) are typically designed using an empirical California bearing ratio (CBR) design chart, where the required thickness of each granular layer is a function of the CBR of the layers below it and of the design traffic in ESALs. This empirical design methodology considers permanent deformation as the only mode of failure (Austroads 2019).

When the design includes a thin AC layer on top of a granular pavement, some states in Australia require the use of a mechanistic–empirical pavement design procedure. This procedure considers AC fatigue as a failure criterion in addition to permanent deformation. The design AC fatigue life is typically reduced compared to the pavement design life (typically 15 years versus 40 years). This is justified by the fact that thin AC wearing courses present damage not addressed by the design methodology prior to the end of the pavement design life, requiring regular milling and replacement.

For thin AC layer pavements, the AC fatigue life predicted by the Austroads (2019) mechanistic-empirical design procedure is highly dependent on the modulus of the granular base course assumed, the AC modulus, and the thickness of the thin AC layer. A higher modulus of the granular base course increases the predicted AC fatigue life, whereas a higher AC modulus and thicker layers typically reduce the predicted AC fatigue life. The reduction in predicted AC fatigue life with increasing AC layer thickness can be explained by the strain behavior illustrated in figure 9. The peak strain typically occurs in the range of 1.6 to 3.1 inches (40 to 80 mm) AC thickness.

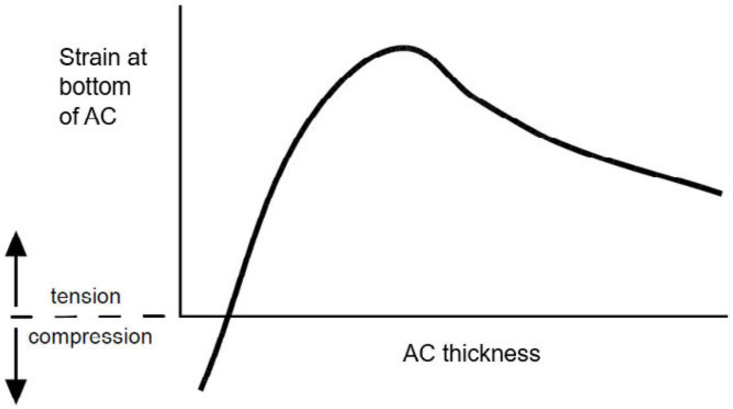


Figure 9. Graph. General relationship between AC thickness and horizontal strain at the base of an AC layer (adapted from Austroads 2019).

For granular pavements with no bound cemented material, the Austroads (2019) mechanistic–empirical design procedure considers the granular pavement layers to be anisotropic with a modulus of elasticity decreasing with depth. This model represents the stress-dependent behavior of granular materials. The granular pavement, in its entirety (i.e., base course and subbase), is divided into five sublayers of equal thickness with modulus values assigned as a function of the material properties (i.e., maximum modulus of elasticity at the top of the granular layer), the subgrade modulus of elasticity, and the total granular thickness.

Granular layers constructed on top of bound cemented layers (as in IP) are assumed to be anisotropic (vertical-to-horizontal modulus ratio of 2:1) with a single modulus of elasticity. In other words, the granular layer is not sublayered and is not assigned decreasing modulus values with depth. This procedure reflects the increased support that the cemented layer provides to the granular layer above it, to simulate the increased performance of the pavement.

Regarding the cemented layer, the Austroads (2019) mechanistic–empirical design procedure considers two phases: pre-fatigue cracking and post-fatigue cracking. In the pre-fatigue cracking phase, the cemented layer is assumed to be an isotropic bound layer with a single modulus of elasticity and a Poisson's ratio of 0.2. The design method considers the cemented layer fatigue criterion. When the number of load repetitions exceeds the predicted cemented layer fatigue life, the layer goes to its post-fatigue cracking phase. In this phase, the cemented layer is assumed to behave like a granular material, with a reduced modulus of elasticity (72,520 psi vertical and 36,260 psi horizontal; 500 MPa vertical and 250 MPa horizontal) and a Poisson's ratio of 0.35, but it is not sublayered (i.e., the modulus of elasticity is not considered to decrease with depth).

Actual AC fatigue life in granular pavements with relatively thin AC surfacing typically surpasses what is predicted using the Austroads (2019) pavement design methodology. In Western Australia, for example, the Department of Transport (Main Roads Western Australia [MRWA]) allows, in some instances, designers to adopt a design AC fatigue life of five years while expecting an actual AC fatigue life of 15 years in the field (MRWA 2013).

It is noted that the Austroads (2019) mechanistic–empirical design method considers the AC layer to be an elastic layer with one representative modulus of elasticity, which is calculated for the weighted mean annual pavement temperature and for a representative value of heavy vehicle traffic speed.

To limit reflection cracking, MRWA (2013) in Western Australia requires a minimum total thickness of 9.0 inches (230 mm) of granular pavement material or 6.9 inches (175 mm) of dense-graded AC on top of cemented material. In South Australia, DPTI (2018a) specifies a minimum cover of combined AC and granular materials on top of cemented layers, as shown in figure 10.

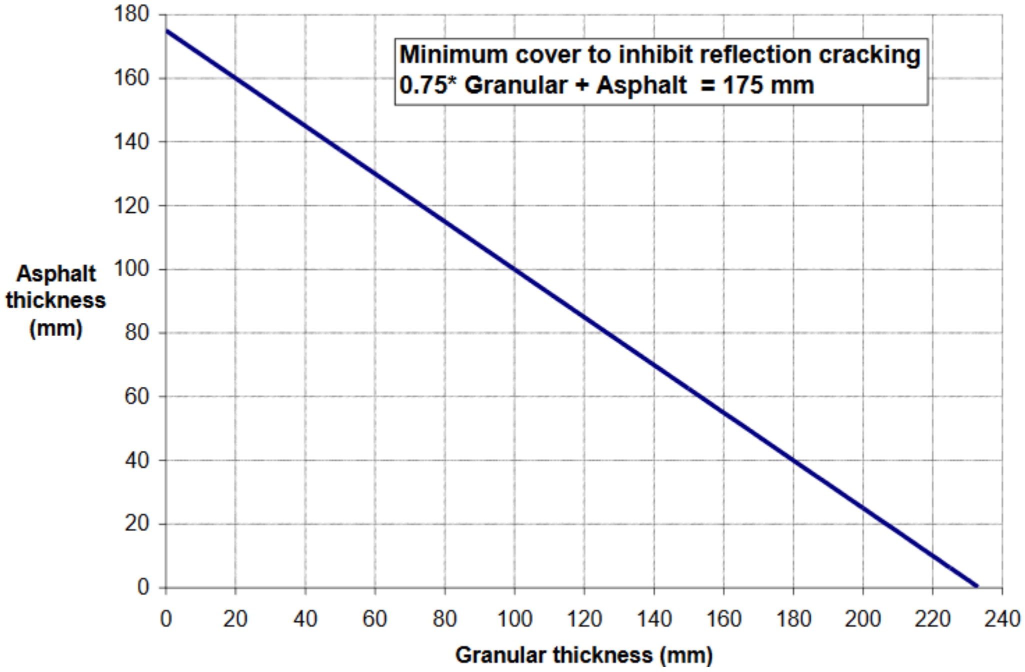


Figure 10. Graph. Minimum cover to inhibit reflection cracking (DPTI 2018a).

Australian Material Specifications and Construction Procedure

The performance of granular pavements with relatively thin AC surfacing depends on several factors, including the following:

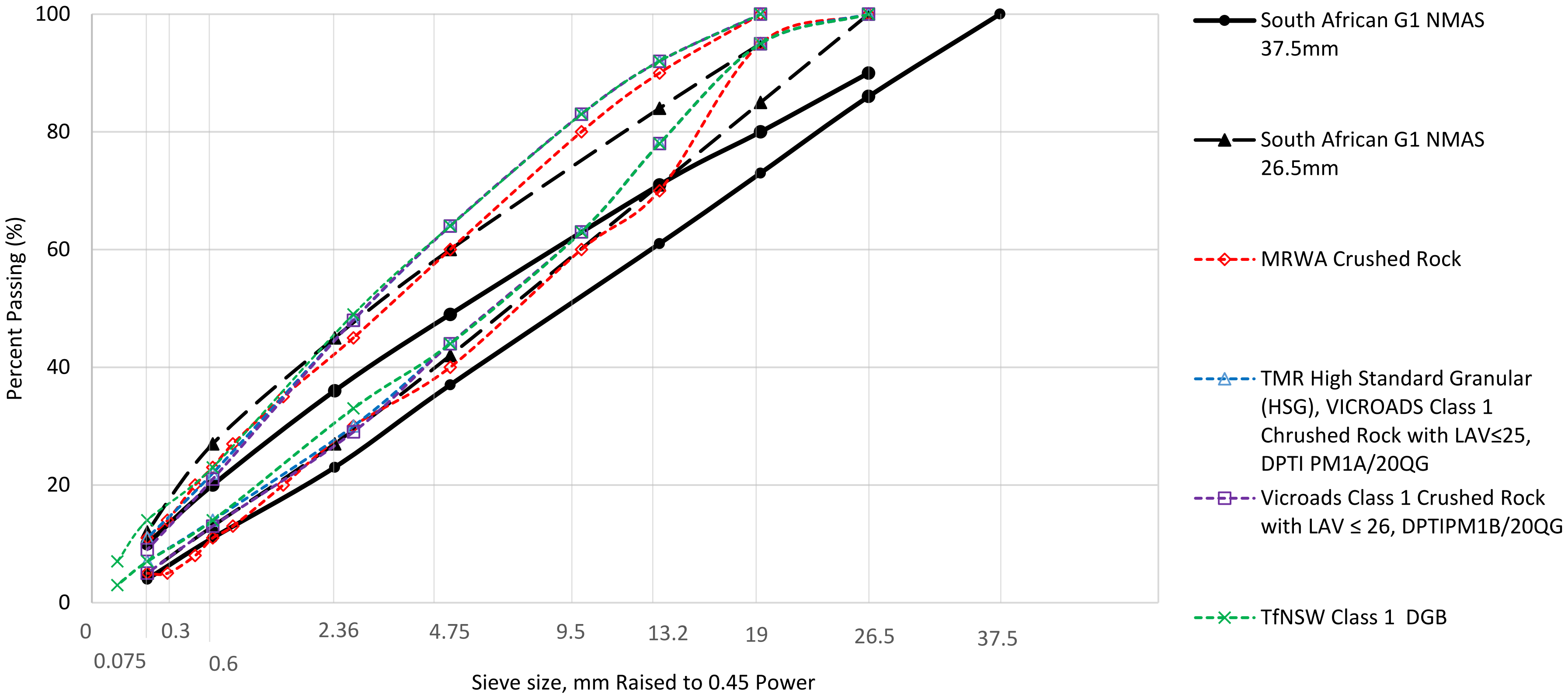
- the level of compaction and uniformity of subgrade and pavement layers
- drying of subgrade and all granular pavement layers to an acceptable low moisture content (i.e., dry-back) prior to proceeding with the construction of subsequent layers
- minimizing the risk of water infiltration into the granular layers, which can be achieved by applying a prime coat followed by a single- or two-coat chip seal followed by a tack coat to the granular base course, prior to construction of the AC layer
- a good bond between the AC layer and the granular layer underneath it, which can be achieved by including a prime coat and a tack coat, respectively, before and after the chip seal is applied.

These practices recognize that the modulus of elasticity of granular layers is significantly impacted by level of compaction and moisture condition. Given that some granular materials are more sensitive to moisture than others, dry-back requirements vary depending on the nature of the granular material, as well as on the position of the layer within the pavement. For crushed rock base courses, for example, MRWA requires the layer to dry to a maximum of 60 percent of the Modified Optimum Moisture Content (MOMC) level prior to application of the prime coat and construction of subsequent layers. Jameson et al. (2017) reported, for Western Australian crushed rock materials, that an increase in moisture content from 2.8 to 3.2 percent resulted in modulus decreasing from about 122 ksi (840 MPa) to 93 ksi (640 MPa)—that is, a 14 percent increase in moisture led to a 24 percent reduction in material modulus.

The South African slushing technique is not used in Australia. Compaction is carried out at a moisture content close to optimum, with a uniform compaction effort applied longitudinally and transversely to the road alignment. Experience in Australia, however, shows that achieving target densities is not sufficient to ensure good pavement performance. Apart from compaction levels, material handling (e.g., how it is watered, for how long it rests, how it is mixed and laid, how it is compacted, what equipment is used, and if and when it is trimmed) also plays a role in the layer modulus and subsequent pavement performance. All these factors influence the orientation of the particles in the final constructed layer. Experienced contractors typically achieve better results.

For important projects in Western Australia, MRWA requires FWD testing on the granular base course before and after construction of the seal and AC layer(s). MRWA requires contractors to comply with maximum acceptable deflections and curvature values at different stages of construction.

Figure 11 and table 2 summarize standard specification requirements for the highest standard crushed rock used as base course under relatively thin AC surfacing in the various states of Australia compared to South African G1 requirements. The table includes the most stringent specification requirements, targeted for high-trafficked roads. Lower-quality granular materials are allowed in granular pavements for sections with lower traffic volume, where a high standard of surface preparation may not be required or where the pavement does not incorporate a thin AC surfacing layer. These are not included in figure 11 and table 2. Less-strict specification requirements apply for granular subbase layers.



Source: adapted from COTO, 2020a, DPTI (2020), MRWA (2020), TfNSW (2020a), TMR (2020), VICROADS (2017)

Figure 11. Graph. Particle-size distribution upper and lower limits for crushed rock base course materials in South Africa and Australia.

Table 2. Standard specification requirements for high-quality granular base course materials in South Africa and Australia.

Material property		South Africa G1				Australia													
						Western Australia (MRWA)		Queensland (TMR)		Victoria (VICROADS)				New South Wales (RMS)		South Australia (DPTI)			
		G1 37.5 NMAS		G1 26.5 NMAS						Class 1 crushed rock with LAV ≤ 25		Class 1 crushed rock with LAV ≤ 26		Class 1 DGB		PM1A/20QG		PM1B/20QG	
Sieve Size		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
(in)	(mm)																		
1-1/2	37.5	100						100	100										
1	26.5	86	90	100		100		100	100	100		100		100		100		100	
3/4	19	73	80	85	95	95	100	95	100	95	100	95	100	95	100	95	100	95	100
1/2	13.2	61	71	74	84	70	90	78	92	78	92	78	92	78	92	78	92	78	92
3/8	9.5					60	80	63	83	63	83	63	83	63	83	63	83	63	83
#4	4.75	37	49	42	60	40	60	44	64	44	64	44	64	44	64	44	64	44	64
#8	2.36					30	45	30	48	30	48	29	48	33	49	30	48	29	48
#10	2	23	36	27	45														
#16	1.18					20	35												
#30	0.6					13	27												
#40	0.425	11	20	13	27	11	23	14	22	14	22	13	21	14	23	14	22	13	21
#50	0.3					8	20												
#100	0.15					5	14												
#200	0.075	4	10	5	12	5	11	7	11	7	11	5	9	7	14	7	11	5	9
	0.0135													3	7				

Material property	South Africa	Australia					
		Western Australia (MRWA)	Queensland (TMR)	Victoria (VICROADS)	New South Wales (TfNSW)	South Australia (DPTI)	
						PM1A/20QG	PM1B/20QG
Minimum 10% fines aggregate crushing value	see Table 1						
Los Angeles abrasion value		≤ 35%				≤ 25%	25% to 30%
Degradation factor			≥ 40% to 50%(i)				
Liquid limit (LL)	< 25%	≤ 25%	≤ 25%	≤ 30%	≤ 20%	≤ 25%	≤ 25%
Linear shrinkage (LS)	< 2%	0.4% to 2%				≤ 3%	≤ 3%
Plasticity index (PI)	> 15million ESALS: nonplastic ≤ 15 million ESALS: <4%			2% to 6%	2% to 6%	2% to 6%	2% to 6%
Plastic limit (PL)					≤ 20%		
Dust ratio (or fines ratio)		0.35 to 0.6	0.30 to 0.55				
Flakiness index		≤ 30%	≤ 35%	≤ 35%			
Max. dry compressive strength		≥ 1.7 MPa					
Soaked CBR		≥ 100%					
Wet strength			≥130 to 150 kN(ii)				
Wet/dry strength variation		≤ 35%	≤ 30 to 40%(iii)				
Secondary mineral content in basic igneous rock		≤ 25%					
Accelerated soundness index by reflux		≥ 94%					
Water absorption			≤ 2%				
Permeability				≤ 5×10^{-8} m/sec	≤ 5×10^{-8} m/sec		
pH (sources containing sulphide/sulphate mineralization)				≥ 6.0 units(iii)			
Conductivity (sources containing sulphide/sulphate mineralization)				≤ 1500 m^{S}/cm (iv)			
Max. percentage of supplementary materials permitted				5%			
Max. percentage of total marginal and unsound rock				10%			
Max. percentage of unsound rock				5%			

Material property	**South Africa**	**Australia**					
		Western Australia (MRWA)	**Queensland (TMR)**	**Victoria (VICROADS)**	**New South Wales (TfNSW)**	**South Australia (DPTI)**	
						PM1A/20QG	**PM1B/20QG**
Required compaction	density > 88% of solid particle density	99% MMDD(iv)	100% MMDD(iv)	100% MMDD(iv)	100% MMDD(iv)	Contract specific requirements	Contract specific requirements

Source: adapted from COTO (2020a), DPTI (2018b, 2020), MRWA (2020), TfNSW (2020a,b), TMR (2020), VICROADS (2013, 2017).
Notes:

MRWA = Main Roads Western Australia; TMR = Transport and Main Roads; TfNSW = Transport for New South Wales; DPTI = Department for Infrastructure and Transport; LAV = assigned Los Angeles value; MMDD = modified maximum dry density.
Dust ratio = ratio of the percentage passing by mass the 0.075-mm (#200) sieve to the percentage passing by mass the 0.425-mm (#40) sieve.
(i) Depending on material type
(ii) Soil to water ratio 1:2.5
(iii) Soil to water ratio 1:1
(iv) Minimum characteristic dry density ratio

EARLY U.S. EXPERIENCE WITH INVERTED PAVEMENTS

The first application of IPs in the United States is traced back to 1954 in New Mexico (Barksdale and Todres 1983). Initial IP sections involved the overlaying of several badly broken concrete pavements with 6 inches (150 mm) of unstabilized granular base and 2 inches (50 mm) AC. Johnson (1960) reported that after six years of heavy traffic, no reflection cracks or significant rutting had developed in the test sections. Subsequently, two experimental roads were constructed in New Mexico in about 1960, consisting of a 3-inches-thick (75 mm) AC surfacing, 6-inches-thick (150 mm) granular base, and a 6-in-thick (150 mm) granular subbase treated with 4 percent cement.

The performance of IP highway test sections was reported by McGhee (1971). The subbase was constructed by stabilizing a residual micaceous silt and clayey silt subgrade with 10 percent cement by volume. The importance of using a high quality cement-stabilized layer was demonstrated through field performance (Tayabji, Nussbaum, and Ciolko 1982). Based on a five-year study, McGhee (1971) found an inverted section to be the most effective design and the one that exhibited the lowest overall cost of sections. The successful use of inverted sections in Virginia, which is in a high rainfall area, suggested water trapped in the base might not be a significant problem (McGhee 1971). When water was of concern, a free-draining base with provision for positive water collection was recommended.

Horak, du Pisani, and van der Merwe (1986) developed criteria for optimal performance for unstabilized aggregates used in inverted sections. O'Neil, Mahoney, and Jackson (1992) have shown that using an unstabilized aggregate layer as an overlay between old pavement and resurfacing reduced reflective cracking. Work by Maree, van Zyl, and Freeme (1982) and Maree et al. (1982) in South Africa and later O'Neil, Mahoney, and Jackson (1992) in Washington State reported that unstabilized aggregate layers, when confined in an inverted section or a granular overlay, developed a high elastic modulus—as high as 100,000 psi (690 MPa). On the other hand, the degree of saturation of an IP base course has been found to increase as a result of cracks that may form in the cement-stabilized layer from shrinkage and/or fatigue (Horak, du Pisani, and van der Merwe1986; Maree et al. 1982). This would increase rutting and jeopardize the layer's elastic modulus. However, a high-quality, well-constructed crushed aggregate base, such as the South African G1 base used in an inverted section, could reduce rutting and the impact of wet conditions (Maree et al. 1982; Horak, du Pisani, and van der Merwe 1986). Horak, du Pisani, and van der Merwe (1986) reported total rutting in an IP at one-half the rate of a conventional pavement section.

U.S. Army Corps of Engineers Experience

The US Army Corps of Engineers studied the behavior of various layers in flexible pavements that have lime-stabilized and cement-stabilized subbases—i.e., IP-type structures (Ahlvin et al. 1971; Barker, Brabston, and Townsend 1973; Grau 1973). The main objective of the study was to measure the mechanical response of full-scale pavement structures and compare results against predictions from layered elastic theory and other available constitutive models. The base courses of two IP structures were investigated. The pavement sections were composed of a 3.5-inches-thick (90 mm) AC layer, a 5.9-inches-thick (150 mm) crushed limestone base, a

15-inches-thick (380 mm) stabilized clay subbase, and a clay subgrade (CBR of 4 percent). The structures were subjected to traffic under controlled conditions while displacements and stresses were monitored at key locations (Ahlvin et al. 1971; Barker, Brabston, and Townsend 1973; Grau 1973). Linear elastic analyses failed to adequately predict the measured stresses and strains in the various layers as well as the plastic subgrade deformation. The performance of the IP structures was found to be influenced by the stiffness and tensile strength of the CTB. The study highlighted the importance of performing a comprehensive material characterization and numerical analysis through appropriate constitutive models. Furthermore, it recommended the development of laboratory tests capable of simulating field conditions and introducing nonlinear models for numerical simulations (Barker, Brabston, and Townsend 1973).

Georgia Tech Study (1983)

Barksdale and Todres (1983) constructed 12 laboratory-scale instrumented pavement structures and cyclically loaded them to failure under controlled environmental conditions. In addition to conventional flexible pavement and full-depth AC pavement test sections, they tested two IP sections. The IP sections were composed of 3.5-inches-thick (90 mm) AC layers over 8-inches-thick (200 mm) unbound aggregate layers (well-graded granitic gneiss) over a 6-inches-thick (150 mm) cement-stabilized subbase over a micaceous nonplastic silty sand subgrade. One IP section had a 6-inches-thick (150 mm) cement-stabilized crushed stone subbase, whereas the other had a 6-inches-thick cement-treated silty sand subbase. The cement-stabilized crushed stone subbase had 4.5 percent portland cement by weight of aggregate and achieved an average 28-day unconfined compressive strength (UCS) of 1,160 psi (8.0 MPa), and the soil-cement subbase had 5.0 percent portland cement by weight of subgrade soil and achieved an average 28-day UCS of 217.5 psi (1.5 MPa).

The micaceous nonplastic silty sand subgrade was compacted to 98 percent in accordance with AASHTO T 99[1] density. The cement-stabilized crushed stone subbase was compacted to 100 percent of AASHTO T 180 density. The cement-treated subbase facilitated compaction of inverted structures leading to relatively denser unbound aggregate base layers, approximately 105 percent in accordance with AASHTO T 180[2] density (Barksdale 1984). The AC surfacing consisted of a GDOT B-binder AC, AC-20 asphalt binder at 5.2 percent, 4 percent air void content, 2.3-kip (10.2 kN) Marshall stability with 0.09-inches (2.29 mm) flow, and a maximum aggregate size of 0.75 inches (19 mm).

Table 3 presents the performance summary of the Georgia Tech pavement test sections. The sections were subjected to a 6.5-kip (28.9 kN) cyclic load for the first two million repetitions, followed by a cyclic application of a 7.5-kip (33.4 kN) load until failure. The two IP sections outperformed equivalent pavement structures in terms of lower resilient surface displacement, reduced transferred compressive stress onto the subgrade, and less tensile–radial strain at the bottom of the AC layer (Barksdale and Todres 1983, Cortes 2010). In addition, the IP sections

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[1] The use of AASHTO T 99 is not a Federal requirement.

[2] The use of AASHTO T 180 is not a Federal requirement.

withstood a higher number of load cycles to failure: 4.4 compared to 3.5 million repetitions with CP (Barksdale 1984, Tutumluer and Barksdale 1995).

Table 3. Georgia Tech pavement test section performance summary (Barksdale and Todres 1983).

Sections	AC thickness (in)	Base thickness (in)	Repetitions to failure	Failure mode
Conventional	3.5	8–12	Up to 3.5 million	Fatigue/rutting
Full-depth AC	6.5–9	None	Up to 440,000	Rutting*
Inverted	3.5	8	Up to 4.4 million	Fatigue/rutting

*Rutting failure in full-depth AC could be related to material and construction practice.

Tutumluer and Barksdale (1995) conducted numerical modeling of the two full-scale instrumented IP sections along with the full-depth AC and conventional AC pavement test sections tested by Barksdale and Todres (1983) to adequately incorporate cross-anisotropic and nonlinear behavior of crushed stone base courses in advanced analyses and modeling of multilayered flexible pavements using the GT-PAVE finite element (FE) tool. Table 4 presents the measured critical pavement responses for all three types of pavement structures. The measurements were successfully predicted through the modeling work by Tutumluer and Barksdale (1995). In addition, a sensitivity analysis was conducted to further evaluate mechanistic response benefits of the IP test sections.

Table 4. Georgia Tech pavement test section measured responses (Barksdale and Todres 1983).

Sections	Top subgrade			Bottom AC	Surface deflection			
	Vertical stress σ_Z		Vertical strain ε_Z (10^{-6})	Radial strain ε_R (10^{-6})	At 10 in (254 mm) from the load centerline δ_{254}		At 14.5 in (368 mm) from the load centerline δ_{368}	
	(psi)	(kPa)			(mils)	(mm)	(mils)	(mm)
Full-depth AC	8.7	60	1380	319	0.47	0.012	0.28	0.007
	12.6	87	1500	460	0.79	0.020	0.47	0.012
	12.9	89	2200	410	0.75	0.019	0.51	0.013
Conventional	11.9	82	1850	300	0.79	0.020	0.51	0.013
	11.1	76	1750	280	0.87	0.022	0.51	0.013
	6.8	47	2500	400	0.67	0.017	0.39	0.010
Inverted	3.3	23	390	340	0.28	0.007	0.12	0.003
	3.4	23	340	260	0.24	0.006	0.12	0.003

The following observations were made by Tutumluer and Barksdale (1995):

- Cement-stabilized inverted sections could withstand heavy loadings because of (1) lower vertical subgrade stresses as a result of the stiff base layer, (2) lower tensile strain at the bottom of the AC, and (3) lower resilient surface deflection.

- The upper portion of the cement-treated subbase and almost all the unstabilized crushed stone base near the load were in horizontal compression. The bottom half of the subbase, as well as a thin layer on top of the subgrade, was in horizontal tension.

- The presence of the cement-stabilized layer beneath the aggregate base resulted in horizontal compressive stresses of magnitudes ranging from 0 to 16 psi (0 to 110 kPa) in the unstabilized crushed stone base. This was probably a major factor contributing to the lower permanent deformation and higher resilient moduli of the base layers as observed from laboratory testing, as shown in figure 12.

- From sensitivity analyses conducted using the GT-PAVE FE tool, it was noted that an optimal and economical IP section constructed over a weak subgrade would consist of a 6-inches-thick (150 mm) unstabilized aggregate base, and a 6-to 8-inches-thick (150 to 200 mm) cement-stabilized subbase.

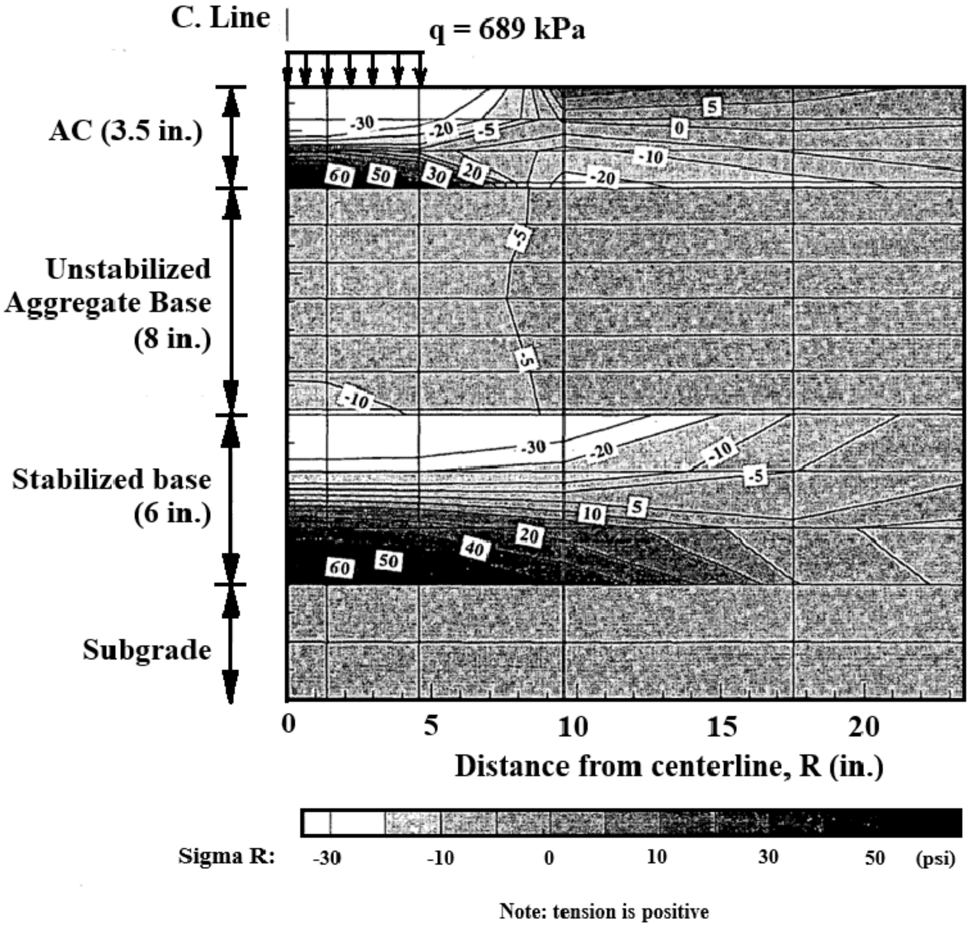


Figure 12. Graph. Horizontal compressive stresses predicted in unbound aggregate base of the inverted pavement section with crushed stone cement-stabilized subbase (Tutumluer and Barksdale 1995).

Application of Stone Interlayer Pavements in Louisiana

Research efforts in Louisiana in early 1990s focused on identifying a sustainable alternative to reduce reflective shrinkage cracking and improve the long-term performance of semirigid pavements built with soil-cement layers. The LaDOTD started using semirigid pavement or IP structures to meet this challenge to improve pavement performance and reduce environmental impact. The CP design adopted by LaDOTD consists of an AC surface layer on a soil-cement or CSB base and a lime-treated subgrade to overcome soft soils and poor support conditions. Commonly referred to in Louisiana as "stone interlayer pavement designs," the IP concept of the placement of a granular material between the soil-cement base and the AC surface effectively creates as a cushion between the two stiff layers and thereby minimizes reflection of shrinkage cracks from the base into the pavement, as illustrated schematically in figure 13 (Rasoulian, Becnel, and Keel 2000; Rasoulian et al. 2001). The approach allows for the optimization of granular materials and cement contents to achieve cost effective designs. The LaDOTD design is optimized for the locally limited crushed aggregate sources, and different design configurations could be used to optimize sustainability benefits, given that good-quality crushed aggregate sources are available.

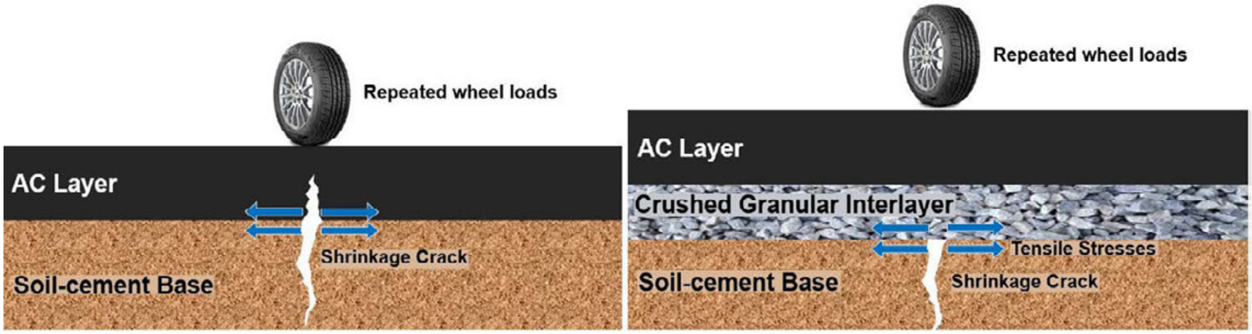


Figure 13. Illustration. Stone interlayer design concept used in Louisiana to control reflection of shrinkage cracks caused by cement-stabilized base course (Ozer and Al-Qadi 2021).

Thousands of miles of highway pavements with soil-cement bases have been installed in Louisiana, some of which have been in service for more than 40 years (Titi et al. 2003). However, the use of soil-cement bases with a high percentage (typically 10 percent) of cement causes shrinkage cracking in the base, which reflects into the AC layers and forms block cracking that significantly affects pavement performance (figure 14).

Figure 14. Photo. Reflective shrinkage cracks in the form of block cracking on LA-97 (LaDOTD).

The first installation of an IP in Louisiana was on state highway LA-97 near Jennings in 1991. Based on the encouraging results from the LA-97 project and from an accelerated pavement testing (APT) study, additional IP sections were designed, constructed, and monitored after 2000 (Chen, Zhang, and Lambert 2014). Two IP case studies in Louisiana are presented in more detail in Chapter 3 of this report.

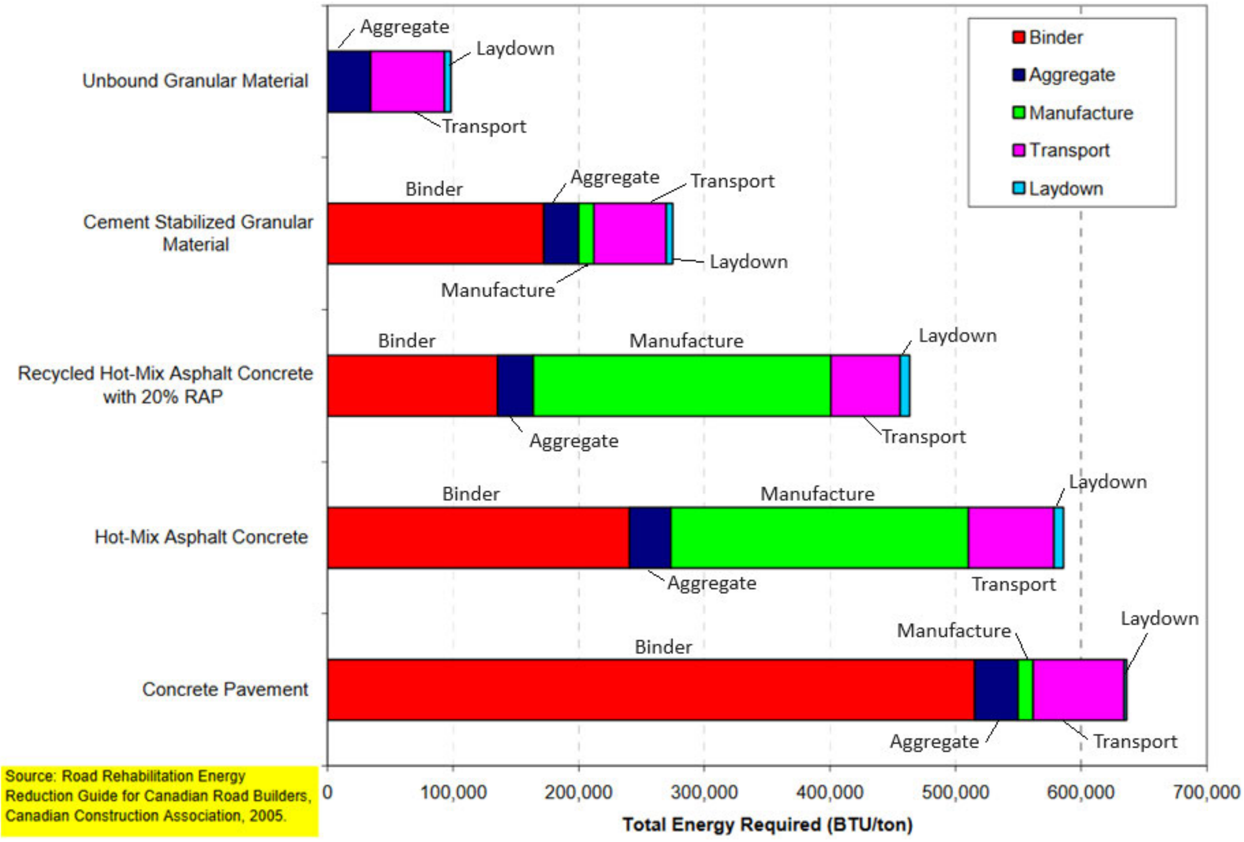
Over the past three decades, LaDOTD has fully endorsed the IP concept and has been designing most of the new projects with high traffic volume using a stone interlayer design in lieu of full-depth stone/cement-stabilized bases. The innovative design concept has already resulted in significant life-cycle savings by mitigating reflective shrinkage cracking problems in Louisiana pavements and has proved to provide long-term pavement performance. LaDOTD plans to continue to design pavements using this concept to serve the infrastructure needs of Louisiana.

Currently, the AASHTO (1993) pavement structural design method is used for IP in LaDOTD. Because the mechanics of IP are quite different than those of conventional flexible and semirigid pavements, mechanistic–empirical (M-E) methods are more appropriate for calculating critical responses in the future. In addition to considering proper AC properties in the design, rutting in the granular interlayer and fatigue in stabilized layers are critical responses that could be considered in the design. The use of M-E design methods could help optimize the structural design, save costs, and reduce environmental impacts.

BENEFITS OF INVERTED PAVEMENTS

With the aggregate base layer functioning as the primary structural component, IP may offer an economical alternative to CP construction with acceptable performance. From the review of IP applications in the United States and abroad, it is evident that IP achieves satisfactory performance. In addition, some studies have reported a cost saving over the life-cycle of the pavement. However, the data in the United States have been limited. Papadopoulos and Santamarina (2019) recently reviewed many IP sections constructed in South Africa and in the United States and highlighted the main advantages of the use of IP. They suggested that IP could be a viable alternative that might outperform CP at a lower cost.

Buchanan (2010b) summarized the overall benefits of IP technology through its potentially relative reduced energy demand. Figure 15 illustrates product energy demand comparisons based on 2005 construction data for various pavement layers. Considering conventional flexible and rigid pavement alternatives with thick bound layers of AC and PCC, the total energy demand of UAB could be approximately 80 percent less than that of AC or PCC, according to Buchanan (2010b). This number appears to be much higher than that reported by Al-Qadi et al. (2015).

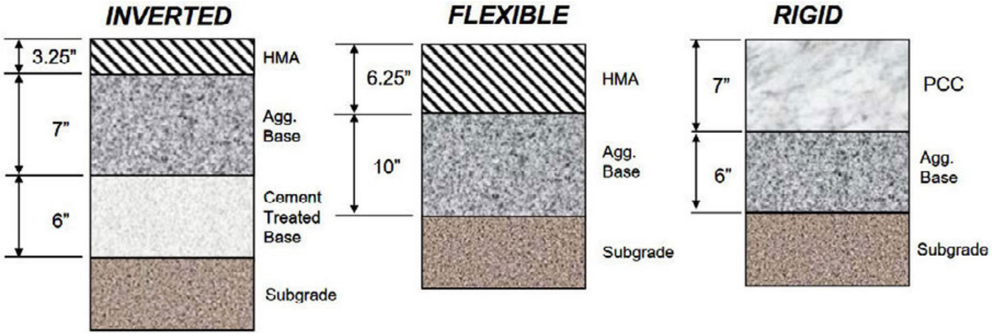


Source: Road Rehabilitation Energy Reduction Guide for Canadian Road Builders, Canadian Construction Association, 2005.

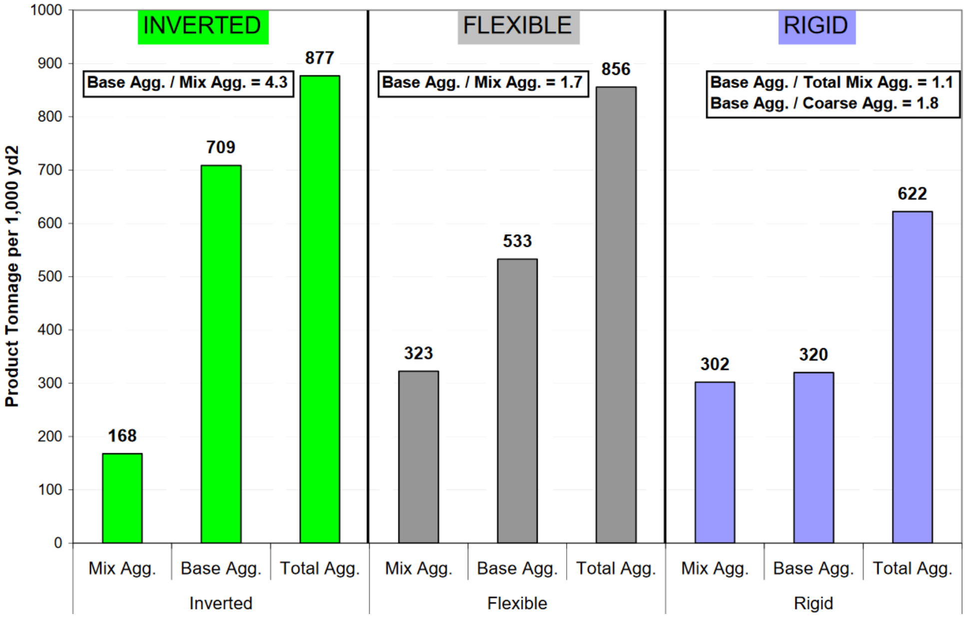
Figure 15. Graph. Product energy demand comparison (after Buchanan 2010b).

The energy savings are related to reduced AC layer thickness (in the case of flexible pavement) or elimination of PCC layer (in the case of rigid pavement) and using base and CTB (at 2 to

4 percent cement). Buchanan (2010b) demonstrated his logic in the comparison shown in figure 16 using the AASHTO (1993) pavement design specifications. He suggested that the total amount of aggregate used in IP design is somewhat similar to the amount needed for the flexible pavement design alternative. However, the product mix would be different (i.e., the base quantity would increase while the clean stone quantity would decrease). This is the result of the CTB layer being used and a reduction in AC thickness. It was suggested that this might help the aggregate plant through a more balanced operation and better use of resources (Buchanan 2010b).



A. Medium duty pavement design alternates.



B. Product mix for medium duty pavement alternates.

Figure 16. Graph. Aggregate products for medium-duty alternates (Buchanan 2010b).

SUMMARY

The construction of pavements with thick UAB layers appears to be a common practice in countries such as South Africa, but the IP experience has been limited in the United States. Inverted pavements rely on the complementary interaction between layers. The CTB provides a stiff foundation for efficient compaction and constrains the deformation of the stress-sensitive granular aggregate base. It is controversially argued in this chapter that the relatively thin AC surface layer behaves like a membrane, resulting in primarily compressive stresses or low tensile stresses—hence, better fatigue life.

The limited use of IP in the United States could be attributed to (1) experience with traditional AC and PCC pavement designs and construction practices; (2) overlooking the technologies related to UAB compaction, such as the South African slushing technique; (3) the cracking potential of cement-treated subbases used in IP, especially in northern climates. Hence, an effort is needed to quantify the benefits and limitations of IP. Benefits may include cost and energy savings and reducing GHG. Limitations may include potential pavement distresses occurring as a result of the cement-treated subbase shrinkage cracking and exposure to freeze–thaw conditions, and from poor performance of the granular layer caused by moisture accumulation.

Inverted pavements with a lightly cement-stabilized subbase may achieve better compaction of unstabilized aggregate placed over the stabilized layer. This may minimize reflective cracking of the cement-stabilized subbase, protect the subgrade from wheel-load stresses, provide improved AC fatigue, and could withstand large numbers of heavy loadings. Some of the case studies documented in this report provide examples of lightly cemented-stabilized subbases to mitigate potential reflective cracking.

Recognizing the sensitivity of IPs to cold weather, their freeze–thaw durability could be improved through long-term cementation mechanisms using dolomite fines in stabilized subbase. This approach was found to be a viable alternative in full-scale pavement testing studies conducted at ICT. In summary, it is important that high-quality crushed aggregate is selected for the base layers and that good compaction and quality control are achieved during construction of field projects.

In IP analysis and design, stress hardening–type base course modulus characterization and using nonlinear, anisotropic material models for analysis are suggested. A good-performing UAB stiffens under applied loading. Its horizontal stiffness increases relative to the vertical because the former reduces its tendency to spread laterally under wheel loads and results in lower critical pavement responses.

Finally, additional large-scale field tests may be needed to assess the performance of IP designs in a wide range of conditions relevant to the United States.

CHAPTER 3. CASE STUDIES

This chapter presents a summary of compiled information and data analysis on recent cases of IP in the United States. Data collected for the case studies were provided by departments of transportation (DOTs), private companies, and academics; and vary for each case study. Information presented in this chapter on each case study includes location, pavement configuration, construction and maintenance history, traffic loading, environmental conditions, performance, analysis of FWD data, cost analysis, and environmental sustainability assessment. For the sections that had a control or conventional pavement (CP) built at the same time and were subjected to the same or similar traffic, comparable information is presented for the control/conventional sections. The case studies presented are the following:

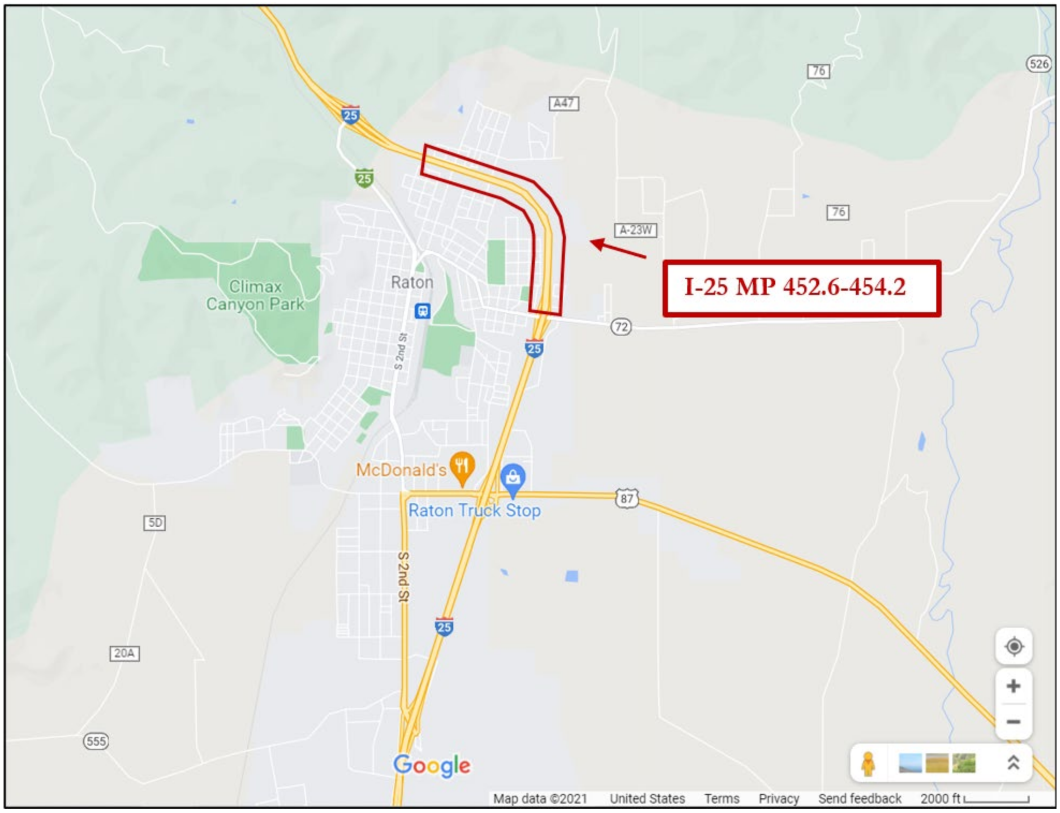
- Interstate 25 in Raton, Colfax County, New Mexico
- Louisiana Highway 97
- US Route 165 in Ouachita Parish, Louisiana
- Quarry Access Road, North Carolina
- Quarry Access Road in Morgan County, Georgia
- LaGrange Bypass, Pegasus Parkway, Georgia
- Virginia State Route 659, Virginia
- ICT Accelerated Testing and Loading Assembly (ATLAS)

INTERSTATE 25, COLFAX COUNTY, NEW MEXICO

The I-25 IP section in New Mexico was constructed in 2012–13 as part of the reconstruction of the four lanes of I-25 between mileposts (MP) 452.606 and 454.199 (approximately 1.6-miles [2.6-km] long). The new pavement was opened to service in 2013. The previously existing pavement consisted of concrete pavement, which was replaced by an IP section in the northbound (NB) lanes and a conventional AC pavement in the southbound (SB) lanes.

Location

The IP is located in the NB lane between MP 452.606 and 454.199 in Raton, Colfax County, in north-central New Mexico. The elevation at the location is about 6,680 ft (2,036 m). Figure 17 shows the location of the road section, northeast of Raton.



Original Photo: © 2015 Google® (see Acknowledgements section.)

Figure 17. Illustration. I-25, Colfax County, New Mexico.

Pavement Configuration

The pavement cross sections for the NB IP and SB CP are summarized in table 5, in accordance with the construction plans provided by the New Mexico Department of Transportation (NMDOT). The SB CP at bridge overpasses is slightly different from the remainder of the SB CP, as shown in the table.

For a similar design traffic adopted in the project (20-year design life of approximately 1.0×10^7 ESALs), the South African flexible pavement design following TRH4 (1996) would consist of the following:

- For moderate or dry regions: 1.6–2.0 inches (40–50 mm) AC plus 5.9 inches (150 mm) granular base and 9.8 inches (250 mm) CTB, or
- For wet regions: 1.6–2.0 inches (40–50 mm) AC plus 5.9 inches (150 mm) granular base and 11.8–15.7 inches (300–400 mm) CTB—noting that the CTB can be reduced to 9.8–15.7 inches (250–300 mm) if water is prevented from entering the base.

The total AC layer in the I-25 IP section is 3.6 inches (92 mm) thick, which is considerably more than typical IP in South Africa, where the AC layer is generally not thicker than 2.0 inches (50 mm). The unbound granular base course in the I-25 IP is also thicker than the typical South African granular base course for the same design traffic. The I-25 CTB thickness corresponds to the typical South African CTB thickness for similar design traffic in moderate to dry regions, or in wet regions where water is prevented from entering the base.

The natural subgrade generally consists of A-4, A-6, and A-7 materials (silty to clayey soils) with moderate to moderately high PI. The design subgrade R-value was 16, which represents a relatively soft soil (resilient modulus of approximately 3,500 psi [24.1 MPa]). Subgrade R-value data collected by NMDOT in 2008 and 2012 are summarized in figure 18. Materials with lower R-values were not allowed within the top 2 ft (610 mm) of the subgrade.

Table 5. Pavement cross section; I-25, Colfax County, New Mexico.

Pavement layer	**Thickness**		
	Northbound (NB)	**Southbound (SB)**	
	Inverted pavement	**Conventional pavement**	**Conventional pavement at bridge overpasses***
Open graded friction course (OGFC Type I)	5/8 in (15 mm)	5/8 in (15 mm)	5/8 in (15 mm)
AC (HMA SP-III)	3 in (75 mm)	7 in (180 mm) Two lifts with tack coat in between	7 in (180 mm) Two lifts with tack coat in between
Prime coat	yes	yes	yes
Unbound granular layer	8 in (200 mm)	6 in (150 mm)	6 in (150 mm)
Cement-treated base course	10 in (250 mm)	8 in (200 mm)	—
Lime-treated subgrade	12 in (300 mm)	—	12 in (300 mm)
Subgrade	Mostly A-4, A-6, and A-7 materials with moderate to moderately high PI.	Mostly A-4, A-6, and A-7 materials with moderate to moderately high PI.	Mostly A-4, A-6, and A-7 materials with moderate to moderately high PI.

*MP 452.631 to 452.821 and 453.900 to 454.090.

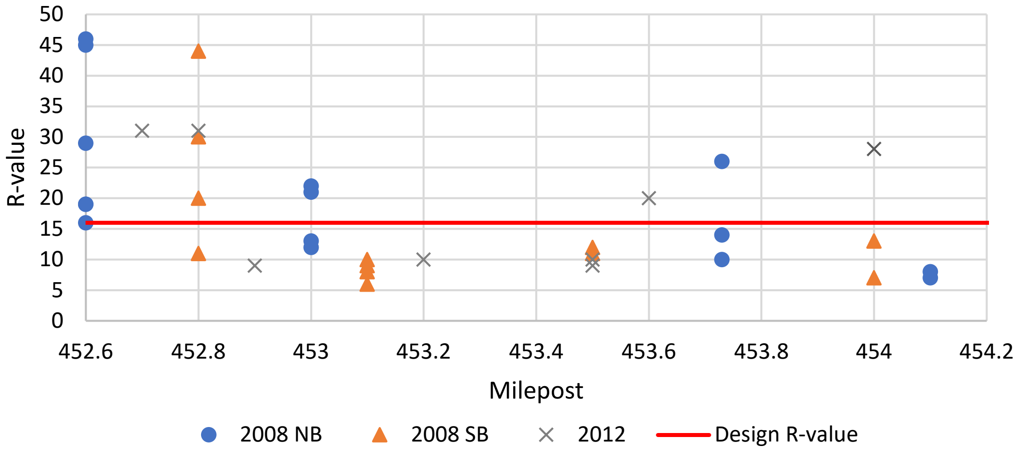
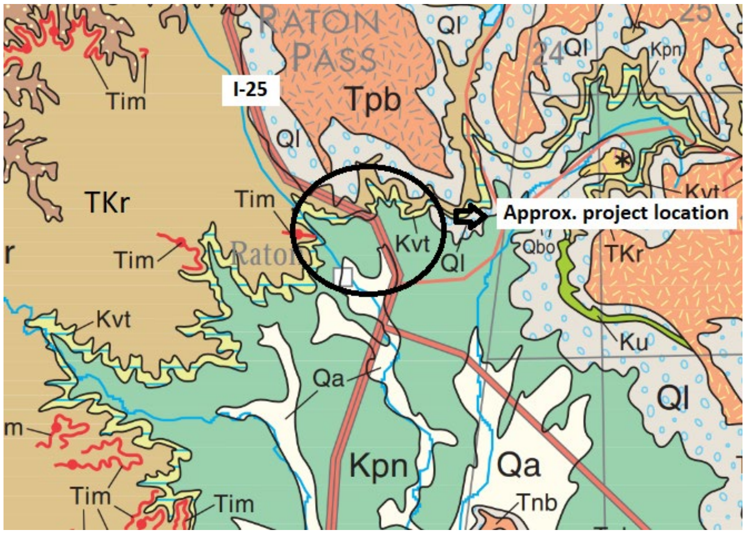


Figure 18. Graph. Subgrade R-value (based on data provided by New Mexico DOT).

According to the 1:500,000 USGS Geologic Map of New Mexico (figure 19), the road section under consideration intercepts the following geologic units:

- Kpn: Pierre shale and Niobrara formation (Companian to Coniacian)
- TKr: Raton formation (Paleocene and Upper Cretaceous)—Distal sandstones, mudstones, and coal beds in the eastern Raton Basin; the middle barren zone is laterally equivalent to the Poison Canyon formation
- Kvt: Vermejo formation and Trinidad sandstone (Maastrichtian to Campanian)
- Ql: Landslide deposits and colluvium (Holocene); includes associated alluvial and eolian deposits of major lake basins
- Qa: Alluvium (Holocene to Upper Pleistocene)



Original Photo: USGS

Figure 19. Illustration. 1:500,000 geologic map of New Mexico (modified from New Mexico Bureau of Geology and Mineral Resources in cooperation with the USGS 2003).

Figure 20 shows that Colfax County is in an area with abundant clay having high swell potential.

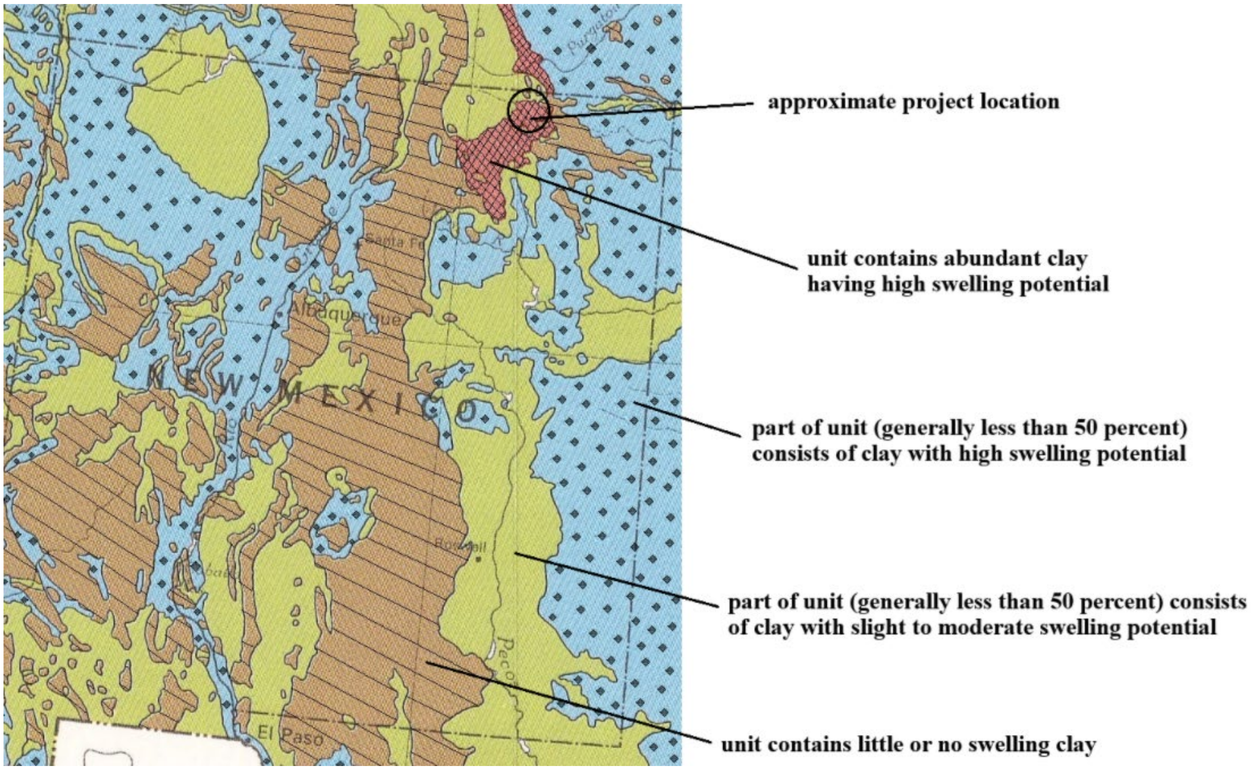


Figure 20. Illustration. Swelling clays map, New Mexico (modified from Olive et al. 1989).

The pavement was designed using the conventional empirical AASHTO Design Guidelines (AASHTO 1993). Design parameters adopted for the IP section are summarized in table 6. The total structural number of 6.28 surpasses the total structural number of the CP section, which was 5.14 (information provided by NMDOT).

The total structural number for the SB CP at bridge overpasses was not included in the information provided by NMDOT. Based on the structural coefficients provided in table 6 for cement-treated base (CTB) course and lime-treated subgrade, it is expected that the SB pavement at bridge overpasses had a total structural number 0.44 less than the SB CP in the remainder of the project (i.e., 0.22 × 8 inches minus 0.11 × 12 inches).

Table 6. Structural coefficient and number; inverted pavement I-25, Colfax County, New Mexico (information provided by New Mexico DOT).

Pavement design element	Structural coefficient	Structural number	Reference
Lime-treated subgrade	0.11	1.32	NMDOT 2008 pavement policy per laboratory testing
CTB	0.22	2.2	AASHTO 1993, Figure 2.8, unconfined compressive = ~800 psi (5.5 MPa)
High-quality graded crushed stone base	0.18	1.44	AASHTO 1993, Figure 2.6, resilient modulus, M_r = ~40,000 psi (275 MPa)
AC SP-III	0.44	1.32	NMDOT 2008 pavement policy
Total structural number		6.28	

Additionally, NMDOT conducted analysis based on the South African design approach using the AASHTO Mechanistic–Empirical Pavement Design Guide (MEPDG [AASHTO 2008]) procedure, which had not yet been calibrated for New Mexico materials and conditions. The MEPDG model indicated that the IP section could experience random top-down cracking (surface tensile stress/strain) and vertical plastic strain (rutting) within 10 years of completion. The model predicted that tensile strains would remain within tolerable limits, not developing into bottom-up fatigue cracking (alligator cracking). It was noted by the New Mexico design engineer at the time, however, that the South African National Roads Agency does not consider the thin AC layer to add any structural value to the pavement, pointing to the need of preventive surfacing maintenance to be considered within the life-cycle costs of IP.

Construction

Previously Existing Pavement

The existing pavement prior to construction of these sections consisted of two 12-feet (3.7 m) portland cement concrete pavement lanes with 8-feet (2.4 m) AC shoulders. The composition of the previously existing concrete pavement is summarized in table 7. Figure 21 includes photos showing the condition of the previous pavement.

Table 7. Pavement cross section; I-25, Colfax County, New Mexico.

Pavement layer	Thickness (in)
	Prior SB and NB pavement
Portland cement concrete paving	8.0
CTB	4.0
Subbase	4.0
Subgrade	—

Figure 21. Photo. Previous concrete pavement, I-25, Colfax County, New Mexico (credit: New Mexico DOT).

Cement-Treated Base Course

The initial plan was to reutilize the existing pavement by pulverizing and treating the existing subbase to turn it into a new CTB. However, to minimize risks, NMDOT decided to remove the existing pavement, stabilize the subgrade with lime, and construct the CTB layer with new materials. Figure 22 shows the subgrade preparation.

Figure 22. Photo. Subgrade preparation at I-25, Colfax County, New Mexico (credit: Bryce Simons).

The CTB layer incorporated Type III cement without fly ash and was constructed in one single lift (Simons 2016). Figure 23 shows the CTB construction, the required CTB minimum compressive strength measured at 28 days was between 850 and 1,000 psi (5.9 to 3.9 MPa). According to documentation provided by NMDOT, a 5.0 percent cement content was recommended for an anticipated compressive strength of 904 psi (6.2 MPa). Construction records provided by NMDOT indicate that an average cement content of 4.85 percent was used. The project contract specified that the CTB be placed in one lift and kept moist for a curing period of no fewer than five days. The CTB was required to achieve a minimum of 97 percent of maximum density as determined by AASHTO T 180. Achieved field compactions on the SB and NB pavements are summarized in figure 24. Higher values were generally achieved in the SB section, with an average of 102.4 percent of maximum dry density (MDD), whereas the NB pavement achieved an average compaction value of 99.1 percent of MDD. It is possible that the lower compaction levels in the NB pavement were related to the thicker CTB layer (10 inches [250 mm], as opposed to 8 inches [200 mm] for the SB pavement).

Figure 23. Photo. Cement-treated base construction; I-25, Colfax County, New Mexico (credit: Bryce Simons).

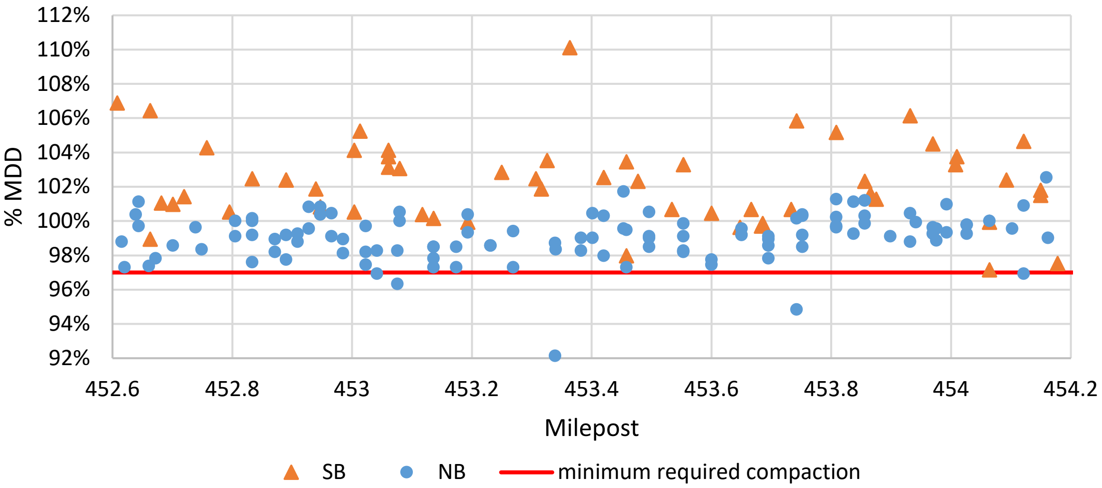


Figure 24. Graph. Achieved cement-treated base field compaction; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

High-Quality Graded Crushed Stone Base

The NB unbound granular base course consisted of a well-graded material with no gaps. Multiple stockpiles were used to allow for a uniform consistent gradation. The individual stockpiles were managed to prevent segregation, with the materials mixed to provide the required gradation and then loaded into trucks (Simons 2016). Figure 25 shows the granular base course production, and figure 26 shows the batch plant.

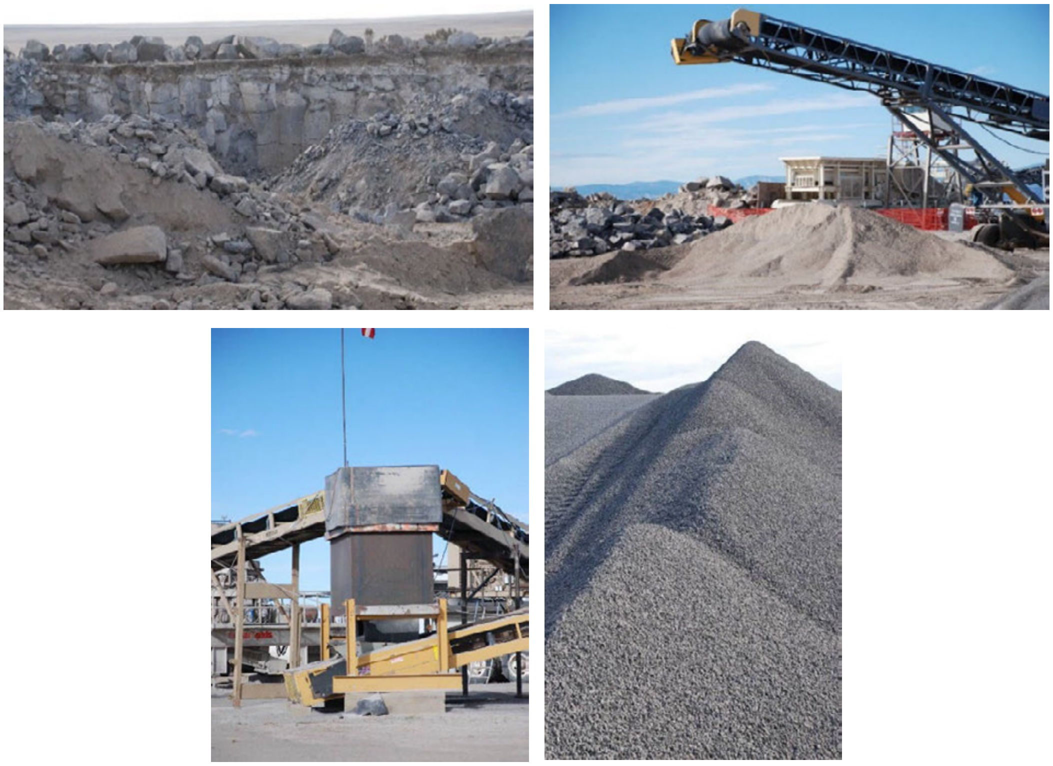


Figure 25. Photo. Granular base course production for I-25, Colfax County, New Mexico (credit: Bryce Simons).

Figure 26. Photo. Granular base course batch plant for I-25, Colfax County, New Mexico (credit: Bryce Simons).

Specification requirements for the NB IP high-density base course are summarized in table 8 and figure 27. The table and figure also include requirements for the South African G1 1 inch (about

26.5 mm) normal maximum aggregate size (NMAS) and for the New Mexico CP base course used (SB pavement). The requirements for the IP section were based on the South African G1 1 inch (about 26.5 mm) NMAS material requirements with some modifications, which are believed to have been included to allow for locally available materials to be used.

Table 8. Granular base course requirements; I-25, Colfax County, New Mexico (based on New Mexico DOT 2007; data provided by New Mexico DOT and South African Committee of Transport Officials [COTO 2020a]).

Sieve size		**Percent passing**		
(in)	**(mm)**	**South African G1 1 in (26.5 mm) NMAS**	**I-25 Base course conventional pavement)**	**I-25 High-density base course (inverted pavement)**
1.10	26.5	100		
1.00	25.4		100	100
0.75	19	85–95	90	85–95
0.52	13.2	71–84		
0.37	9.51			70–85
0.187 (No. 4)	4.76	42–60	45	40–60
0.0787 (No. 10)	2	27–45	32	
0.0496 (No. 16)	1.18			25-45
0.0167 (No. 40)	0.425	13–27		
0.0117 (No. 50)	0.297			13–27
0.0029 (No. 200)	0.074	5–12	6	5–12
Liquid limit (max.)		—	25	25
Plasticity index (max.)		**0.425 mm**: 4 (for up to 15×10^{6}ESALs) and NP (more than 15×10^{6}ESALs)	6	4
		0.075 mm: 8		
Aggregate Index (max.)		—	35	25
Acceptable materials		Sound, clean, unweathered high-quality crushed rock	Crushed stone, crushed screened gravel, caliche, sand, AC RAP, or recycled pavement (< 50%), processed glass aggregate (< 10%)	Crushed stone, crushed or screened gravel, sand
Other requirements		All fractured faces; maximum flakiness index 35 on all individual fractions above 14 mm; maximum linear shrinkage 2	At least 50% of the material retained on or above the No. 4 sieve have at least two fractured faces	At least 50% of the material retained on or above the No. 4 sieve has at least two fractured faces; plus 3/8 in (9.5 mm) material contain max. of 15% flat, elongated particles with a dimensional ratio of 3:1 but no more than 5:1

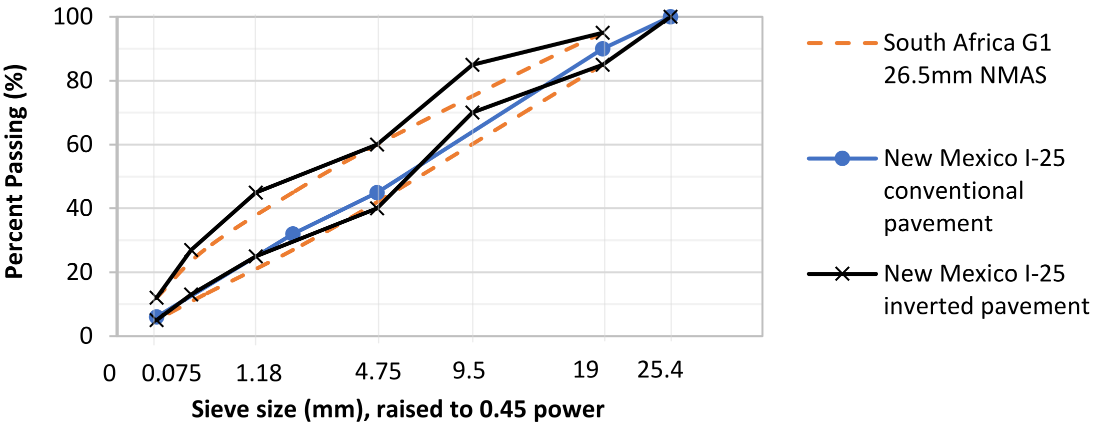


Figure 27. Graph. Particle-size distribution requirements for the granular basecourse; I 25, Colfax County, New Mexico (based on NMDOT 2007, COTO 2020a, and data provided by New Mexico DOT).

The New Mexico standard specification at the time of the project included target particle-size distribution for the base course rather than maximum and minimum limits.

The granular base course was constructed in a single lift, compacted to a minimum of 102 percent of the MDD as determined from AASHTO T 180. The construction team did not encounter difficulties in achieving minimum compaction requirements.

The South African slushing technique was adopted to finalize the NB granular base course (Simons 2016). The base course was saturated and rolled with static vibratory rollers, steel-wheeled rollers, and pneumatic-tired rollers to expel the excess fines and form a dense, interlocked matrix. Figure 28 shows the granular base course construction, and figure 29 shows the slushing technique being applied. Contract specification requirements included the following details for when the base course would be considered sufficiently slushed: (1) air bubbles would no longer appear behind roller wheels; (2) no more movement of the layer under the roller wheels, pneumatic-tired rollers leave no more indentations on the surface, and no more fines are extracted; (3) expelled water loses its coloration and becomes clear; and (4) no final material on the surface with the base course, showing a firmly interlocked mosaic. The length of each slushing operation was specified at a maximum of 600 ft. (183 m), with the exact length depending on equipment and worker availability.

Figure 28. Photo. Granular base course construction at I-25, Colfax County, New Mexico (credit: Bryce Simons).

Figure 29. Photo. Slushing at I-25, Colfax County, New Mexico (credit: New Mexico DOT and Bryce Simons).

Prior to constructing the AC layer, a prime coat was applied to the finished granular base course as soon as practical after the slushing process (Simons 2016).

Field construction test data indicated that the required compaction level (102 percent of MDD) was achieved throughout the project, with an average of 103.2 percent and a standard deviation of 1.2 percent. Field moisture conditions of the unbound granular base course layer during construction in the IP varied from about 20 to 80 percent of OMC, with an average of 53.1 percent and a standard deviation of 16.4 percent. Figure 30 shows the variation in the achieved NB unbound granular base's relative compaction and its 2012 backcalculated moduli.

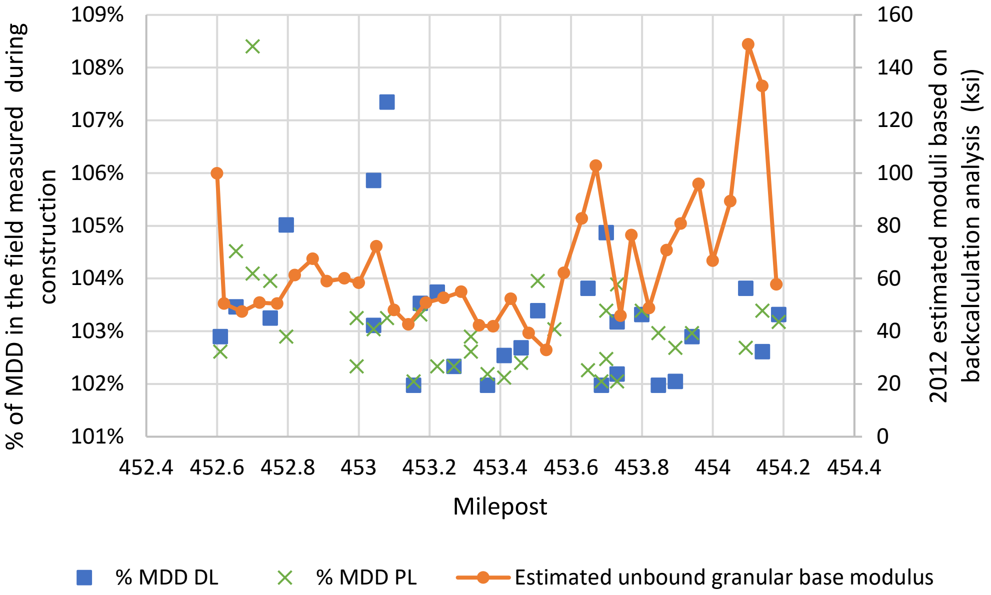


Figure 30. Graph. Compaction levels and 2012 backcalculated moduli in the inverted pavement unbound granular base course; I-25, New Mexico (based on data provided by New Mexico DOT).

Figure 31 presents the variation in field moisture conditions measured during construction and the same backcalculated moduli. Although figure 30 does not show any clear trend regarding variation in compaction levels with backcalculated moduli, it is possible to observe from figure 31 that lower backcalculated moduli generally corresponded to locations where moisture content as measured during construction was higher. In other words, the plot generally indicates that higher moisture conditions in the unbound granular base lead to lower moduli.

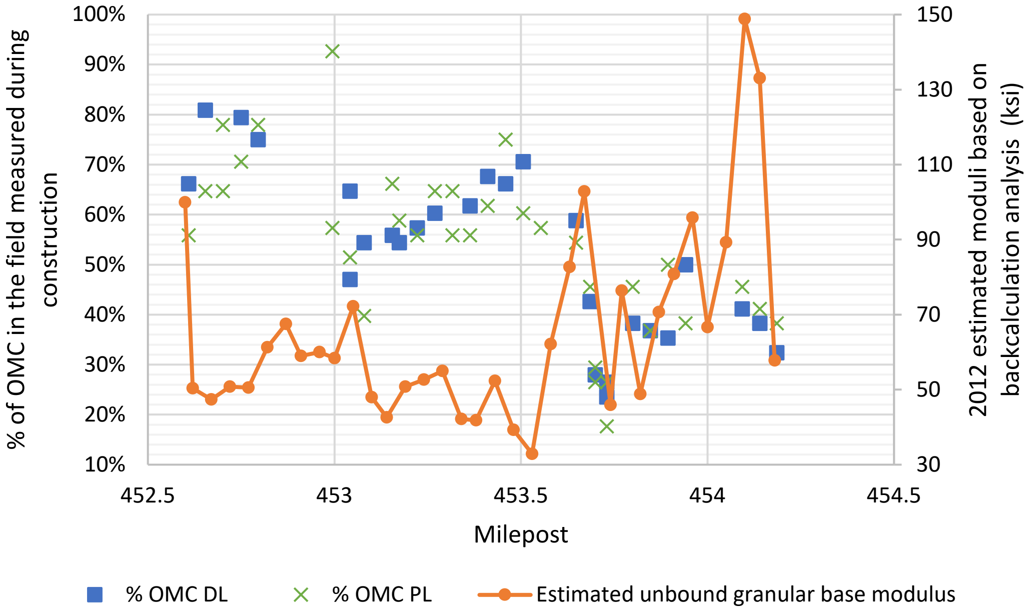


Figure 31. Graph. Moisture levels and 2012 backcalculated moduli in the inverted Pavement unbound granular base course; I-25, New Mexico (based on data provided by New Mexico DOT).

Asphalt Concrete Construction

The AC mix used had a NMAS of 3/4 inches (19 mm) with an asphalt binder grade PG 64-28, incorporating 15 percent reclaimed asphalt pavement (RAP) and 1 percent Versabind as a replacement for hydrated lime. A summary of the AC mix design is included in appendix A.1. Specification requirements for air voids were a minimum of 2.4 percent and a maximum of 5.6 percent. Construction test data indicated air voids varied from around 2.2 to 5.6 percent, with an average of 3.3 percent and a standard deviation of 0.9 percent. Compaction values varied from about 91.5 to 95.7 percent (with one test report of 98.2 percent), with an average of 93.3 percent and a standard deviation of 1.9 percent.

OGFC Construction

The open-graded friction course (OGFC) mix incorporated a PG 70-28+ asphalt binder, 6.5 percent by weight of total mix, and 1 percent Versabind. Test results for the OGFC mix are included in appendix A.1.

Maintenance and Rehabilitation

According to NMDOT records, maintenance included pot-holing activities in 2017 and 2021. It can also be observed that some crack sealing was conducted, especially of a continuous longitudinal joint believed to have originated from a construction joint. The right lanes in both directions were blade patched in November 2021. The NMDOT blade-patching maintenance activity consists of an application of AC followed by blading of the surface. Some of the longitudinal cracks in the left lane, which was not blade patched, were sealed, whereas some remained unsealed. In 2022, both the NB and SB sections received an AC overlay.

Traffic Loading

The pavement design assumed a 20-year design traffic of approximately 1.0×10^7 ESALs. According to a traffic monitoring program study carried out for the year of 2019, the measured 2019 traffic data for the I-25 sections relevant to the project are summarized in table 9.

Table 9. Two-way traffic; I-25, Colfax County, New Mexico.

Beginning mile point	End mile point	Traffic section	2019 average annual daily traffic (AADT)
452.54	452.76	1567	11,117
452.76	453.76	1569	4,719
453.72	453.88	1579	11,519
453.88	454.09	1581	9,195
454.09	455.58	1583	10,580

The projected traffic assumes a yearly traffic volume increase of 1.5 percent. For the most trafficked section, if conservatively assumed the traffic before 2019 was the same as 2019, and after that the yearly traffic per NMDOT prediction, the calculated 20-year actual traffic for the period of 2012 to 2032 would be 6.6×10^6 ESALs. In other words, the available traffic data indicated that the actual expected 20-year traffic from construction would be less than the traffic volume for which the pavement was designed.

Environmental Conditions

Table 10 includes average temperatures, rainfall, and snowfall for Raton, New Mexico.

Table 10. Raton, New Mexico, average temperatures, rainfall, and snowfall (source: NOAA).

Month	Temperature		Rainfall			Snowfall		
	Highs (°F)	Lows (°F)	Days	in	mm	Days	in	mm
Jan	47	21	2	0.5	13	2	6.7	170
Feb	49	23	2	0.5	13	2	5.2	132
Mar	55	28	4	1.1	28	2	6.2	157
Apr	62	34	4	1.2	30	1	2.8	71
May	71	43	6	2.2	56	0	0.6	15
Jun	80	52	6	1.9	48	0	0	0
Jul	84	56	8	3.1	79	0	0	0
Aug	82	55	9	3.5	89	0	0	0
Sep	76	49	5	1.8	46	0	0.1	3
Oct	66	38	3	1.2	30	0	1.5	38
Nov	55	29	2	0.6	15	1	3.9	99
Dec	47	22	2	0.6	15	2	6.0	152
Total			53	18.2	462	10	33.0	838

Raton is considered dry–freeze area in accordance with the FHWA and the long-term pavement performance (LTPP) classification (figure 32). However, a detailed Thornthwaite moisture index (TMI) map (figure 33) indicates that the project is in an area of relatively high TMI values.

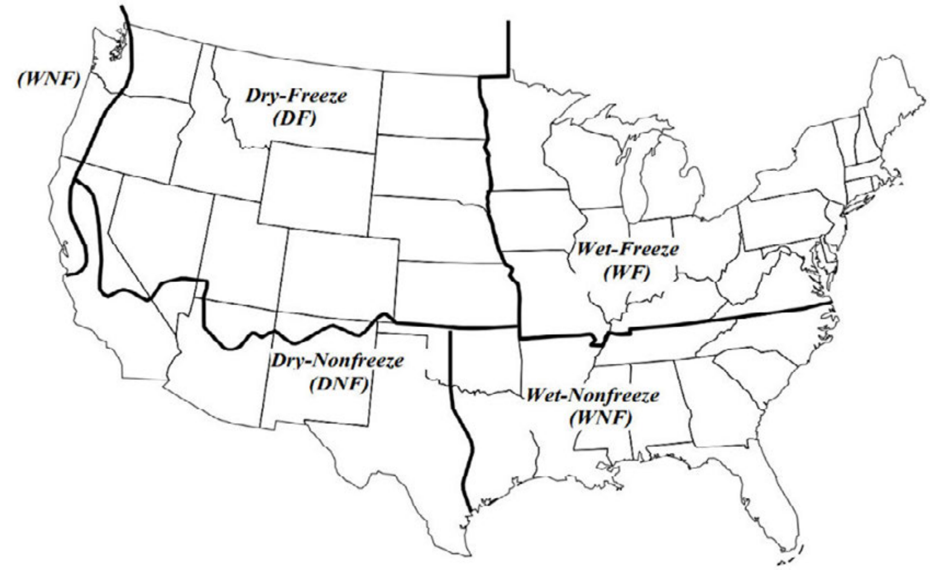


Figure 32. Illustration. Climatic zones in the United States, as classified by FHWA and the Long-Term Pavement Performance program (ARA 2004).

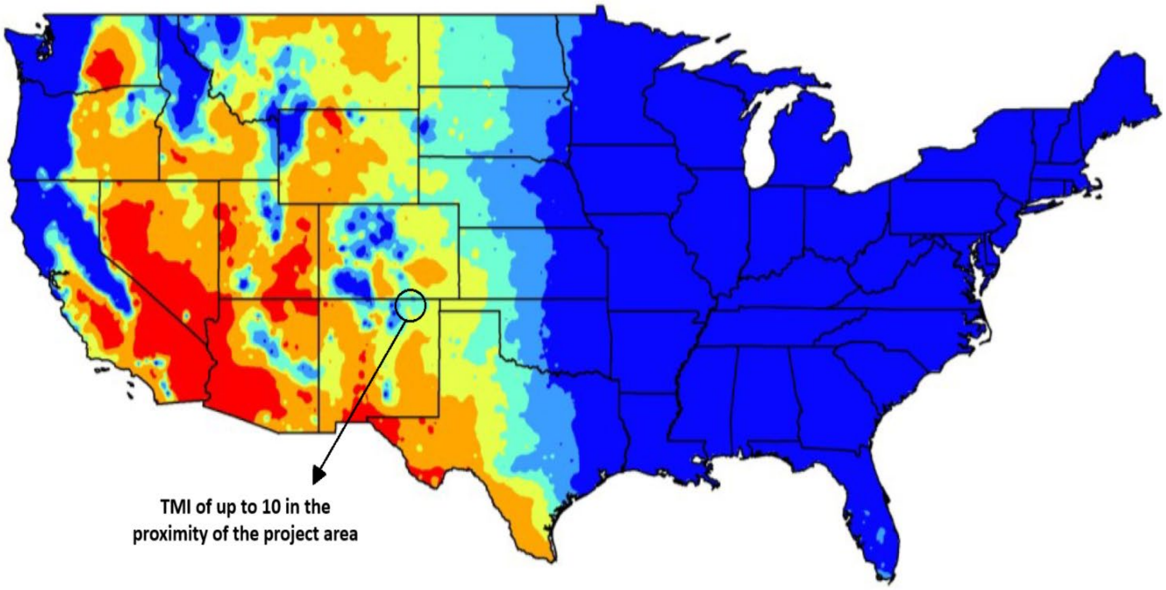
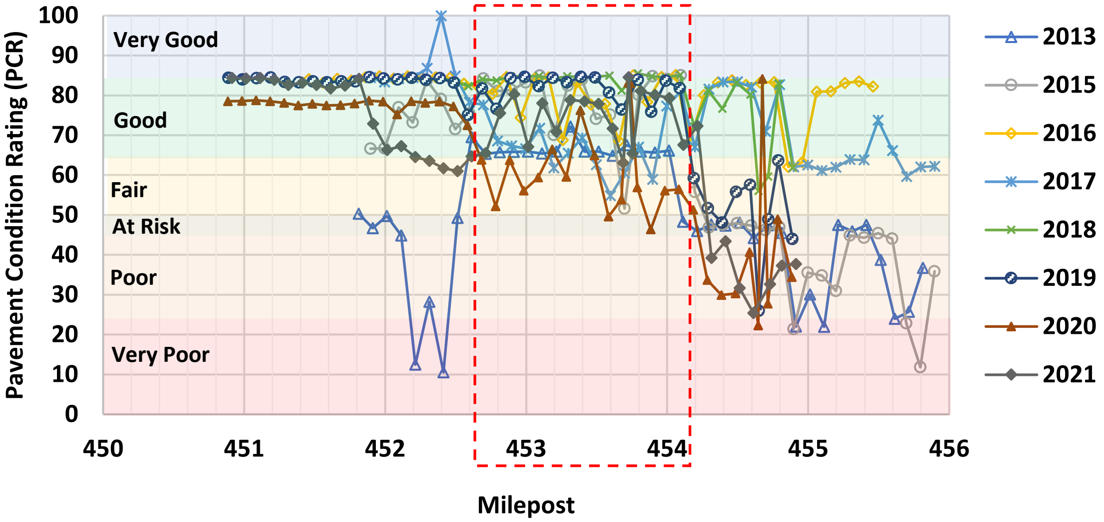


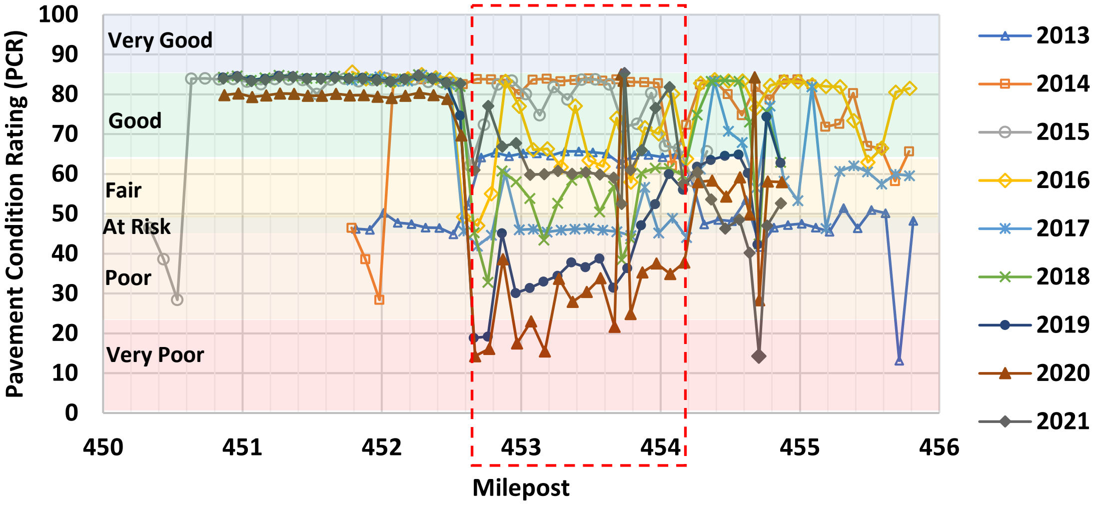
Figure 33. Illustration. TMI-2006 isopleth map of contiguous United States (Singhar 2018).

Performance

Figure 34, figure 35, figure 36, figure 37, and figure 38 show, respectively, the pavement condition rating (PCR), roughness index, rutting index, highway performance monitoring system (HPMS) cracking, and international roughness index (IRI) for the SB CP section and the NB IP sections from 2013 through 2021. The project section (MP 452.606 to 454.199) is the area marked with the red rectangle. Data for other mileposts were included to show the performance of the pavement before and after the project. The pavement south of the project (from approximately MP 448 to 452.606) is believed to be comprised of 6 inches (150 mm) CTB, 8.5 inches (215 mm) of AC (SP-III), and 3.5 inches (90 mm) of AC (SP-III), with the last maintenance activity comprising a 3.5-inches (90 mm) stone matrix asphalt (SMA) mill and inlay completed in 2015. The pavement north of the project (MP 454.199 to 455.214) is believed to be a 4-inches (150 mm) CTB, a 4-inches (100 mm) untreated base course, a 6-inches (150 mm) AC, and a 2.5-inches (38 mm) AC (SP-III), with the last maintenance activity comprising a 5.5-inches (140 mm) overlay completed in 2007.

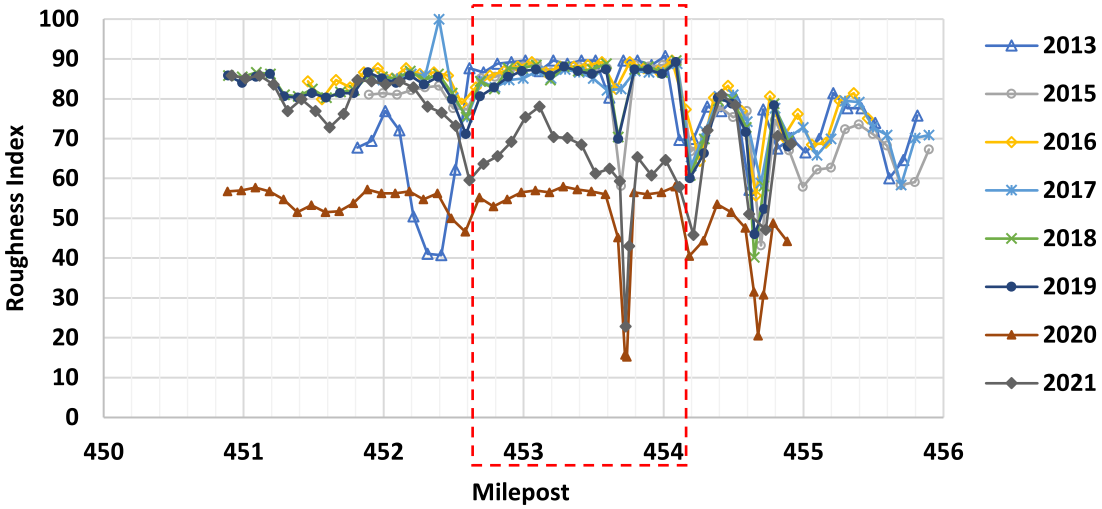


A. Southbound; conventional pavement.

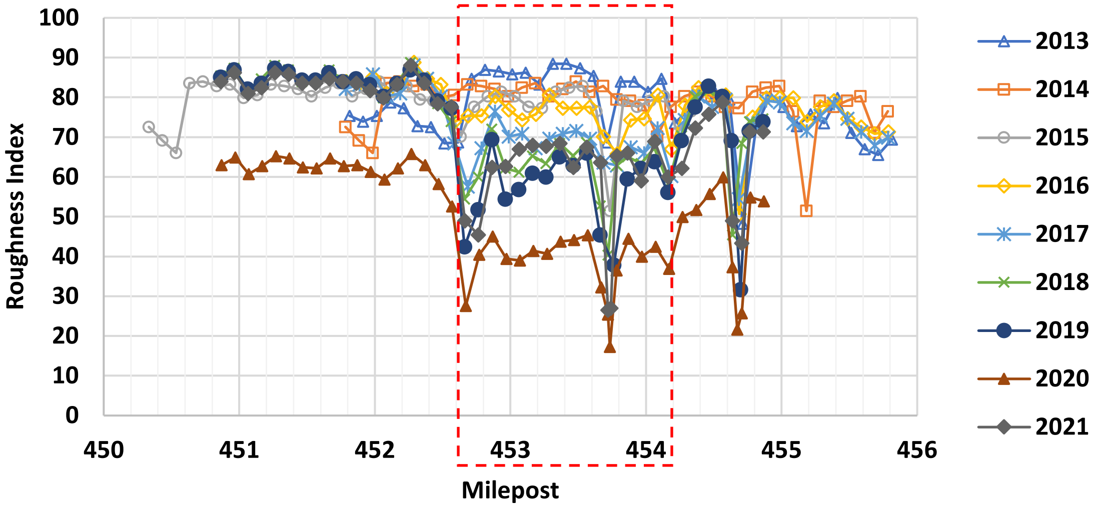


B. Northbound; inverted pavement

Figure 34. Graph. Pavement condition rating; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

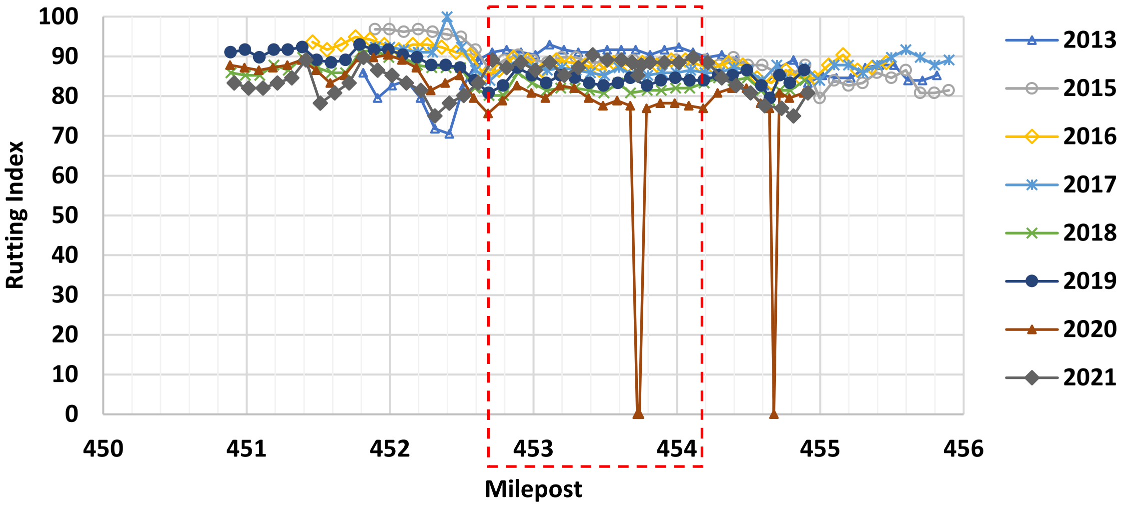


A. Southbound; conventional pavement.

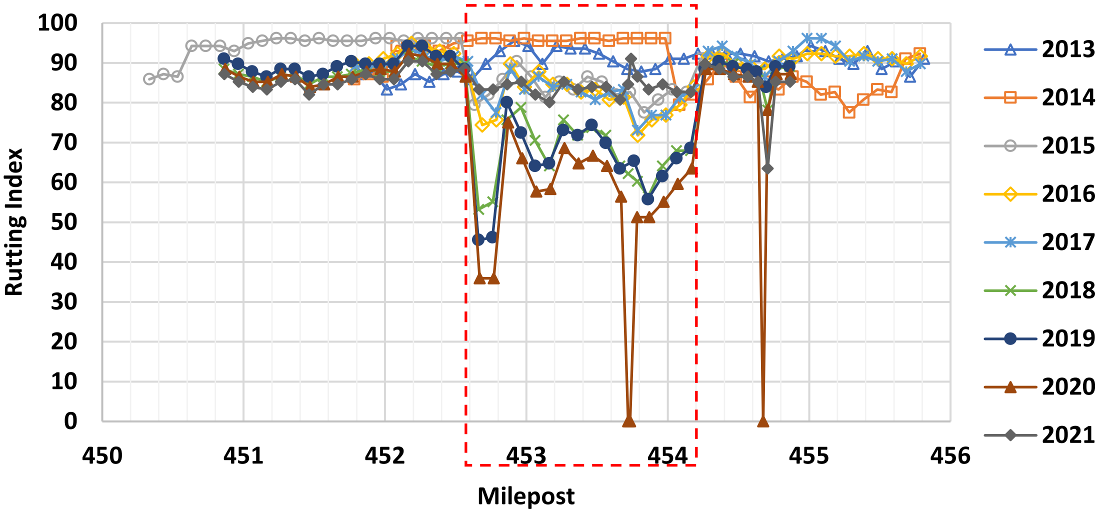


B. Northbound; inverted pavement.

Figure 35. Graph. Roughness index; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

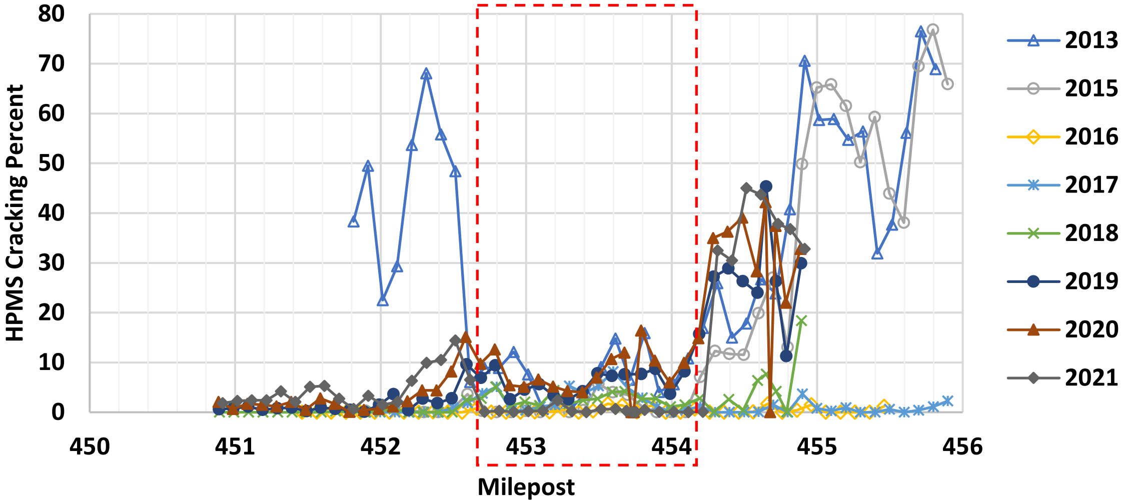


A. Southbound; conventional pavement.

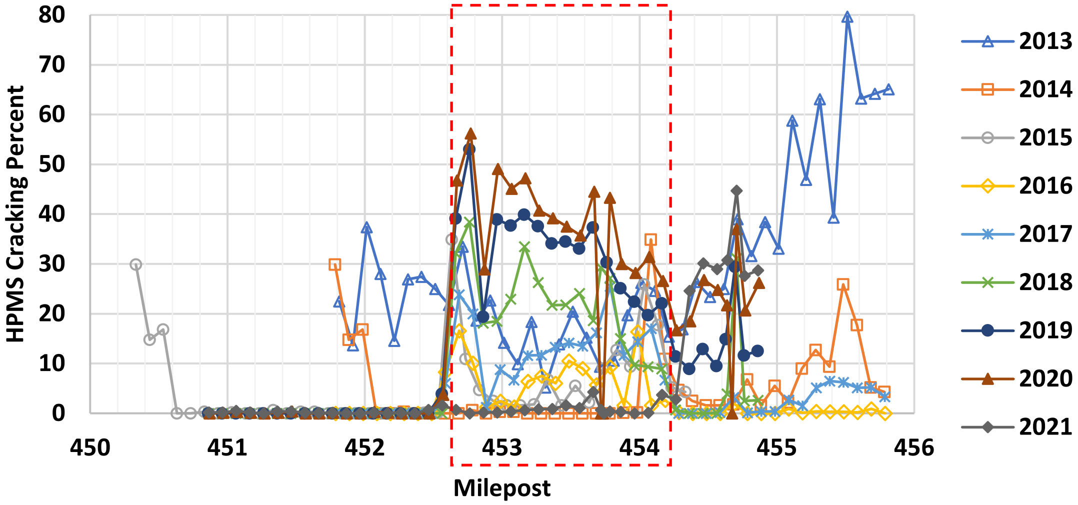


B. Northbound; inverted pavement.

Figure 36. Graph. Rutting index; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

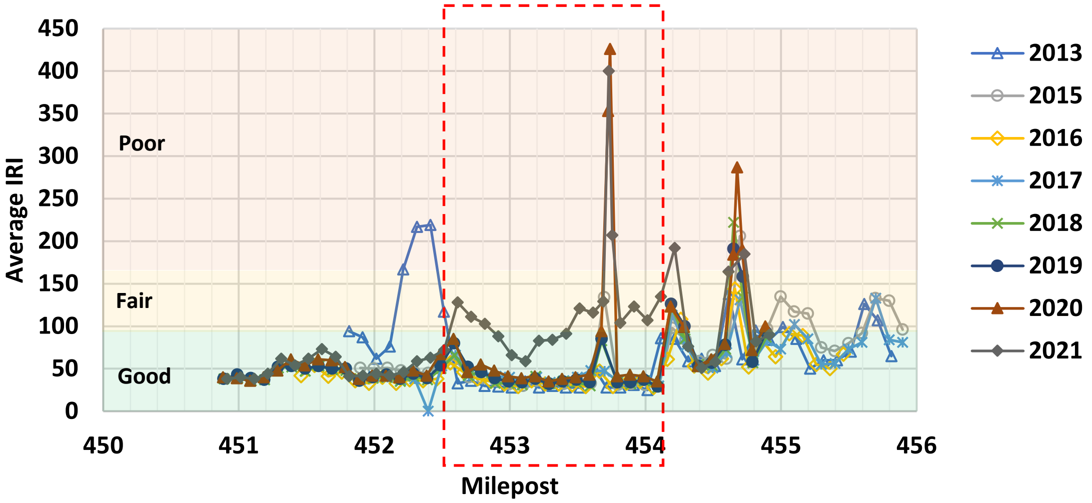


A. Southbound; conventional pavement.

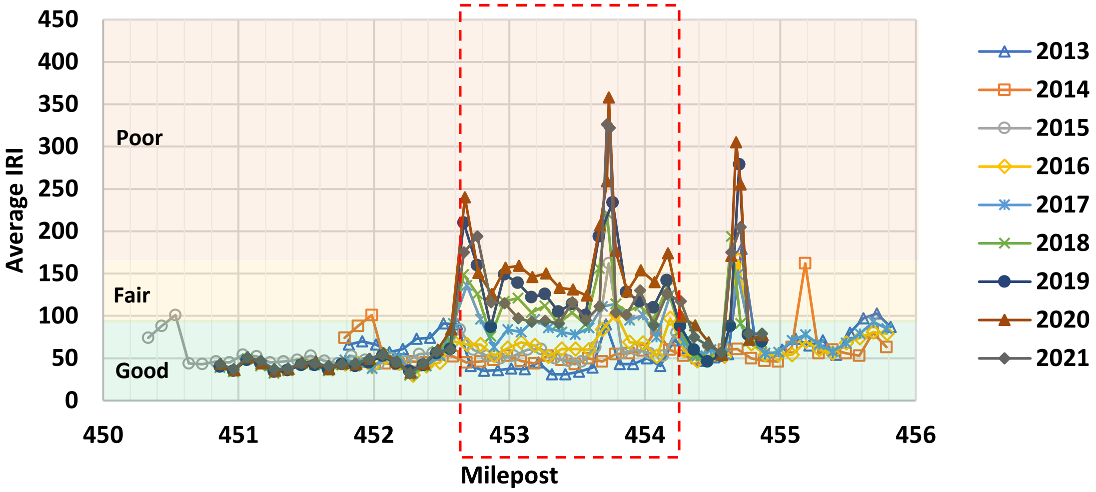


B. Northbound; inverted pavement.

Figure 37. Graph. Highway performance monitoring system cracking; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).



A. Southbound; conventional pavement.



B. Northbound; inverted pavement.

Figure 38. Graph. Average international roughness index; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

The overall performance, reported by PCR, considers rutting and cracking. Based on the PCR, pavement performance in the SB CP section was overall in good condition until 2019, falling to a fair to at-risk condition in Fall 2020. In November 2021, NMDOT performed patch blading on the driving lane (DL), and the condition of the pavement returned to good.

In the NB IP section, the pavement deteriorated significantly faster than that in the SB CP pavement. In 2016, some points already indicated a fair condition, falling to an at-risk condition in 2017. In 2018, the IP was in poor condition and in 2020 was in poor to very poor condition. In 2021, following a blade patching on the DL, the condition of the pavement was good to fair.

The roughness index in the SB CP showed a significant reduction from 2019 to 2020, when it fell to the 50s, with some improvement in 2021 following maintenance. The low values around

MP 453.7 are believed to correspond to the concrete overpass above Lincoln Avenue. The roughness in the NB IP suffered a more gradual reduction, reaching the 40s in 2020.

Rutting was not prominent in the SB CP, where rutting indices remained overall above 80. The NB IP presented significantly more rutting, especially from 2018 onward. The rutting index in 2020 reached 36 at the start of the section and around the 50s and 60s in the remainder of the section. Following maintenance in 2021, both sections (SB and NB) presented an increased rutting index.

Cracking percentage in the SB CP remained relatively low (less than 10 percent), with some locations reaching between 10 and 20 percent in 2013 and 2020. In the NB IP, cracking was significantly higher. In 2013, the NB already had sections with more than 20 percent cracking. In 2018, most of the section had more than 20 percent cracking. In 2019, cracking was overall between 20 and 40 percent, and in 2020 between 30 and 50 percent. Following maintenance in 2021, both sections (SB and NB) presented a significant decrease in cracking percentage.

Figure 39 presents a plot comparing the IP granular base course field moisture condition at the time of construction and HPMS cracking performance in the NB direction. The locations where higher moisture was measured in the NB unbound granular base course during construction appear to coincide with locations showing more cracking immediately prior to blade patching of the pavement (years 2019 and 2020). The same trend was not observed in the SB pavement, where the extent of cracking was considerably less than in the NB pavement and where the unbound granular base course was located deeper (further from the load) in the pavement.

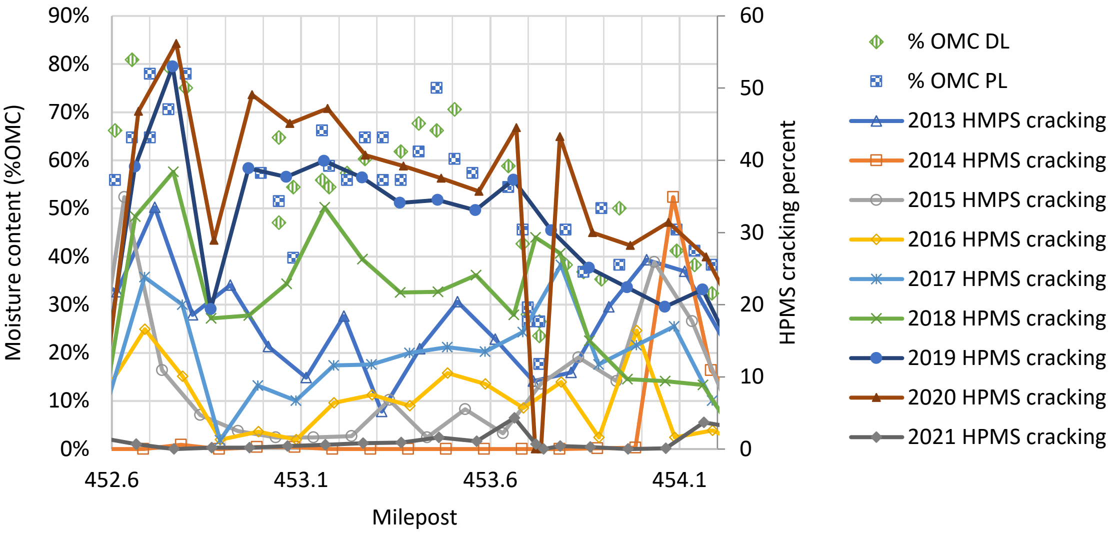


Figure 39. Graph. Moisture levels and 2012 backcalculated moduli for the inverted pavement high-density base course; I-25, New Mexico (based on data provided by Mexico DOT).

Figure 40 includes photos of the NB IP taken in 2015, showing longitudinal cracks outside and within the wheel path, as well as a core indicating AC stripping (figure 40(d)) and a core indicating top-down cracking (figure 40(e)).

A. Longitudinal cracking outside wheel path.

B. Longitudinal cracking within wheel path.

C. Illustration of crack width.

D. Pavement core showing AC stripping.

E. AC core showing top-down cracking.

Figure 40. Photo. (2015 photos) I-25 northbound inverted pavement, Colfax County, New Mexico (photos provided by New Mexico DOT).

Figure 41 through figure 46 are photos of the SB directions in 2020, prior to patch blading the DL, and in 2021, following patch blading. Figure 47 through figure 51 are photos of the NB direction. The downward images (on the right) show the cracking and intensity of the laser on the road surface with a color scale, where:

- Green indicates low cracking severity (approximately 1/4-inches [6.3 mm] or smaller cracks)
- Yellow indicates medium severity (generally 1/4- to 3/4-inches [6.35 to 19 mm] cracks)
- Red indicates high severity (3/4-inches [19 mm] and larger cracks or if pumping is present).
- (Note that the numbers on the right side images correspond to mile points rather than mile posts. The mile points on the NB direction are 1.163 miles [1.872 km] ahead of the mile posts and on the SB direction are 1.189 miles [1.913 km] ahead.)
- The bottom image at each location was taken from Google® Earth™. Images were collected in July and September 2021, after patch blading of the DLs. The condition of the left lanes is more visible from the Google Earth images.

A. 2020 Fugro images.

B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 41. Photo. Fugro and Google® Earth™ Street View images; MP 454.0, I-25 southbound control pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

A. 2020 Fugro images.

B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 42. Photo. Fugro and Google® Earth™ Street View images; MP 453.7, I-25 southbound control pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

A. 2020 Fugro images.

B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 43. Photo. Fugro and Google® Earth™ Street View images; MP 453.4–453.5, I-25 southbound control pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

A. 2020 Fugro images: forward image on the left and downward image on the right.

B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 44. Photo. Fugro and Google® Earth™ Street View images; MP 453.2–453.3. I-25 southbound control pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

A. 2020 Fugro images: forward image on the left and downward image on the right.

B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 45. Photo. Fugro and Google® Earth™ Street View images; MP 453.0, I-25 southbound control pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

A. 2020 Fugro images: forward image on the left and downward image on the right.

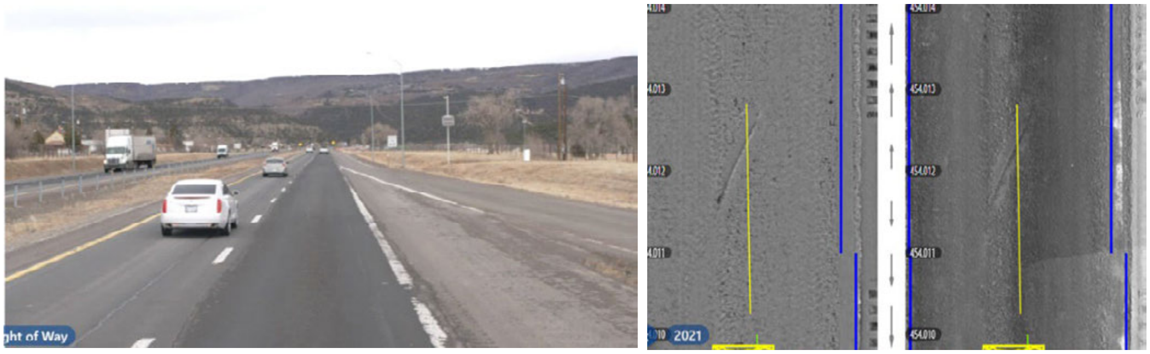
B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 46. Photo. Fugro and Google® Earth™ Street View images; MP 452.9, I-25 southbound control pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

A. 2020 Fugro images: forward image on the left and downward image on the right.

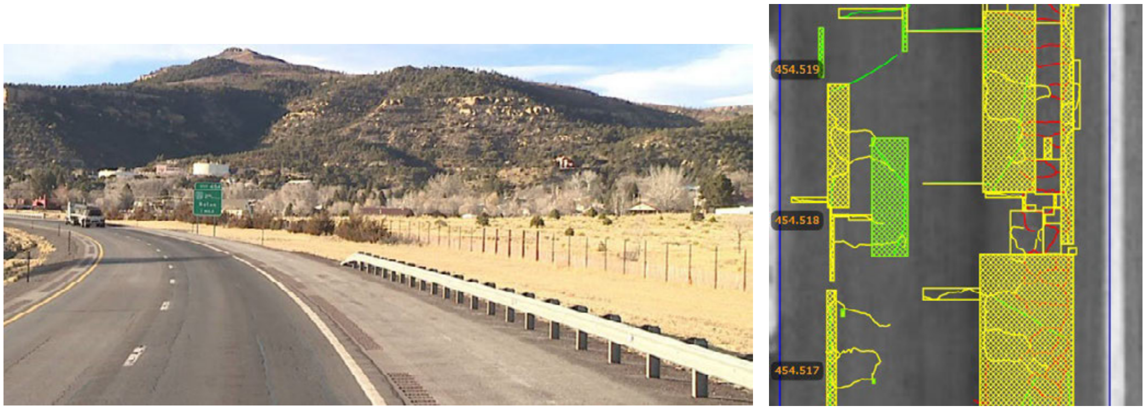


B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 47. Photo. Fugro and Google® Earth™ Street View images; MP 453.1, I-25 northbound inverted pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).



A. 2020 Fugro images: forward image on the left and downward image on the right.

B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 48. Photo. Fugro and Google® Earth™ Street View images; MP 453.3, I-25 northbound inverted pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

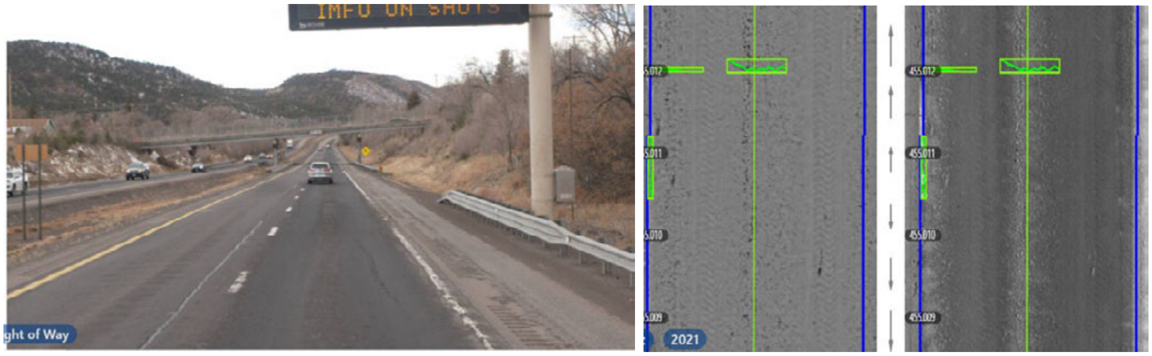
A. 2020 Fugro images: forward image on the left and downward image on the right.

B. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 49. Photo. Fugro and Google® Earth™ Street View images; MP 453.6, I-25 northbound inverted pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

A. 2020 Fugro images: forward image on the left and downward image on the right.



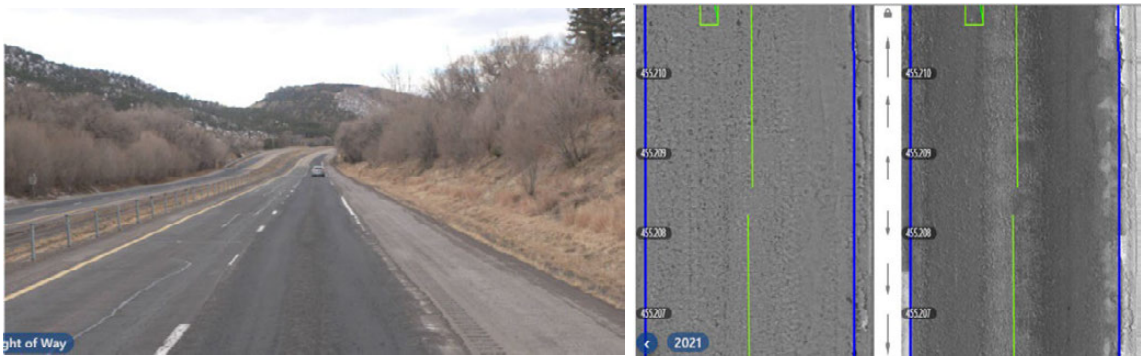
B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 50. Photo. Fugro and Google® Earth™ Street View images; MP 453.8, I-25 northbound inverted pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

A. 2020 Fugro images: forward image on the left and downward image on the right.



B. 2021 Fugro images: forward image on the left and downward image on the right.

C. 2021 Street View image.

Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 51. Photo. Fugro and Google® Earth™ Street View images; MP 454.0, I-25 northbound inverted pavement, Colfax County, New Mexico (Fugro images provided by New Mexico DOT).

The 2020 Fugro images of the DL show that the NB IP presented significantly more cracking than the SB control section. The control section presented low- to medium-severity cracking, limited mostly to longitudinal cracks at the right edge of the lane. The IP presented significant medium- to high-severity alligator cracking, concentrated primarily in the right wheel path (RWP) but also developing in the left wheel path (LWP), especially at MP 453.105.

Continuous longitudinal cracks observed in the left lane in both the IP and CP sections are believed to be related mostly to AC mix design (Simons 2016), construction joints, and/or potential segregation during construction.

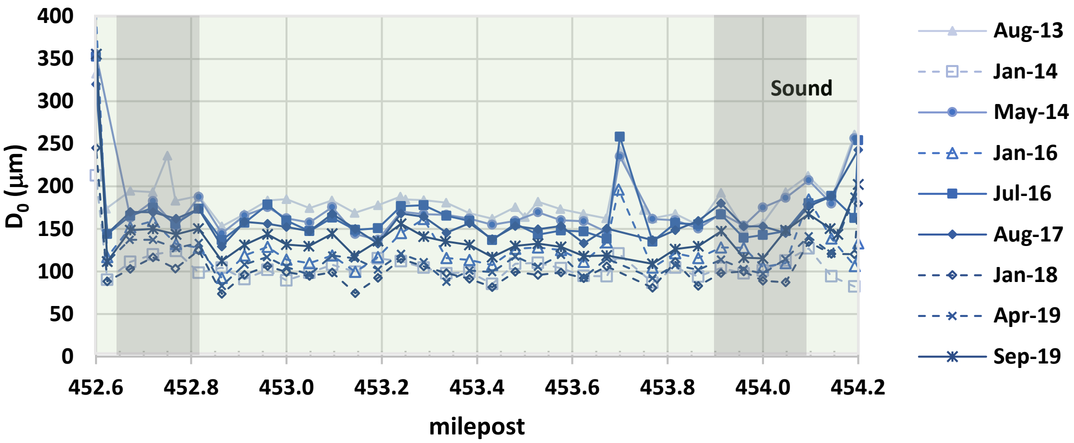
Additionally, some transverse cracking was observed, which is believed to be related to AC contraction in cold weather (i.e., thermal cracking) and potentially to reflection of shrinkage cracks from the CTB to the surface.

Figure 52, figure 53, figure 54, figure 55, and figure 56 show, respectively, FWD maximum deflections, radius of curvature (RoC), base layer index (BLI), middle layer index (MLI), and lower layer index (LLI), as defined by Horak (2008) and summarized in table 11. It is noted that the geophone spacing in the FWD used in the United States differs slightly from the typical South African spacings, for which the indices shown were developed. The deflections assumed that D_{200}, D_{300}, D_{600}, and D_{900} were the deflections at spacings from the load of, respectively, 8 inches (203 mm), 12 inches (305 mm), 24 inches (610 mm), and 36 inches (914 mm) rather than 7.9 inches (200 mm), 11.8 inches (300 mm), 23.6 inches (600 mm), and 35.4 inches (900 mm). The structural condition rating, represented by the colors green (sound), yellow (warning), and red (severe), are included in the plots in figure 52 through figure 56. Horak's (2008) limits for bituminous base pavement were considered for the SB pavement, and limits for pavements with a granular base considered for the NB IP (table 11). The shaded area in the SB plots corresponds to the SB CP at bridge overpasses.

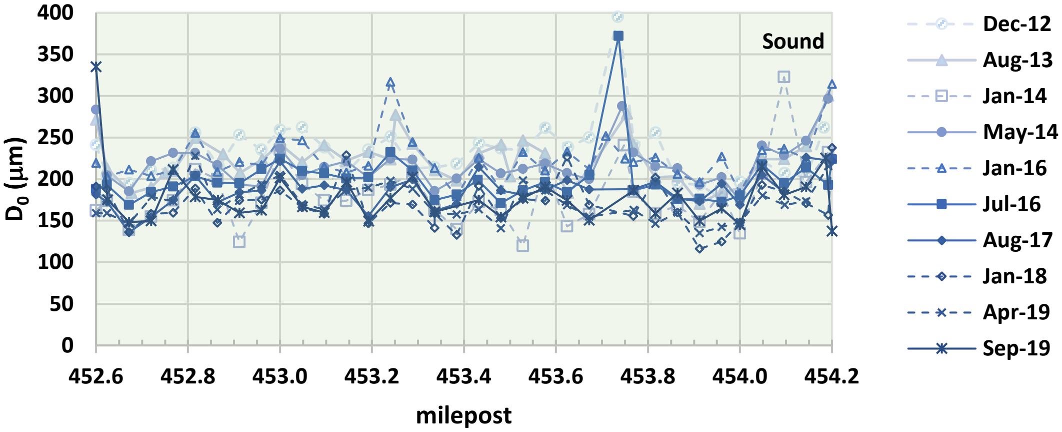
Table 11. Granular base deflection bowl parameter structural condition rating criteria for various pavement types (Horak 2008).

Pavement type and direction	Structural condition rating	Deflection bowl parameters				
		D_0 (µm)	RoC (m)	BLI (µm)	MLI (µm)	LLI (µm)
			$= \frac{L^2}{2D_0\left(1-\frac{D_{200}}{D_0}\right)}$	$= D_0 - D_{300}$	$= D_{300} - D_{600}$	$= D_{600} - D_{900}$
Bituminous base pavement	Sound	< 400	> 250	< 200	< 100	< 50
	Warning	400–600	100–250	200–400	100–150	50–80
	Severe	> 600	< 100	> 400	> 150	> 80
Inverted pavement (granular base)	Sound	< 500	> 100	< 200	< 100	< 50
	Warning	500–750	50–100	200–400	100–200	50–100
	Severe	> 750	< 50	> 400	> 200	> 100

where: D_i = deflection at a distance *i* (in mm) from the load and *L* = 200 mm (7.9 in) for the FWD; 1 in = 25 mm; RoC= radius of curvature; BLI =base layer index; MLI =midle layer index; and LLI=lower layer index

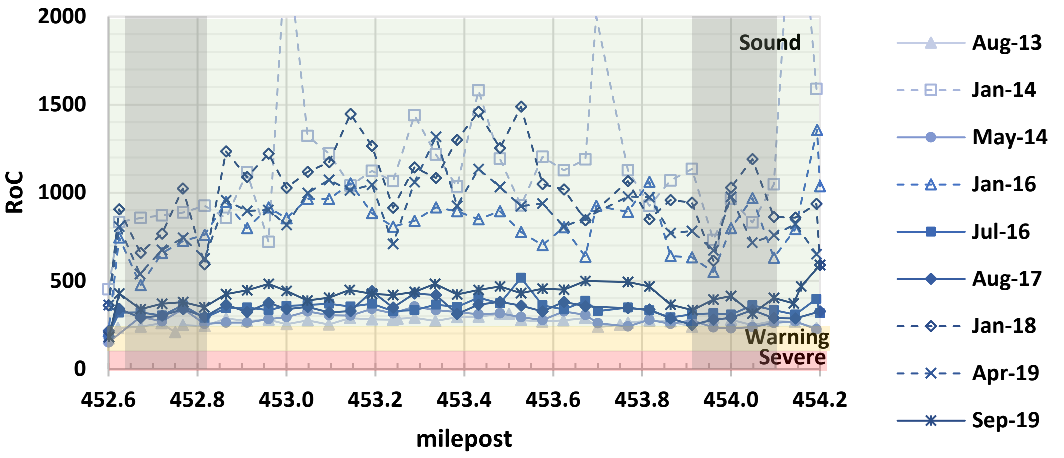


A. Southbound; conventional pavement.

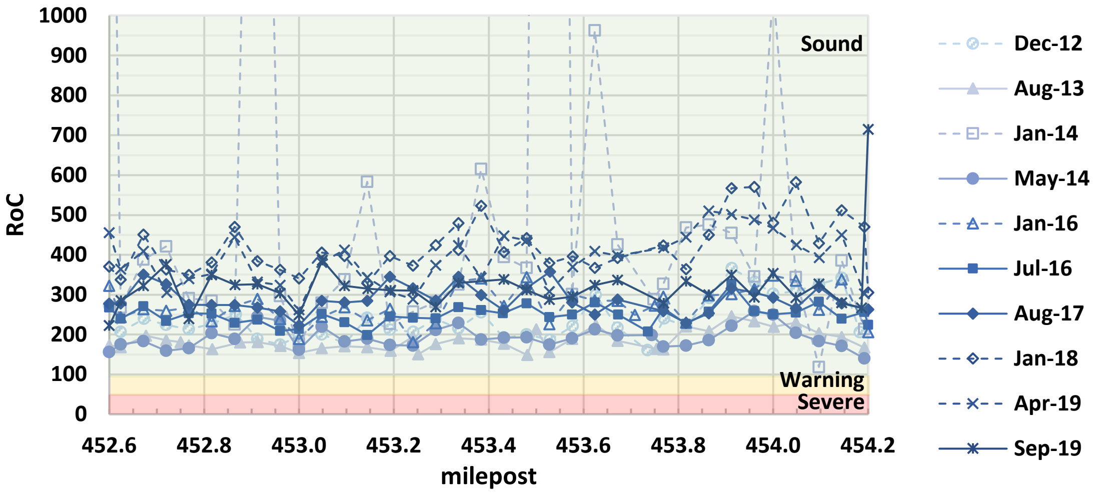


B. Northbound; inverted pavement.

Figure 52. Graph. Maximum deflection; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

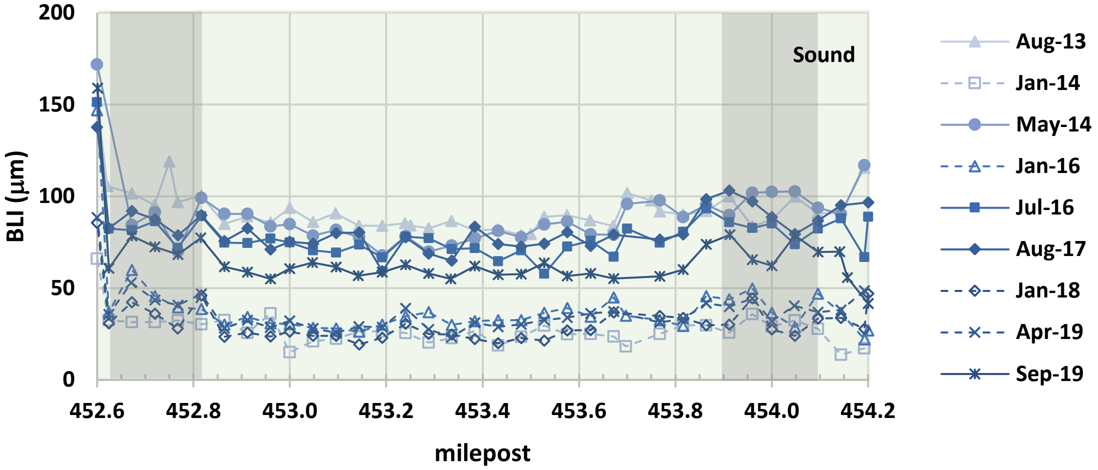


A. Southbound; conventional pavement.

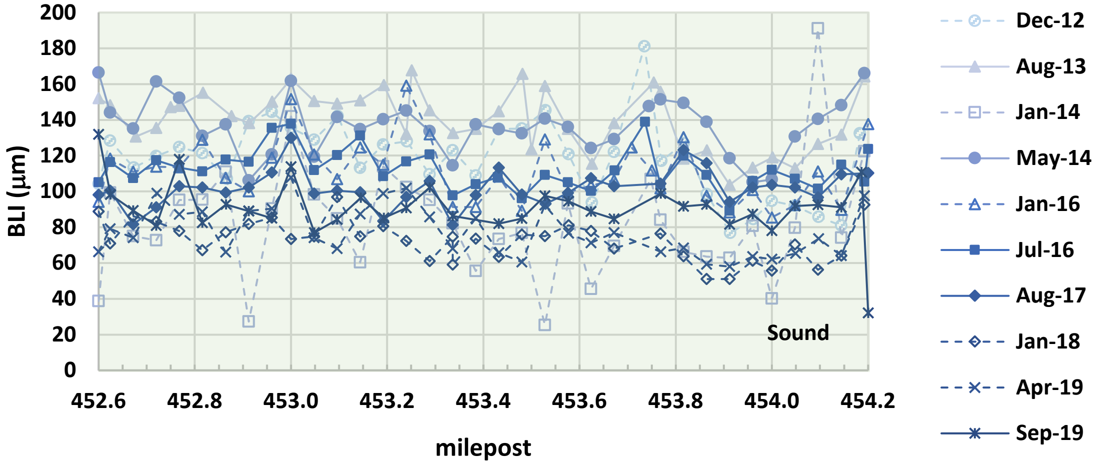


B. Northbound; inverted pavement.

Figure 53. Graph. Radius of curvature; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

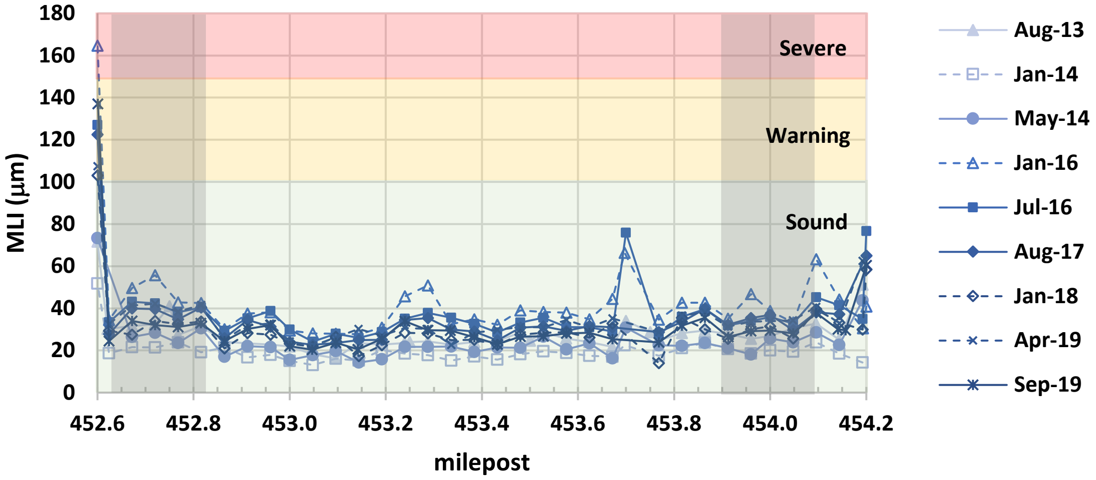


A. Southbound; conventional pavement.

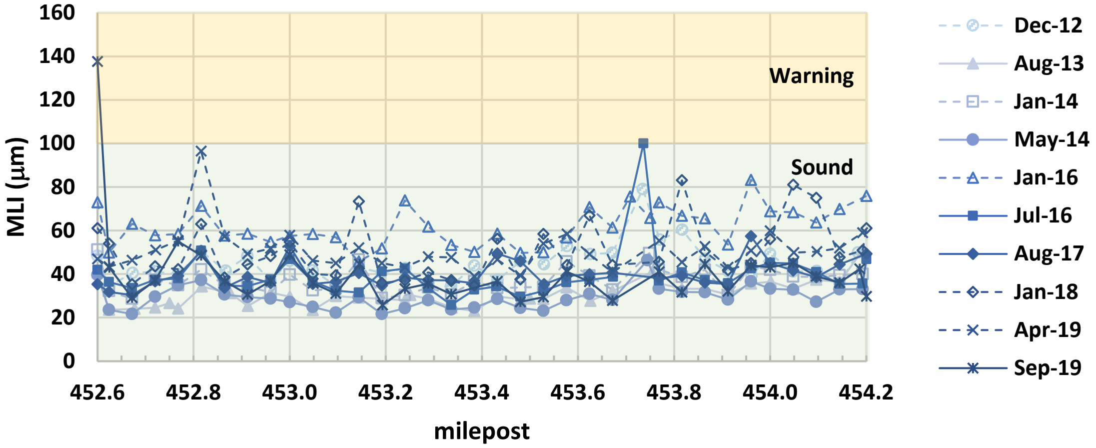


B. Northbound; inverted pavement.

Figure 54. Graph. Base layer index; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

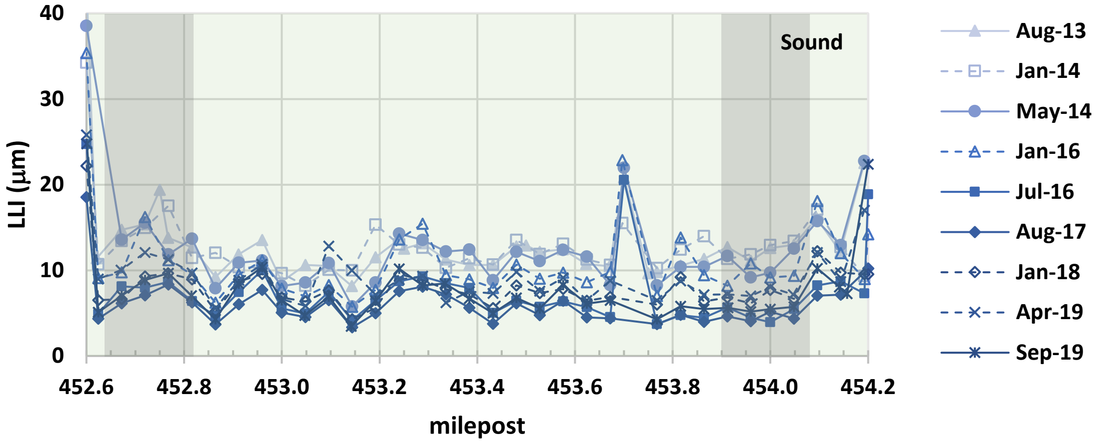


A. Southbound; conventional pavement.

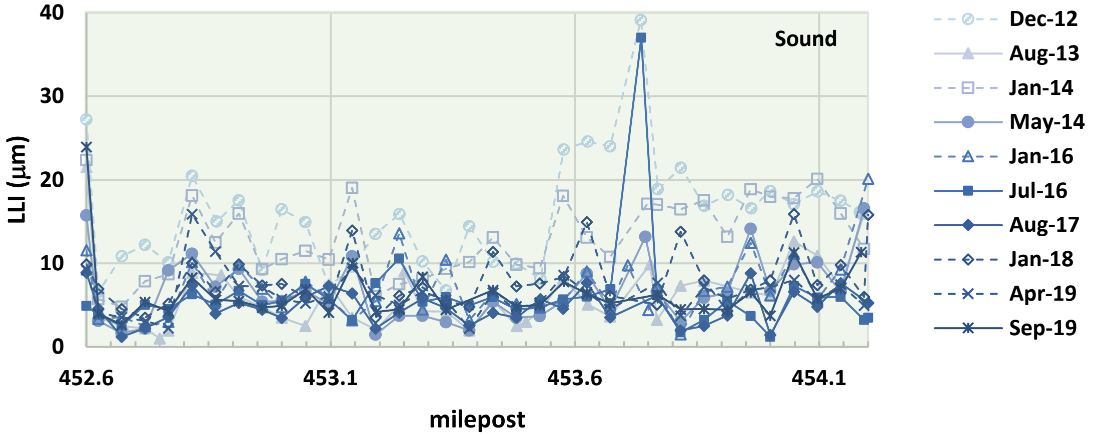


B. Northbound; inverted pavement.

Figure 55. Graph. Middle layer index; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).



A. Southbound; conventional pavement.



B. Northbound; inverted pavement.

Figure 56. Graph. Lower layer index; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

Except for a few isolated locations, the pavement structural condition rating fell within the sound condition limits. However, it is noted that these ratings were developed for South African granular base pavements, for which the IP surfacing layer is either a chip seal or a thin AC layer with thicknesses of approximately 1.6 to 2.0 inches (40 to 50 mm). The IP section in I-25 includes a 3.9-inches-thick (100 mm) AC surfacing layer. Therefore, the structural condition rating as defined by Horak (2008), especially RoC, may overestimate the condition of the NB IP because the additional AC thickness would generally lead to lower deflections.

According to Horak (2008), the RoC and the BLI correlate with surface and base layers, the MLI with the subbase, and the LLI with the selected and subgrade layers, respectively.

The SB CP maximum deflection (D_0) and BLI during the colder months (dotted lines) were lower than during the warmer months (full lines), and the opposite behavior was observed for RoC.

For the NB IP section, the difference between measurements during the colder months and warmer months is less prominent. RoC and BLI are relatively constant. This could be attributed to the relatively thinner AC layer in the IP that minimizes the temperature effect on pavement structural capacity variation.

In general, D_0 appears to be relatively constant, with a few higher values observed at MPs 453.7 and 454.2 in the SB direction, and MPs 453.2, 453.7, 454.1, and 454.2 in the NB direction.

The MLI and LLI showed slightly higher values toward higher MPs, both in the SB and NB sections, though remaining within good condition limits.

As previously noted, the IP in New Mexico incorporated a much thicker AC surface layer than typical IP in South Africa. According to the South African Mechanistic–Empirical Design Method (SANRAL 2014), a thick AC base layer is an AC layer of more than 2.9 inches (75 mm), whereas a thin AC is less than 2.0 inches (50 mm). The AC in the New Mexico IP is 2.9 inches (75 mm), with an additional OGFC layer 5/8-inches-thick (16 mm). If Horak's (2008) limits for bituminous base pavement were used instead of the limits for granular base pavements, the RoC, especially for the warmer months, would be classified as close to or within a warning condition rather than sound, as shown in figure 57.

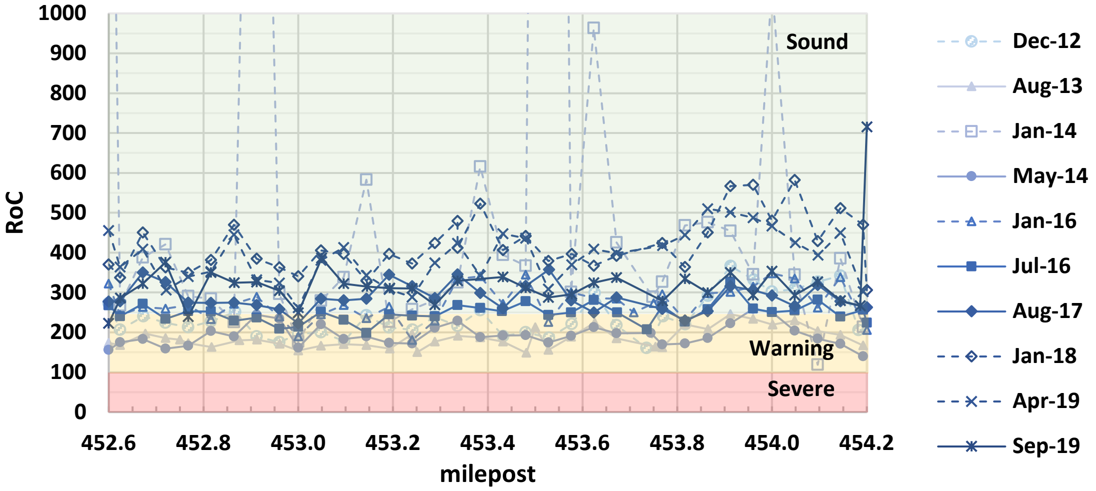
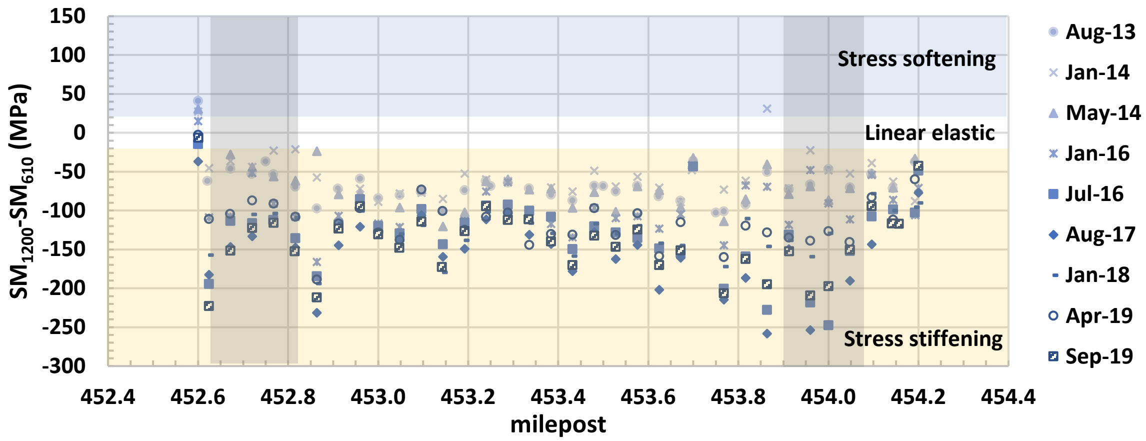


Figure 57. Graph. Radius of curvature; I-25, Colfax County, New Mexico: northbound inverted pavement with structural condition rating of bituminous base pavements (based on data provided by New Mexico DOT).

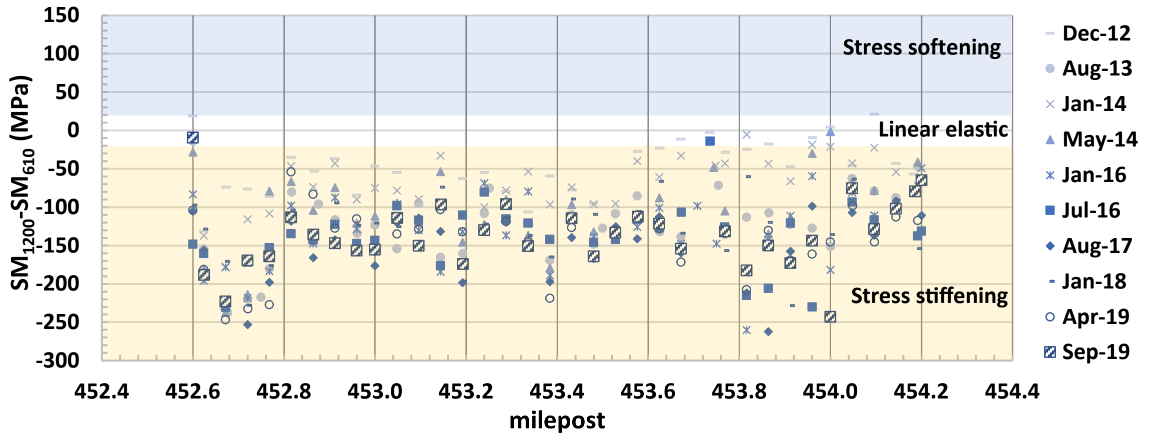
Figure 58 shows the surface modulus differential (SMD) as defined by Horak (2008), which is calculated as the difference between the surface modulus at a distance 47.2 inches (1,200 mm) and 23.6 inches (600 mm) from the load. The surface modulus represents the weighted mean modulus of the equivalent half-space calculated from the surface deflection using adapted

Boussinesq's equations (Horak 2008, Ullidtz 1987). Because the FWD equipment used did not measure deflection at exactly 47.2 inches (1,200 mm) and 23.6 inches (600 mm) from the load, the deflection at 47.2 inches (1,200 mm) was calculated by linearly interpolating the deflections measured at 36 inches (914 mm) and 60 inches (1,524 mm) from the load, and the deflection at 24 inches (610 mm) from the load was considered instead of at 23.6 inches (600 mm). According to Horak (2008), SMD greater than 20 indicates stress-softening subgrade responses, between 20 and –20 indicates linear elastic responses, and lower than –20 indicates stress-stiffening responses.

Figure 58 shows that, according to Horak's analysis methodology, the subgrade response would be considered to be mostly stress stiffening (i.e., stress hardening), with SMD generally decreasing with time, although in the NB section from approximately MP 453.7 onward, some of the testing points indicated a linear elastic response.



A. Southbound; conventional pavement.



B. Northbound; inverted pavement.

Figure 58. Graph. Surface modulus differential; I-25, Colfax County, New Mexico (based on data provided by New Mexico DOT).

FWD Backcalculated Moduli

The FWD measured deflections were used to obtain backcalculated moduli for the various pavement layers and subgrade using the software ELMOD 6.0 software considering stress dependency of granular materials' moduli.

Material input parameters for the backcalculation analysis are summarized in table 12. The parameters were chosen based on engineering judgment and available reasonable ranges encountered in the literature (Luo and Prozzi 2008; Pierce et al. 2017; Stubstad, Jiang, and Lukanen 2006). The OGFC and underlying AC were modeled as one single AC layer because a backcalculation of thin layers can result in unrealistic values.

Table 12. Assumed layer mechanical properties in backcalculation analysis; I-25, Colfax County, New Mexico.

Pavement layer	Poisson ratio	Seed modulus value (ksi)	Allowable modulus range	
			Min.	Max.
OGFC Type I and AC (SP-III)	0.35	600 ksi (4,135 MPa)	50 ksi (345 MPa)	3,650 ksi (25,165 MPa)
Unbound granular layer	0.35	90 ksi (620 MPa)	15 ksi (105 MPa)	220 ksi (1,515 MPa)
CTB	0.25	300 ksi (2,070 MPa)	15 ksi (105 MPa)	1,160 ksi (8,000 MPa)
Lime-treated subgrade	0.20	20 ksi (140 MPa)	5 ksi (35 MPa)	200 ksi (1,380 MPa)
Subgrade	0.45	15 ksi (105 MPa)	5 ksi (35 MPa)	70 ksi (480 MPa)

Modulus stress dependency was considered in two layers: unbound granular pavement layer and subgrade. The model used by ELMOD for stress-dependent layers is represented by the equations in figure 59 and figure 60 for cohesive materials and noncohesive materials, respectively.

$$E = C\left(\frac{\sigma_1}{p}\right)^n$$

Figure 59. Equation. Modulus of elasticity for cohesive materials.

$$E = C\left(\frac{\theta}{p}\right)^n$$

Figure 60. Equation. Modulus of elasticity for noncohesive materials.

where:

E = modulus of elasticity.
C = constant.
σ_1 = major principal stress.

θ = mean normal stress or first stress invariant.
p = atmospheric pressure.
n = exponent of the relationship (*n* is negative for cohesive materials and positive for noncohesive materials).

Figure 61 shows the average and standard deviation of backcalculated moduli for the AC and CTB layer over time (with outliers excluded). Values calculated from FWD measurements taken in winter months are marked with an "×". Figure 62 shows the average and standard deviation backcalculated moduli for the unbound granular layer (base course), the lime-stabilized subgrade (where present), and the subgrade. For the layers assumed to have a stress-dependent behavior (unbound granular pavement layer and the subgrade), the backcalculated values indicate the moduli at the top of the layer. Appendix B.1 includes plots showing the variation of individual backcalculated moduli along the pavement section for each year of measurement.

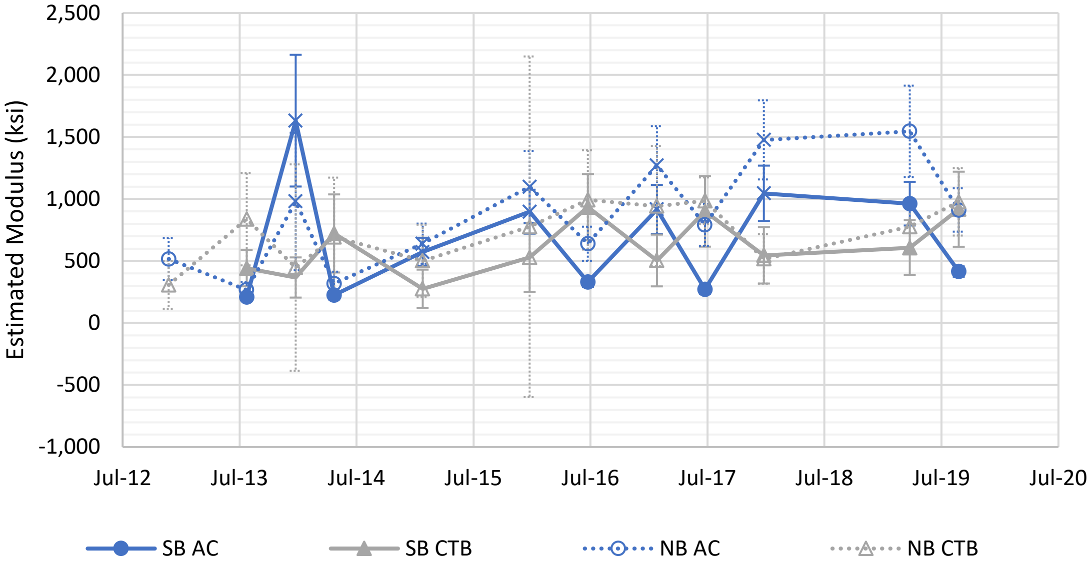
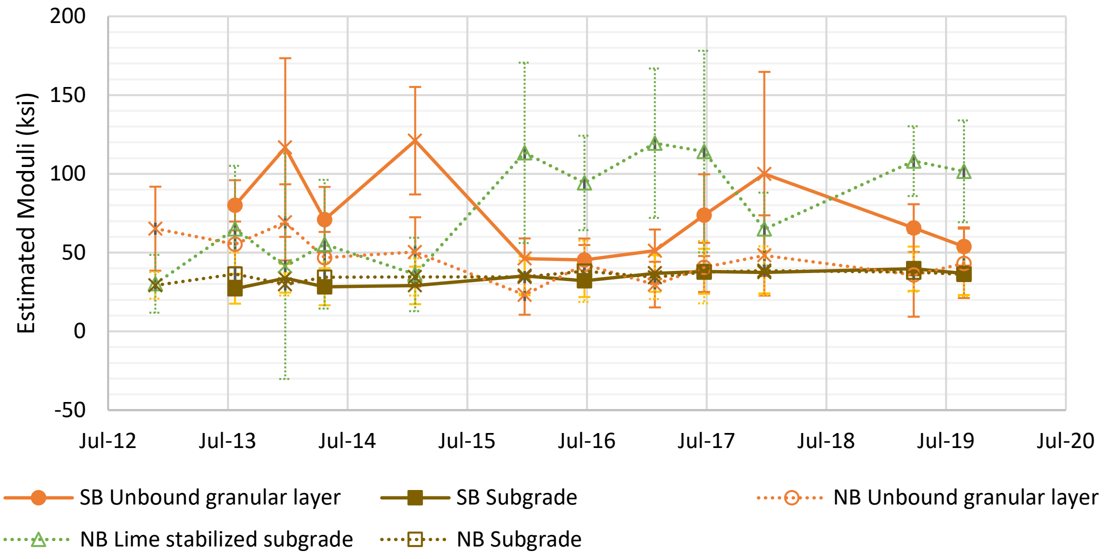
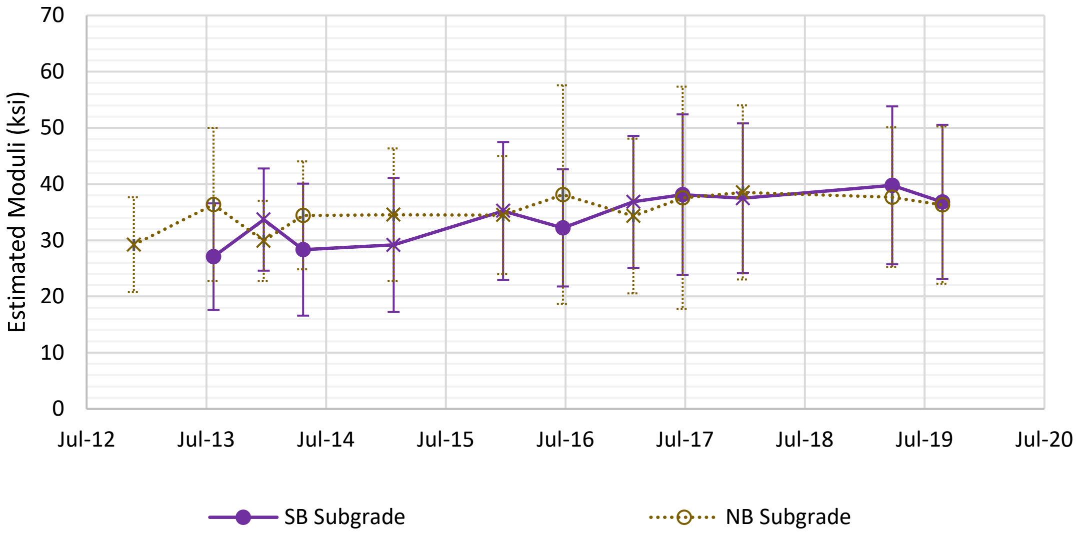


Figure 61. Graph. Average and standard deviation of backcalculated asphalt concrete and cement-treated base moduli; I 25, Colfax County, New Mexico.



A. Unbound granular layer, lime-stabilized subgrade, and subgrade.



B. Subgrade.

Figure 62. Graph. Average and standard deviation of backcalculated moduli at the top of the unbound granular layer and subgrade layers; I-25, Colfax County, New Mexico.

In general, AC mix backcalculated moduli were higher in winter months and CTB backcalculated moduli were lower. AC and CTB moduli were generally higher in the NB IP, despite CTB compaction levels being lower in the NB compared to the compaction in the SB CTB layer. The difference between the AC modulus in the inverted and conventional pavements appears to be higher during winter and to increase with time. This may be related to the thicker AC layer in the CP, which may have kept warmer temperatures toward the bottom of the AC layer and may also have suffered less oxidation toward the bottom of the AC layer compared to the thinner AC layer in the IP.

The backcalculated moduli for the unbound granular layers were generally higher during winter months. The NB unbound granular layer backcalculated moduli were less variable and lower than the values calculated for the SB unbound granular layer. This is contrary to what was expected, because the NB IP unbound granular layer incorporated higher-quality crushed rock, was compacted using the South African slushing technique, was placed closer to the surface (i.e., closer to the load), and comprised non-cohesive materials, for which the moduli is expected to increase with stress. The following could be part of the reason the unbound granular layer in the NB IP resulted in lower backcalculated moduli:

- *The limitations of the backcalculation procedure:* Backcalculation analysis is known to not accurately represent moduli of thin layers, such as the AC layer in the IP.
  The geophones in the FWD were not spaced closely enough to accurately allow capture the behavior of thin layers. The backcalculated moduli of the thin AC layer may have resulted in greater values than the actual moduli, potentially resulting in lower than actual backcalculated moduli for the unbound granular layer.

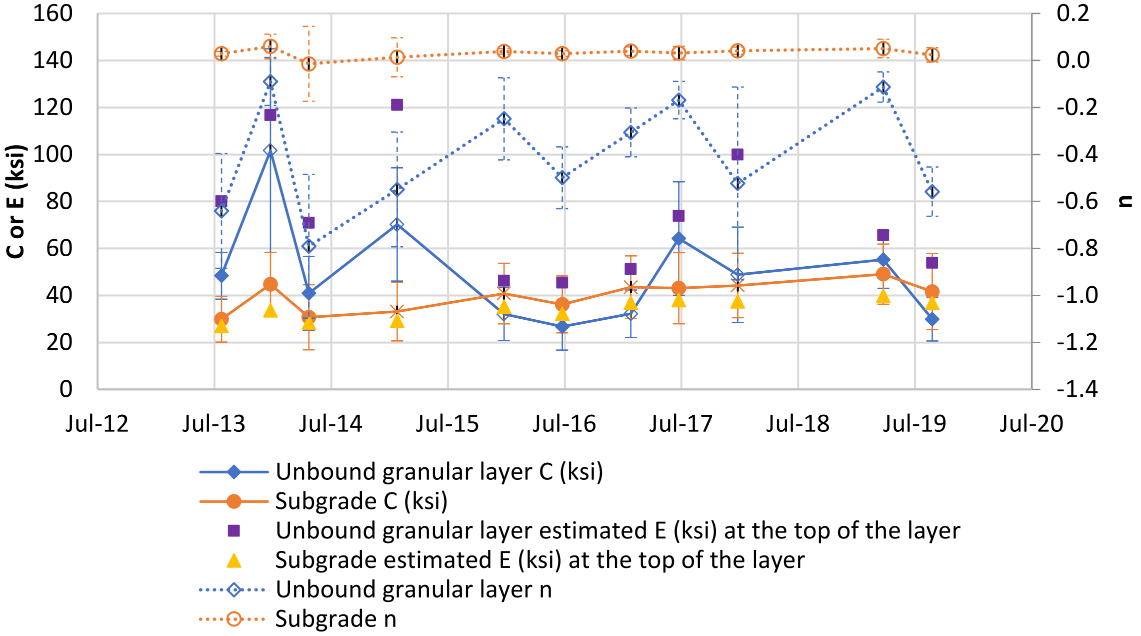
- *The lower compaction levels achieved in the NB CTB layer compared to the SB CTB layer:* The CTB layer is known to assist in the compaction of the overlaying unbound granular base. Although no information was found regarding compaction levels in the SB unbound granular layer, it is possible that lower compaction values in the NB CTB resulted in less support when compacting the NB unbound granular base course layer, leading to lower moduli values.

- *Potential higher moisture content in the NB unbound granular base:* Drying of the granular layer was not required in the project prior to application of the prime coat and construction of the AC layer. Although no information was found regarding moisture content in the SB unbound granular base, it is possible that the additional water used in the slushing technique applied to the NB unbound granular base led to higher moisture trapped underneath the AC layer in the NB pavement. As described in Chapter 2, the crushed rock modulus can be highly dependent on moisture content, with higher moisture leading to lower modulus values.

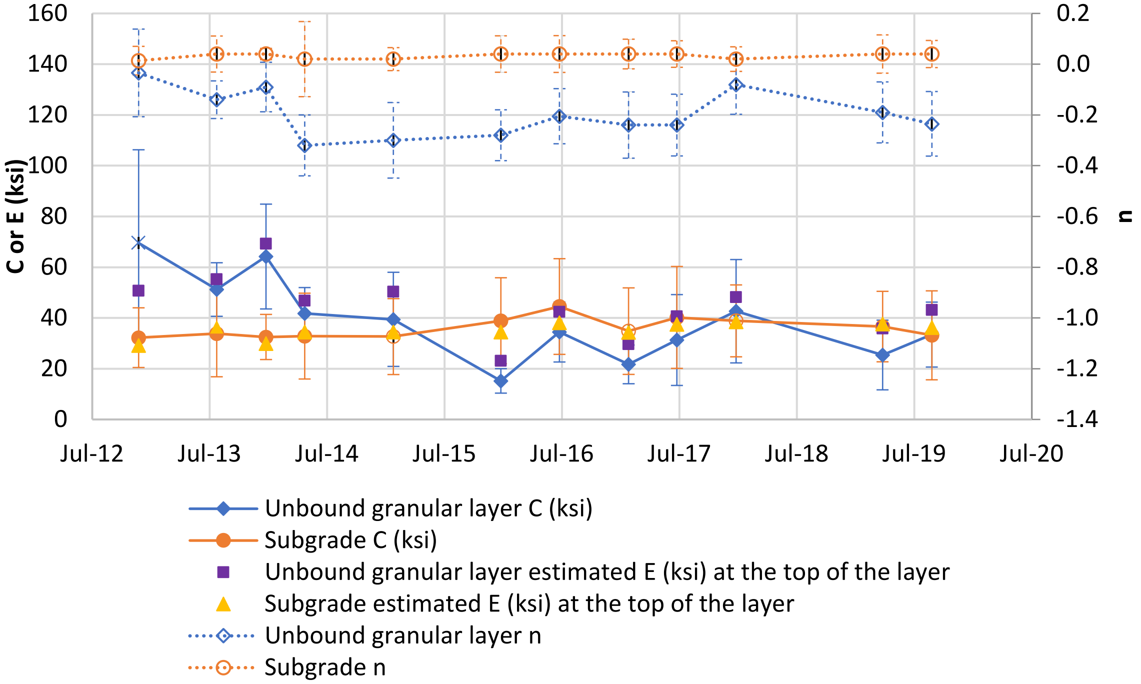
The NB lime-stabilized subgrade and CTB backcalculated moduli were quite variable, potentially the result of the presence of cracks in those layers, especially shrinkage cracks in the CTB layer. The backcalculated subgrade moduli for both directions were similar. The moduli of the AC, CTB, and lime-treated subgrade in the NB pavement appeared to slightly increase with time, whereas the moduli of the unbound granular layer in both directions appeared to slightly decrease over time.

Figure 63 shows the variation of average and standard deviation backcalculated C and n coefficients for the layers where stress dependency was modeled: the unbound granular (base course) and the lower subgrade layers. Contrary to what was expected, the backcalculation resulted in negative n-values for the unbound granular layers (base course), indicating a behavior typical of cohesive materials, whereas for the subgrade, the n-values were positive, indicating a behavior of non-cohesive soils. The cohesive behavior of the granular base course indicates excess fines in the matrix. It was previously noted that NMDOT specification requirements for the IP unbound granular base course material allowed for generally finer material than the standard NMDOT granular target gradation. Additionally, increased compaction efforts in the IP section could also have contributed to the breaking of the particles, resulting in a finer gradation. Nevertheless, it is noted that the n-values are relatively small, resulting in limited variations in the moduli of the granular layers with depth.

Figure 64 shows the variation of vertical resilient moduli (M_{Rv}) with stresses for the SB and NB unbound granular layers based on average C- and n-values. The backcalculated moduli tended to decrease over time.

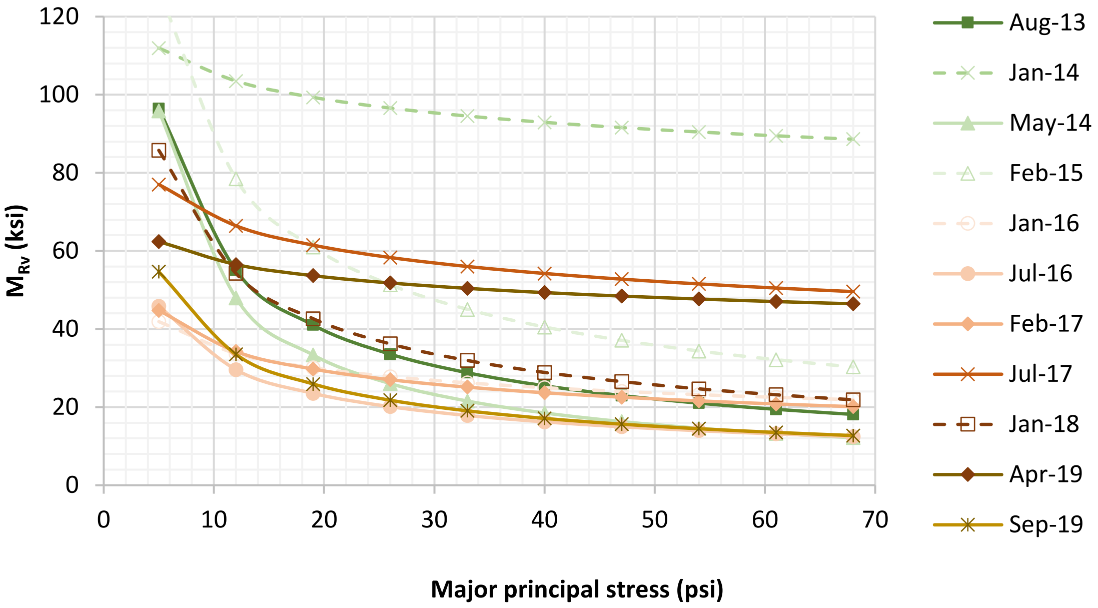


A. Southbound; conventional pavement excluding pavement at bridge overpasses.

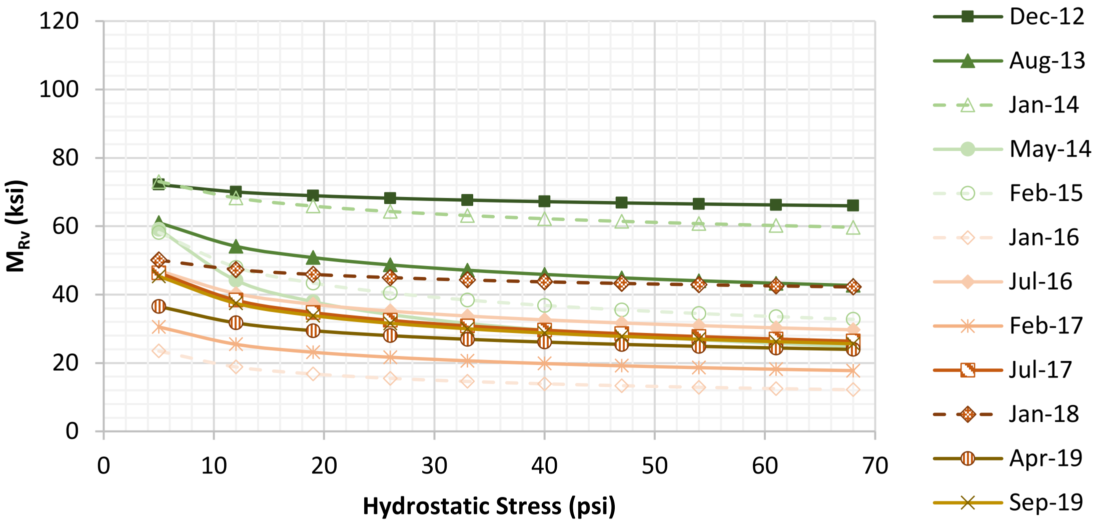


B. Northbound; inverted pavement.

Figure 63. Graph. Backcalculated C and n for the unbound granular layer and subgrade; I-25, Colfax County, New Mexico.



A. Southbound; conventional pavement excluding pavement at bridge overpasses.



B. Northbound; inverted pavement.

Figure 64. Graph. Backcalculated moduli for unbound granular layers; I-25, Colfax County, New Mexico.

Site Visits

First Visit

The first visit took place on April 13, 2022. The main goal of the visit was to meet with NMDOT engineers and consulting team members and develop a field investigation plan based on the onsite conditions. A coring and testing plan were presented to the NMDOT after the visit.

The section is 3 hour drive north of Albuquerque and 2.5-hour drive south of Colorado Springs. When traveling to farther north on I-25, higher elevation terrain was observed to pose challenges to the pavement performance. There were significantly deteriorated sections to the north of the test section. Pavement deterioration appeared to be caused by a combination of heavy truck traffic connecting major population centers in New Mexico and Colorado and weathering. It was noted that the highway, including the test section, was sometimes closed during winter because of heavy snow precipitation.

Upon arrival at the job site, it was apparent that both the NB and SB DL were blade patched. Therefore, the surface condition of the original IP section and control section on the DL could not be observed. However, observations were made based on the condition of the passing lanes, which reflected distresses on the blade patch used on the right DL.

The condition of the patched section appeared to be severely deteriorated on the NB IP section. Reflecting fatigue cracks were visible, as shown in figure 65. Pumping of fines was also common in the severely deteriorated RWP and close to the edge of the patched lanes.


4/13/2022

4/13/2022

Figure 65. Photo. Northbound inverted pavement section patched lane showing reflecting wheel path fatigue cracks; I-25, Colfax County, New Mexico.

The overall condition of the unpatched passing lane was consistent for both NB and SB. A longitudinal construction joint crack was running the entire test section in both sections (figure 66). In addition to longitudinal construction joint cracks, there was secondary longitudinal cracking appearing in the majority of the sections in the NB and SB lanes close to the shoulder of the passing lane. High-severity and -frequency transverse thermal cracks were observed in the NB and SB lanes (figure 67). In some areas, transverse and longitudinal cracks started to connect to form block cracking (figure 68).

4/13/2022

4/13/2022

Figure 66. Photo. Longitudinal construction joint cracking in the northbound (left) and southbound (right) lanes; I-25, Colfax County, New Mexico.

4/13/2022

4/13/2022

Figure 67. Photo. Transverse thermal cracks in the passing lane of the northbound section; I-25, Colfax County, New Mexico.

4/13/2022

Figure 68. Photo. Transverse and longitudinal cracks connecting to form block cracking pattern; I-25, Colfax County, New Mexico.

Second Visit

The second visit took place on July 11, 2022. The main goal of the site visit was to observe the field coring. Upon arrival, it was noted that most of the study section, both in the NB and SB lanes, had been recently overlaid (figure 69). Only about 0.25 mi (0.4 km) at the north of the study sections had not yet received the overlay (figure 70), which was planned to be finalized in July 2022. Field exploration continued as planned.


7/11/2022

7/11/2022

Figure 69. Photo. Northbound lanes after the overlay; I-25, Colfax County, New Mexico.


7/11/2022

Figure 70. Photo. Part of the northbound section left with the blade patch; I-25, Colfax County, New Mexico.

Boring was conducted at the center of the NB and SB right DL. Figure 71 shows the steps during the boring operation along with a typical boring hole (figure 72). Boring depths varied from 36 to 48 inches (915 to 1220 mm) and involved collecting granular base course, cement-treated subbase, and subgrade layer samples.

Figure 71. Photo. Boring operation and sampling of the cement-treated and granular base layers; I-25, Colfax County, New Mexico.

Figure 72. Photo. Boring hole; I-25, Colfax County, New Mexico.

A. Northbound. B. Southbound.

Figure 73. Photo. Surface asphalt concrete layer cores; I-25, Colfax County, New Mexico.

Most of the AC layer cores were taken from outside of the wheel path. In general, these cores were intact and did not show any sign of cracking except for one core in the NB lane, shown in figure 74. At two locations, the coring team was instructed to take cores from the wheel path where fatigue cracking was observed and recorded. These cores could not be obtained intact, as shown in figure 75.

Figure 74. Photo. Bottom-up cracking observed in a field core obtained from northbound lane; I-25, Colfax County, New Mexico.

Figure 75. Photo. Asphalt concrete layer cores taken from wheel path; I-25, Colfax County, New Mexico.

Examples of the subgrade samples are shown in figure 76. The encountered subgrade was consistent with previous investigations, comprising a silty, clayey soil with moderate to high plasticity (A-4, A-6, and A-7). Lime stabilization was apparent in the subgrade layer samples collected from the NB lanes. There were some cementations on the top of the subgrade layer samples collected from the SB lanes. This could be due to cement penetration from the CTB used in the SB lanes.

Figure 76. Photo. Subgrade samples collected from both directions; I-25, Colfax County, New Mexico.

Loose, unbound crushed granular layer materials are shown in figure 77. The CTB layer was observed in both directions. Chunks of CTB, 4 to 6 inches (100 to 150 mm) in diameter were retrieved at almost all coring locations, as shown in figure 78.


7/11/2022

Figure 77. Photo. Unbound granular layer extracted from the northbound lane; I-25, Colfax County, New Mexico.


7/11/2022

7/11/2022

7/11/2022

7/11/2022

Figure 78. Photo. Cement-treated base layer materials extracted from both directions; I-25, Colfax County, New Mexico.

Six pavement cores were taken in the NB IP. According to Mann and Giron's (2023) field investigation report, the AC layer thickness varied from about 4.5 to 9.0 inches (115 to 230 mm), the granular base course thickness from about 4 to 7.5 inches (100 to 190 mm), and the cement-treated layer from about 3 to 7 inches (75 to 180 mm). These thicknesses varied considerably from the designed thicknesses.

Cost Assessment

The bid price for the construction of the NB IP section was $2,302,808 and for the SB CP section was $1,945,170. According to Simons (2016), although the bid price for the SB section was 15 percent lower than for the NB, the actual cost for both pavement sections was the same: $2,134,324. Based on indicative unit costs provided by NMDOT for the construction of each pavement layer normalized, the IP could be approximately 4 percent cheaper per lane-mile than the CP (table 13).

An LCCA was conducted using FHWA's RealCost 2.5 LCCA tool. The analysis considered unit costs provided by NMDOT for the construction of each pavement layer normalized by lane-mile. The analysis compared the SB CP with the NB IP. The SB CP at bridge overpasses was not included because it represented smaller sections with reduced structural capacity and limited pavement performance data.

User costs and the cost of removal and disposal of the pavement at the end of its life were not included in the analysis. Initial construction costs and the costs of each maintenance or rehabilitation activity were considered and are summarized in table 13.

Table 13. Assumed construction, maintenance, and rehabilitation activities for LCA analysis; I 25, Colfax County, New Mexico.

Impact indicator	Cost ($1,000)/lane-mile
Initial construction: SB conventional pavement	368.68
Initial construction: NB inverted pavement	352.82
Blade patching	14.38
Mill and overlay with 3-in (75 mm) AC and 5/8-in (15 mm) OGFC	129.37

NMDOT performed blade patching on DL of both pavements in the same year (2021), although the performance of the IP in the NB direction had deteriorated considerably faster than the SB control section did.

The LCCA considered a hypothetical scenario where the maintenance and rehabilitation activities are triggered by the condition of the pavement rather than waiting to perform maintenance for both pavement sections at the same time. The assumed schedule of construction, maintenance, and rehabilitation activities for each section is summarized in table 14. The first blade patching in the NB IP was assumed to happen in year 5, considering that the PCR (see figure 34) indicated that the pavement was already at risk then. For the SB CP section, the first blade patching was assumed to happen in year 9, per the actual date blade patching was performed, which corresponds to the year when some of the pavement reached the at-risk condition (see figure 34). Blade patching was assumed to last for up to three years, when a mill-and-fill activity is then required (OGFC and 3 inches [75 mm] AC). Following a mill-and-fill activity, the NB pavement is assumed to last for another five years and the SB pavement another nine years before requiring another blade-patching activity. The same cycle is assumed to be repeated until year 20, when the entire AC in both sections is assumed to be removed and disposed.

Table 14. Assumed construction, maintenance, and rehabilitation activities for LCCA and LCA analysis; I 25, Colfax County, New Mexico.

Impact indicator	Pavement year	
	SB conventional pavement	NB inverted pavement
Initial construction	0	0
Blade patching	9	5
Mill and overlay (3-in [75 mm] AC and 5/8-in [15 mm] OGFC)	12	8
Blade patching	—	13
Mill and overlay (3-in [75 mm] AC and 5/8-in [15 mm] OGFC)	—	16
AC removal and disposal	20	20

Figure 79 shows the present value calculated for both options at varying discount rates. Despite the lower initial construction costs, the assumed additional maintenance and rehabilitation activities required in the NB IP to maintain its performance at a similar level to the SB CP results in higher present-cost values.

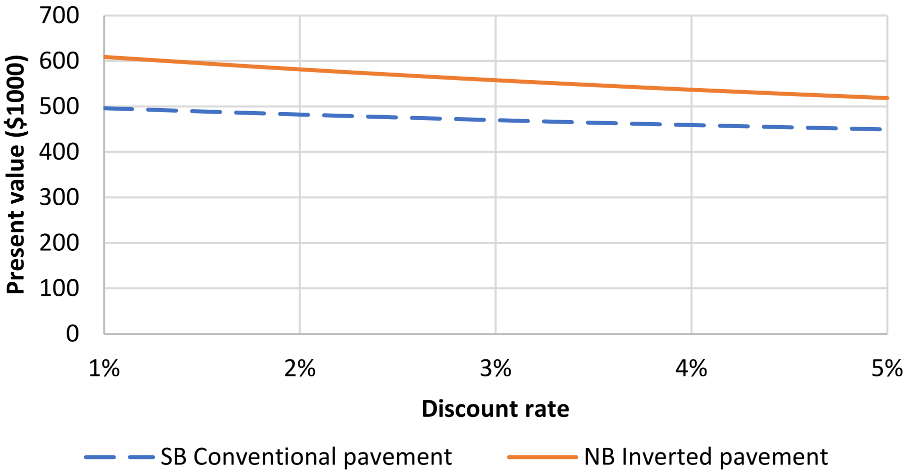


Figure 79. Graph. Present value for varying discount rates; I-25, Colfax County, New Mexico.

Mann and Giron (2023) compiled actual maintenance costs for the NB IP and SB CP sections since construction. Maintenance activities included pothole patching, asphalt blade patching, and AC overlay/inlay. The authors concluded that the cost to maintain the NB IP section was approximately $6,721 per lane-mile per year, whereas the cost to maintain the SB CP was approximately $2,789 per lane-mile per year. (It was noted, however, that some of the maintenance activities included in their analysis may have been extended outside of the project boundaries.)

Environmental Sustainability Assessment

A comparative LCA analysis of the NB IP and SB CP sections was conducted using FHWA's LCA Pave tool, which considered materials, transportation and construction only. The SB pavement at bridge overpasses was not included in the analysis because it corresponded to short sections for which pavement performance data were not detailed. The analysis considered the materials stage; transportation distances; initial construction, maintenance, and rehabilitation; and AC removal and disposal. Construction material transportation distances were assumed based on information found on documents provided by NMDOT, which indicated where some of the materials were sourced. Transportation of construction equipment to the construction site was omitted from the analysis. Earthworks prior to subgrade preparation and other road construction features (e.g., drainage, signage, and lighting) were also not included in the analysis. Water was assumed available at the site. For the IP, additional water consumption was considered for the slushing technique, assuming a rate of water application of about 0.4 lb/ft^2 (2 kg/m^2).
The materials included in the analysis were represented by the materials in the existing tool library. The provided AC mix design indicates Versabind was used as the anti-stripping agent. In the absence of environmental product information for Versabind, the analysis assumed hydrated lime was used instead. Detailed assumptions are included in appendix C.1.

The assumed schedule of construction, maintenance, and rehabilitation activities for each section was the same as the one assumed for the LCCA (see table 14).

The results of the LCA analysis, normalized by lane-mile (functional unit), are included in table 15. Figure 80 shows the impact indicators normalized by lane-mile and by the highest value among the pavement cross sections considered.

The initial construction of the SB CP represented higher environmental impacts than the NB IP. However, considering the entire assumed life-cycle of the pavement sections, the NB IP represented higher environmental impacts, given the higher number of activities assumed throughout the pavement life. In terms of global warming potential (GWP), the impact of the SB CP represented 86 percent that of the NB IP. In terms of total use of nonrenewable primary energy resources, the impact of the SB CP represented 91 percent that of the NB IP.

Table 15. Environmental impacts per lane-mile; I-25, Colfax County, New Mexico.

Impact indicator (i)	SB conventional pavement		NB inverted pavement	
	Initial construction	Life-cycle	Initial construction	Life-cycle
Use of renewable energy primary energy, excluding renewable primary resources used as raw materials (MJ) (ii)	58,752	78,219	49,410	88,344
Use of renewable primary energy resources used as raw materials (MJ) (ii)	33.65	33.65	99.81	106
Total use of renewable primary resources (MJ) (ii)	58,784	78,255	49,515	88,456
Use of nonrenewable primary energy, excluding nonrenewable primary energy resources used as materials (MJ)	4,429,301	7,084,762	3,082,540	8,099,926
Use of nonrenewable primary energy used as raw materials (MJ) (ii)	5,392,469	8,315,793	2,884,270	8,730,917
Total use of nonrenewable primary energy resources (MJ)	8,654,835	13,609,535	5,420,110	15,035,973
Recycled material usage (short-tons)	437	611	216	564
Disposed nonhazardous waste (short-tons) (ii)	282	1,855	153	3,297
Disposed hazardous waste (short-tons) (ii)	20.13	31.04	10.77	32.59
Net use of fresh water (m^3) (ii)	6,843	8,823	7,025	10,985
Acidification (kg SO_2 eq)	1,037	1,733	907	2,230
Ecotoxicity (CTUeco/kg) (ii)	25,196	135,655	12,697	233,590
Eutrophication (kg N eq)	219	275	232	341
Fossil fuel depletion (MJ surplus) (ii)	1,905,201	2,928,581	940,117	2,986,877
GWP (kg CO_2 eq)	337,023	500,598	277,547	583,288
Human health, cancer (CTU/kg) (ii)	0.0002	0.0006	0.0001	0.0008
Human health, noncancer (CTU/kg) (ii)	0.0135	0.0567	0.0067	0.093
Human health effects, particulates (kg $PM_{2.5}$ eq) (ii)	41.48	80.22	28.86	96.95
Ozone depletion (kg CFC-11 eq)	0.0039	0.0045	0.0044	0.0057
Smog formation (kg O_3 eq)	25,911	1,877,095	22,062	3,721,987

Notes:

(i) Asphalt mixing (A3 stage) environmental impacts were assumed as the average impacts of two available EPDs from mixes produced in New Mexico (NAPA EPDS 70.903.3231 v1 and 70.903.3230 v1 - https://asphaltepd.org/published/, last accessed May 5, 2024.). The end-of-life stage assumed the AC is recycled offsite and transported 20 mi (32 km) away. Other construction materials were not included in the end-of-life stage.

(ii) The results presented are LCA Pave outputs, which are calculated based on the available information. Calculations of some impact categories can be incomplete due to missing data.

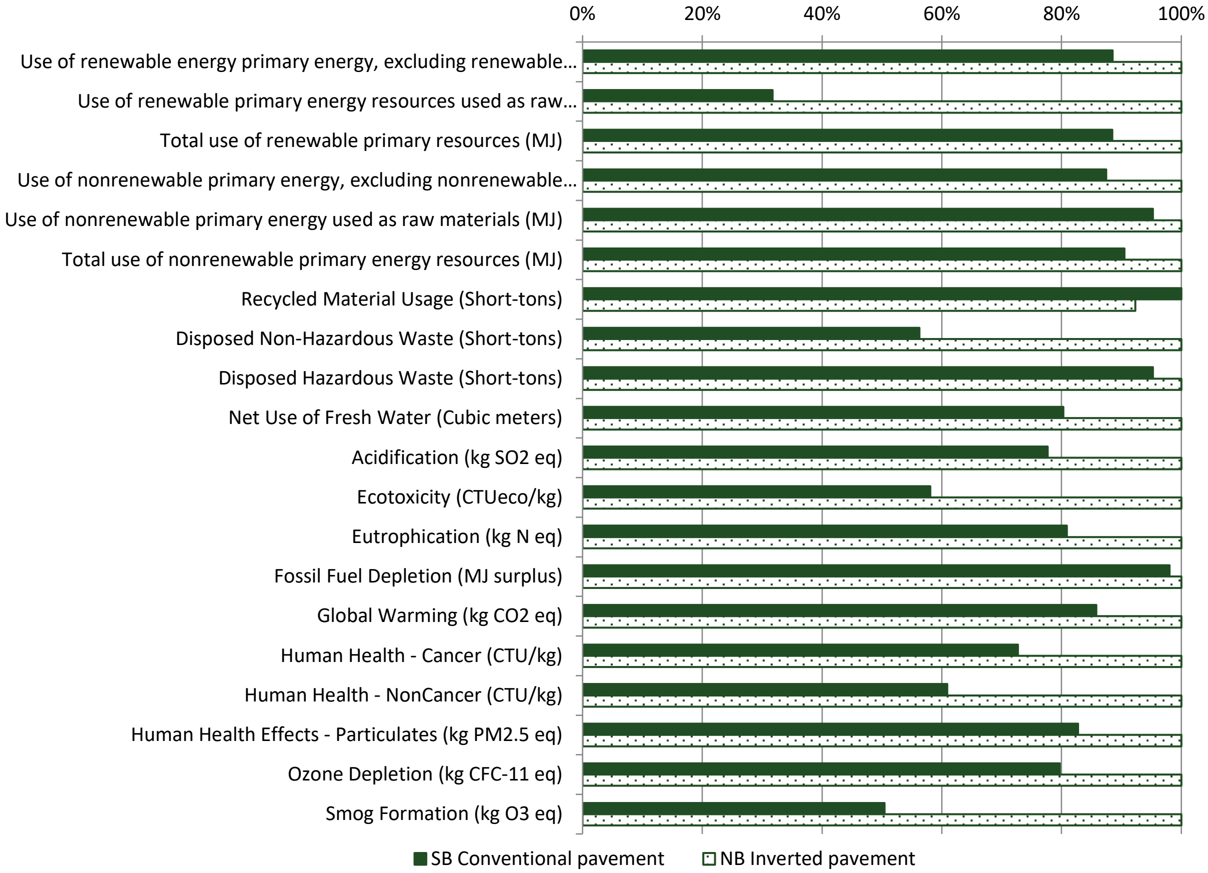
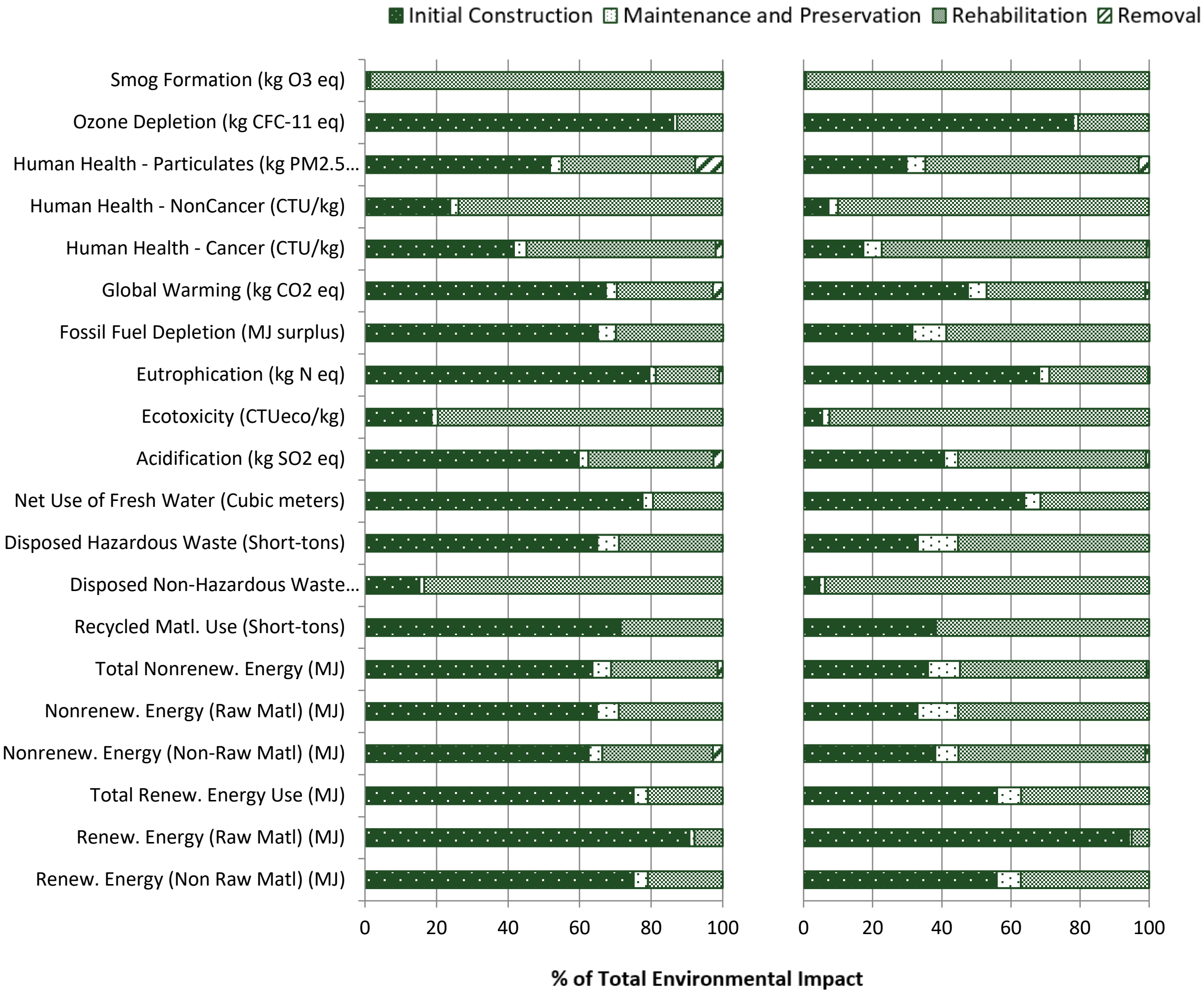


Figure 80. Graph. Comparison of normalized impact indicator values for each pavement section for entire assumed life-cycle; I-25, Colfax County, New Mexico.

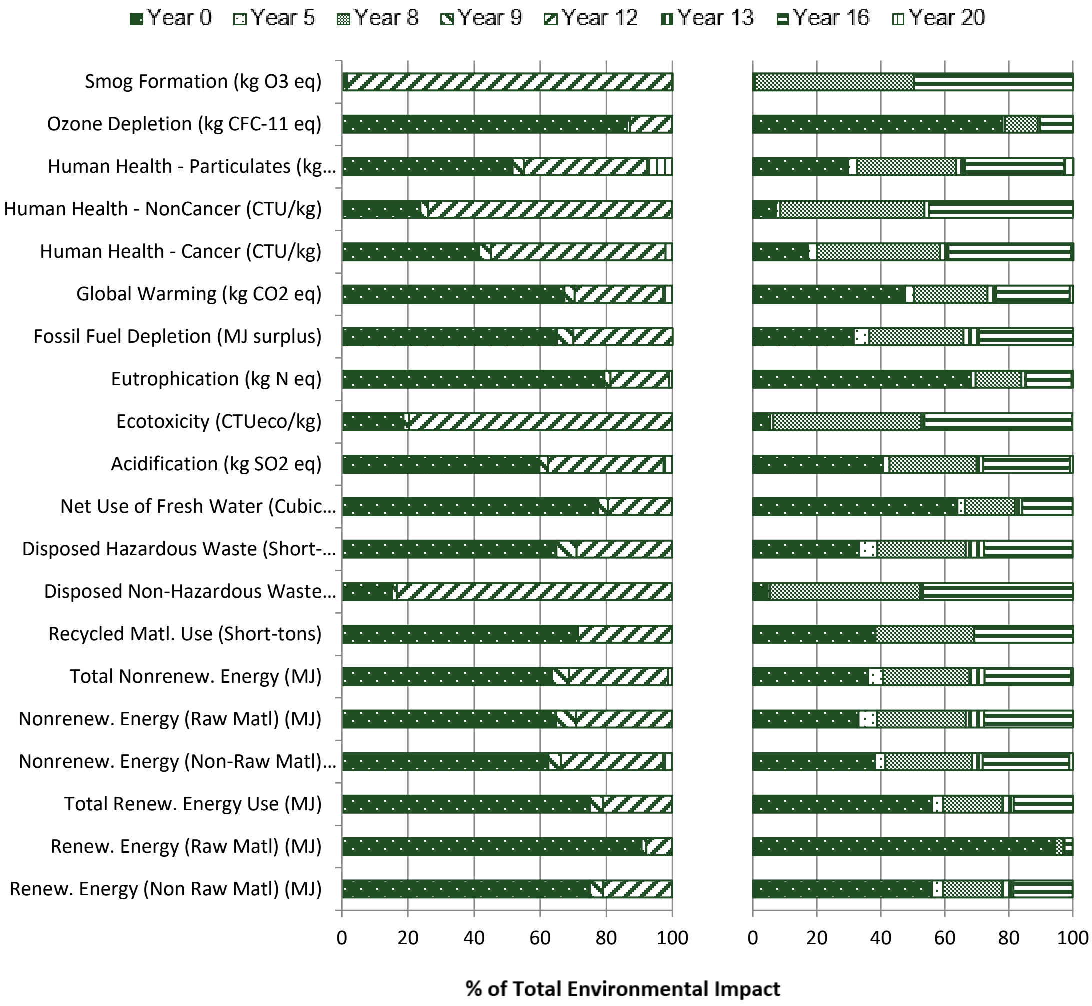
Figure 81 and figure 82 show, respectively, the percentage of total environmental impact per life-cycle stage and by pavement age for both sections. For the SB CP, initial construction represented a higher percentage for most impact indicators, followed by rehabilitation (mill and inlay). For the NB IP, the contribution of rehabilitation (mill and inlay) activities to the total impacts was higher compared to the SB IP. The contribution of removal and disposal was higher for the SB CP because of the thicker AC.

Figure 83 shows the percentage of total environmental impact by process type for both pavement sections. For most impact categories, materials were responsible for most of the impacts, followed by waste or transport of materials.



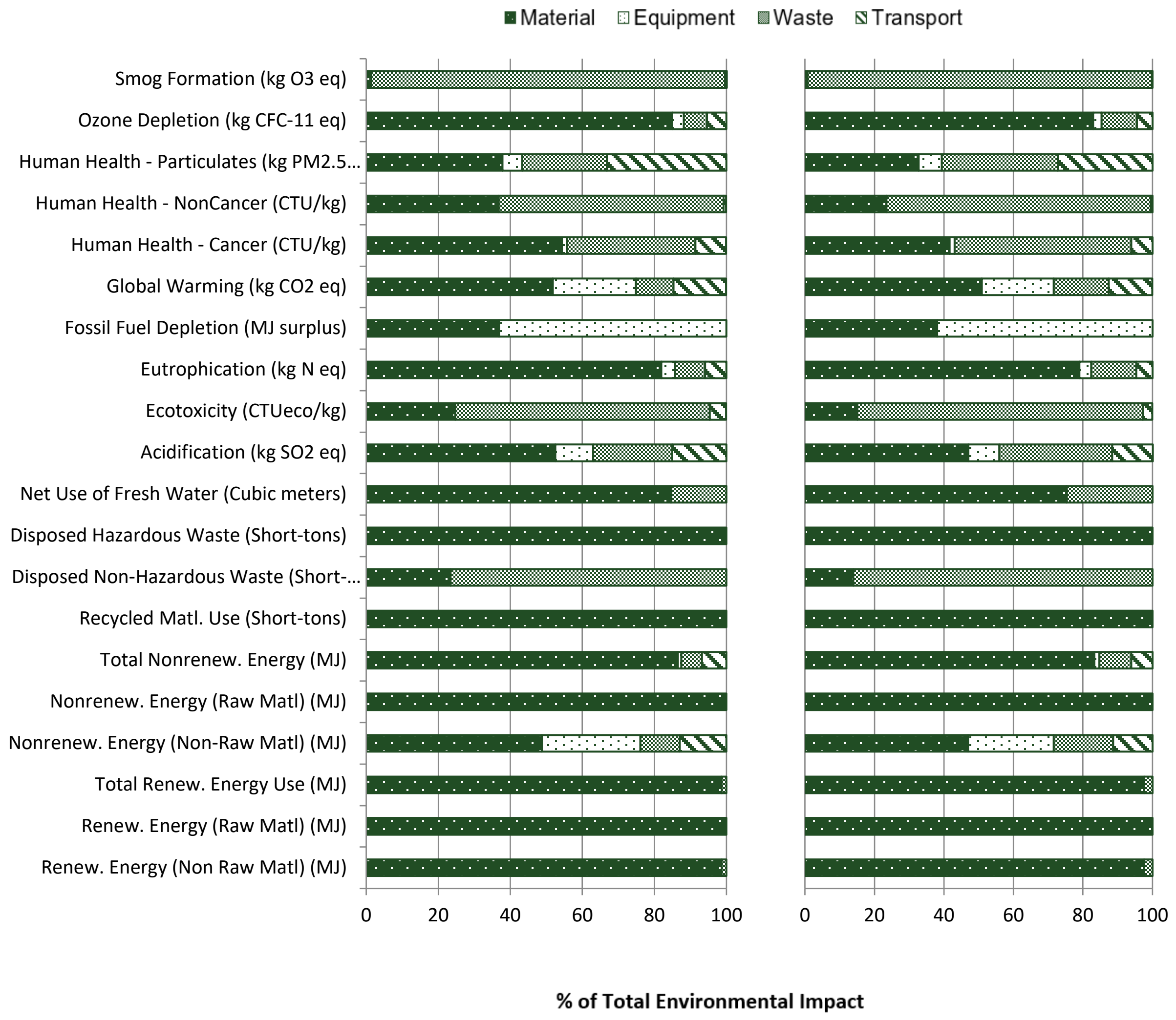
A. Southbound; conventional pavement. B. Northbound; inverted pavement.

Figure 81. Graph. Comparison of impact indicators per life-cycle stage for each pavement section; I 25, Colfax County, New Mexico.



A. Southbound; conventional pavement. B. Northbound; inverted pavement.

Figure 82. Graph. Comparison of impact indicators by age for each pavement section; I 25, Colfax County, New Mexico.



A. Southbound; conventional pavement. B. Northbound; inverted pavement.

Figure 83. Graph. Comparison of impact indicators by process type for each pavement section; I-25, Colfax County, New Mexico.

Summary and Remarks

The AC of the NB IP was 3.6 inches thick (90 mm), which is considerably more than typical IP in South Africa, where AC thickness is no more than 2.0 inches (50 mm). The higher AC thickness is believed to result in more distresses induced in the AC layer, which accelerated the deterioration.

The unbound granular base course in the I-25 IP was also thicker than the typical South African granular base course for the same design traffic. The thicker granular base course could lead to more variability in compaction levels and fines content through depth.

The performance of the NB IP was significantly inferior to that of the SB CP. In 2020, eight years from construction, the PCR indicated most of the CP was in fair condition, whereas the IP was in poor to very poor condition. The very poor condition was mostly at the start of the section (lower MPs), with the PCR generally increasing for higher MPs. Interestingly, recorded moisture content measurements from construction indicated higher moisture content in the unbound granular base course toward lower MPs, with lower moisture content recorded for higher MPs. In other words, where higher initial moisture content in the unbound granular layer were encountered, the PCR indicated worse pavement conditions eight years later.

Fugro images from 2020, taken prior to blading of the right lanes in both directions, confirm that the NB IP was in significantly poorer condition than the SB CP section. The NB IP presented medium to severe cracking along the RWP and some cracking developing along the LWP. The SB control section presented only limited cracking, comprised mainly of a longitudinal crack at the right edge of the lane.

Both lanes in the SB section presented longitudinal cracking within the RWP of the passing lane, with additional longitudinal cracks and transverse cracks interconnecting the longitudinal cracks appearing at a few locations.

Analysis of the FWD data was conducted using Horak's (2008) benchmarking procedure, which is used in South Africa to assess IP. Although the analysis suggested that most of the IP and CP were in sound condition, it was noted that the benchmark limits in South Africa were determined for IP with relatively thinner AC layers, or chip-seal surfacing only. If limits for a thicker AC South African pavement were adopted for the NB pavement, the RoC would fall into warning condition, which may explain why the AC in the IP presented considerably more cracking than the AC in the CP did.

FWD backcalculation analysis indicated the following:

- The AC moduli of the IP was slightly higher than the AC moduli of the CP. This could be related to the pavement aging, as the IP AC would experience more oxidation relative to its thickness when compared to the thicker AC in the CP.

- The backcalculated moduli of the AC, CTB, and lime-stabilized layers were variable, which may have been due to the presence of cracks in those layers in some of the testing locations.

- Contrary to what was expected, the unbound granular base course layer backcalculated modulus were higher in the CP than in the IP. This may be related to (1) limitations of the backcalculated procedure, (2) lower compaction levels achieved in the NB CTB layer compared to the SB CTB layer, which provides support for the compaction of the overlying unbound granular base, and (3) a potentially higher moisture content in the NB granular layer from the use of additional water for the slushing technique and the absence of any requirement to let this layer dry prior to applying the prime coat and construction of the AC layer, as well as the subsequent potential of water infiltrating through cracks.

- The moduli of the AC, CTB, and lime-treated subgrade in the NB pavement appeared to slightly increase with time, whereas the moduli of the unbound granular layer in both directions appeared to slightly decrease over time.

- Contrary to what was expected, the backcalculated unbound granular base course layer n-values were negative, indicating a behavior typical of cohesive materials, and thus a potential excess fines content in that layer.

Although the initial construction of an IP could be cheaper, the assumed hypothetical schedule of maintenance and rehabilitation activities to keep the pavement at a similar performance level as a CP resulted in a higher life-cycle cost. Similarly, the CP represented fewer environmental impacts (in terms of GWP and total energy consumption).

It is important to note that the assumptions made for the LCCA and LCA analysis were based on assumed maintenance and rehabilitation activities to keep pavement performance above a certain condition level based on the observed I-25 performance during the first eight years of life. Potential reasons for the rapid deterioration of the NB IP section include the following:

- The contract specifications did not include any requirement for the granular base course in the IP to dry to a specific level of the OMC before prime coat application and AC layer construction. This would be exasperated given that Raton experiences freeze-thaw conditions and relatively high moisture conditions. Drying to at least 60 percent of OMC would be desired.

- The IP used a relatively thicker AC layer compared to typical South African AC thicknesses, as well as a relatively high NMAS in the AC mix. The first would increase the distress in the AC.

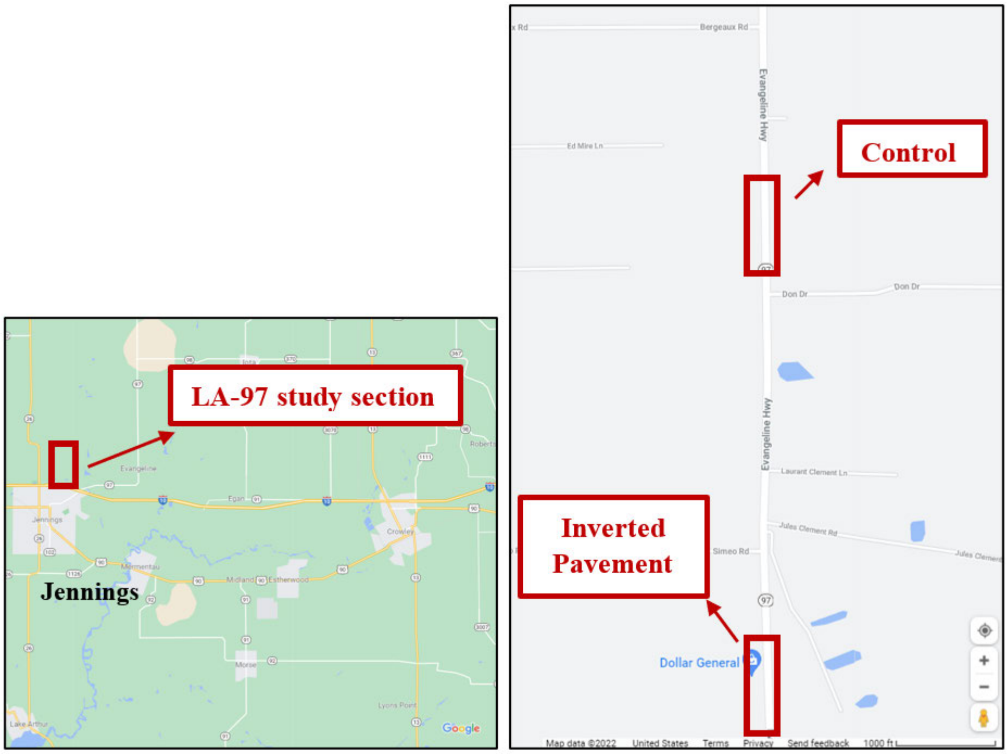
- Although some cracks had been sealed, there were extensive cracks left unsealed, potentially allowing water infiltration into the pavement, which would accelerate damage.

- The higher level of CTB compaction at the SB, compared to that at the NB, would potentially facilitate better compaction of the unbound granular base in the SB pavement.

LOUISIANA HIGHWAY 97

Location

The IP on LA-97 consists of a 4.7 mile (7.6 kilometer) section near Jennings, from a junction with LA-100 in Evangeline to a junction with LA-1123 (Station 10+00, log mile 3.920; to Station 258+16, log mile 8.620), in Acadia Parish. The road has two travel lanes and a width of 24 feet (7.3 meter). The project included an IP section from Station 30+96 to Station 41+52 and a control section comprising a CP with a soil-cement base from Station 73+36 to Station 83+92. Each section was 1,056 feet (322 meter) long (Rasoulian, Becnel, and Keel 2000). The approximate location of the project is shown in figure 84.



Original Photos: © 2015 Google® (see Acknowledgements section).

A. Study section. B. Control and IP sections.

Figure 84. Illustration. LA-97 case study location.

Pavement Configuration

The inverted and conventional pavement cross sections are summarized in table 16.

Table 16. Pavement cross section; LA-97 inverted pavement and control section.

Pavement layer	Thickness (in)	
	Inverted pavement section	Control section
AC	3.5 (90 mm)	3.5 (90 mm)
Crushed limestone interlayer	4.0 (100 mm)	—
Cement-stabilized base (10% cement content by mass)	6.0 (150 mm)	8.5 (215 mm)
Lime-treated subgrade	12 (300 mm)	12 (300 mm)
Subgrade (untreated)	(A4 material, modulus 8,800 psi [60 MPa])	

Accelerated Pavement Testing

In addition to LA-97, LaDOTD performed testing at the Louisiana Pavement Research Facility using an accelerated loading facility (ALF) device on a similar pavement configuration to that used at LA-97. ALF testing included Lane 008 with a soil-cement base course and Lane 009, with an IP solution similar to LA-97. The pavement configuration for those two lanes is summarized in Table 17. Louisiana's ALF consists of a dual-wheel trolley traveling in one direction, applying load at a constant speed of 10.4 mile per hour. The load consists of a standard dual tire between 9,750 and 18,950 lb (4,422 and 8,595 kg) (Titi et al. 2003).

Table 17. Pavement cross section; ALF (based on Rasoulian, Becnel, and Keel 2000).

Pavement layer	**Thickness (in)**	
	Inverted pavement section (LA 009)	**Soil-cement section (LA 008)**
AC surface	3.5 (90 mm)	3.5 (90 mm)
Stone interlayer	4.0 (100 mm)	—
Cement-stabilized base (soil-cement; 10% cement content by mass)	6.0 (150 mm)	8.5 (215 mm)
Select soil	2 (50 mm)	3.5 (90 mm)
Subgrade	Soft heavy clay (CH) with 84% clay and 14% silt overlain by embankment material consisting of silty clay (CL-ML) with 23% clay and 70% silt	Soft heavy clay (CH) with 84% clay and 14% silt overlain by embankment material consisting of silty clay (CL-ML) with 23% clay and 70% silt

Construction and Maintenance

LA-97 was the first case of IP in Louisiana, and it opened to traffic in 1991.

The common aggregate gradation requirements for the granular interlayer (unbound granular layer) materials in Louisiana compared to the South African G1 gradation requirements are presented in table 18 and figure 85.

Table 18. Gradation requirements for stone interlayer material in Louisiana (Chen, Zhang, and Lambert 2014).

Sieve size		Percent passing			
in	mm	Louisiana interlayer material		South African G1 NMAS 26.5 mm	
1.04	26.5			100	
1.00	25.0	90	100		
0.75	19	70	100	85	95
0.55	14				
0.52	13.2			71	84
0.187 (No. 4)	4.75	35	65	42	60
0.0787	2			27	45
0.0167	0.425	12	32	13	27
0.0029 (No. 200)	0.074	5	12	5	12

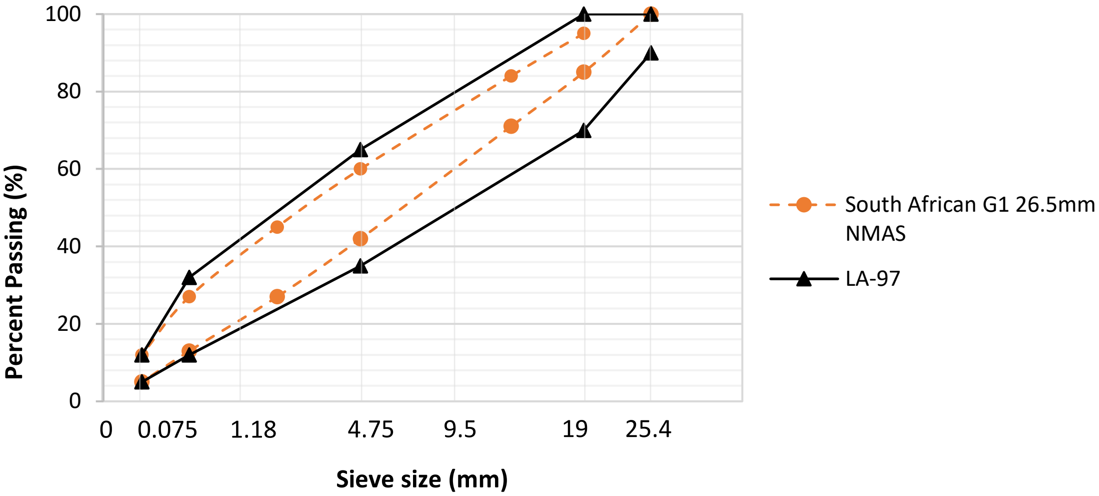


Figure 85. Graph. Louisiana typical aggregate gradation requirement for granular interlayer material (based on COTO 2020a; and Chen, Zhang, and Lambert 2014).

LaDOTD advised that there were some patch areas on the control section for which data were not available. Aerial images from Google Earth indicate that there is a patch of new AC about 3.7 ft (1.4 m) wide at the right side of the SB lane extending through all or most of the control section, which appears to have been constructed sometime between 2010 and 2012.

The ALF test sections were constructed in 1995 (Rasoulian, Becnel, and Keel 2000).

FWD Backcalculated Moduli

Chen, Zhang, and Lambert (2014) performed backcalculation of layer moduli for the IP section from FWD testing data collected in the 17th year of the pavement life. The backcalculated moduli obtained by the authors are summarized in table 19. A coefficient of variation (COV) of 71.7 to 90.0 percent was obtained for the CSB layers. This significant variation is believed to be due to the presence of discontinuities in the form of cracks in that layer. In addition, the backcalculated moduli were higher than typical values for this material, especially for the IP section. This may be partially due to the fact that stress dependency and anisotropic behavior of granular materials was not considered.

Table 19. FWD backcalculated moduli (Chen, Zhang, and Lambert 2014).

Pavement section	Pavement layer	FWD backcalculated moduli	
		Average	COV (%)
Inverted pavement	AC	738 ksi (5,090 MPa)	27.6
	Crushed limestone interlayer	44 ksi (305 MPa)	33.4
	Cement-stabilized base	6,464 ksi (44,570 MPa)	90.0
	Lime-treated subgrade	29 ksi (195 MPa)	35.9
	Subgrade (untreated)		
Control section	AC	619 ksi (4,270 MPa)	30.7
	Cement-stabilized base	3,796 ksi (26,170 MPa)	71.7
	Lime-treated subgrade	26.7 ksi (185 MPa)	54.1
	Subgrade (untreated)		

Traffic Loading

LA-97 is a rural major collector road with low traffic, except some heavy agricultural haul vehicles. The average daily traffic was reported as 2,000 vehicles per day in 1990 and the design traffic was 5.75 by 10^5 ESALs (Chen, Zhang, and Lambert 2014; Rasoulian, Becnel, and Keel 2000; Titi et al. 2003).

Environmental Conditions

Table 20 includes average temperatures, rainfall, and snowfall for Jennings, Louisiana. Rainfall is relatively well distributed throughout the year. Jennings is in an area considered wet non-freeze, in accordance with the FHWA and LTPP classification (see figure 32).

Table 20. Jennings, Louisiana, average temperatures, rainfall, and snowfall (source: NOAA).

Month	Temperature		Rainfall			Snowfall		
	Highs (°F)	Lows (°F)	Days	in	mm	Days	in	mm
Jan	59	41	8	5.8	147	0	0.1	3
Feb	64	44	7	4.1	104	0	0	0
Mar	71	51	6	4.2	107	0	0	0
Apr	78	57	5	4.2	107	0	0	0
May	84	65	6	5.5	140	0	0	0
Jun	89	71	8	5.8	147	0	0	0
Jul	91	73	10	5.6	142	0	0	0
Aug	91	73	9	5.8	147	0	0	0
Sep	88	69	7	5.9	150	0	0	0
Oct	80	58	5	4.6	117	0	0	0
Nov	70	49	6	4.9	124	0	0	0
Dec	63	43	7	5.1	130	0	0	0
Total				60.4	1534	0	0.1	3

Performance

Early Years (1991–1998)

Early in the life of the project, LaDOTD selected 100-ft (30 m) sample sections in each pavement-type section for crack mapping. Initial pavement distress surveys were taken in December 1991, October 1992, February 1995, September 1996, and July 1998. Testing included structural capacity measured by the dynamic deflection determination system (Dynaflect), ride roughness measurements for determination of the present serviceability index (PSI) and international roughness index (IRI) and rutting as measured by a laser profiler.

Cracking measured in July 1998 (seventh year of the pavement being in service), indicated that the control section had considerably more cracking than the IP test section. The control section presented a total crack length of 638 ft (194 m), with a crack density of 0.089 ft/ft^2 (0.292 m/m^2), whereas the IP test section presented only 103 ft (31 m) crack length and 0.014 ft/ft^2 (0.046 m/m^2) crack density. The crack density in the control section was more than six times than in the IP section. The cracking was identified as reflective cracking, with little evidence shown, at the time, of fatigue cracking (Rasoulian, Becnel, and Keel 2000).

In terms of overall pavement performance, the control and IP sections were similar. In May 1998, the IRI was 64 in/mi (1,010 mm/km) for the control section and 65 in/mi (1,026 mm/km) for the IP section, both numbers converting to a PSI of 4.2. It was also reported that the ride roughness remained relatively constant through the first seven years of pavement life (Rasoulian, Becnel, and Keel 2000).

Recent Years (1995–2019)

From 1995 to 2019, LADODT recorded the following performance indicators on the LA 97 inverted and control sections: IRI, rut depth, transverse cracking, longitudinal cracking, total cracking, and composite index (CI). It was noted that there had been some modifications within the data collection process. For the collection of rutting data, for example, the equipment used in 1995 and 1998, 2000 and 2003, and after that differed. Other modifications to data collection procedures and calculation procedures took place in 2002, 2006, and 2017. Therefore, caution should be exercised when comparing data from year to year because small variations could be a result of changes in data collection and calculation procedures.

Figure 86 shows the average and standard deviation IRI for both sections over the years. The data show that, in 1995, the IRIs for both the inverted and control sections were similar. From 1998 to 2002, the IRI for the control section was slightly higher than for the IP (stone interlayer) section, though not much change was noticed. From 2007 onward, there was a relatively constant increase in IRI, with the IP values slightly greater than those of the control section. The variability in the performance of the control section was generally higher than in the IP section.

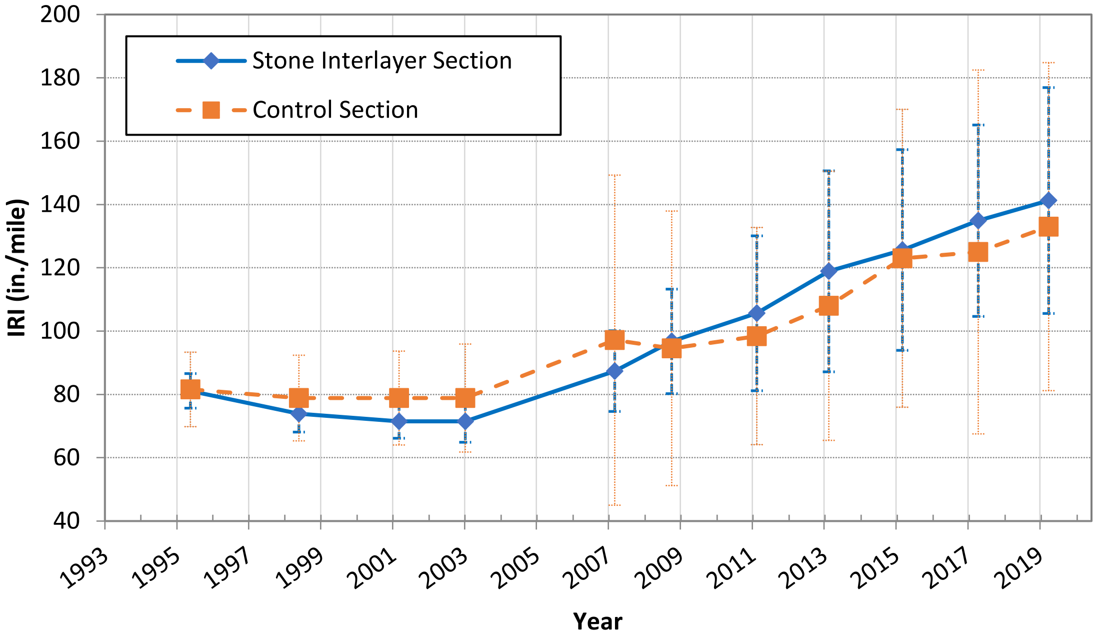


Figure 86. Graph. Average and standard deviation international roughness index; LA-97 (data provided by LaDOTD).

Figure 87 shows the average and standard deviation rut depths for both sections over time. Rut depth in the stone interlayer section was consistently higher than in the control section and appeared to increase at a relatively constant rate from 2008 onward. The decrease in rutting for the years 2000 and 2002 is believed to be associated with the use of different equipment during data collection.

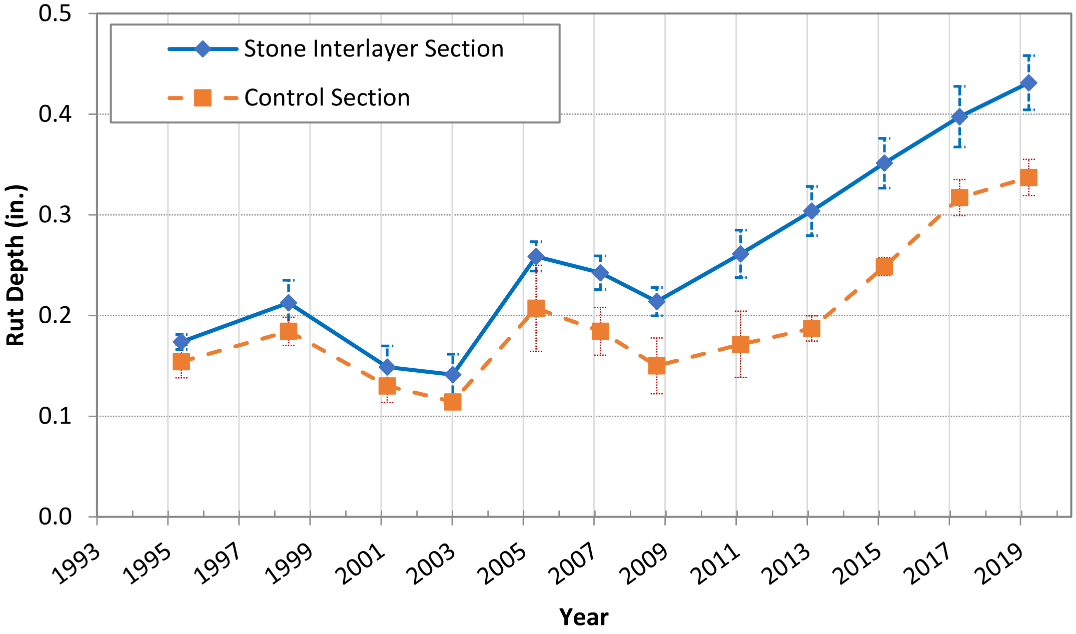
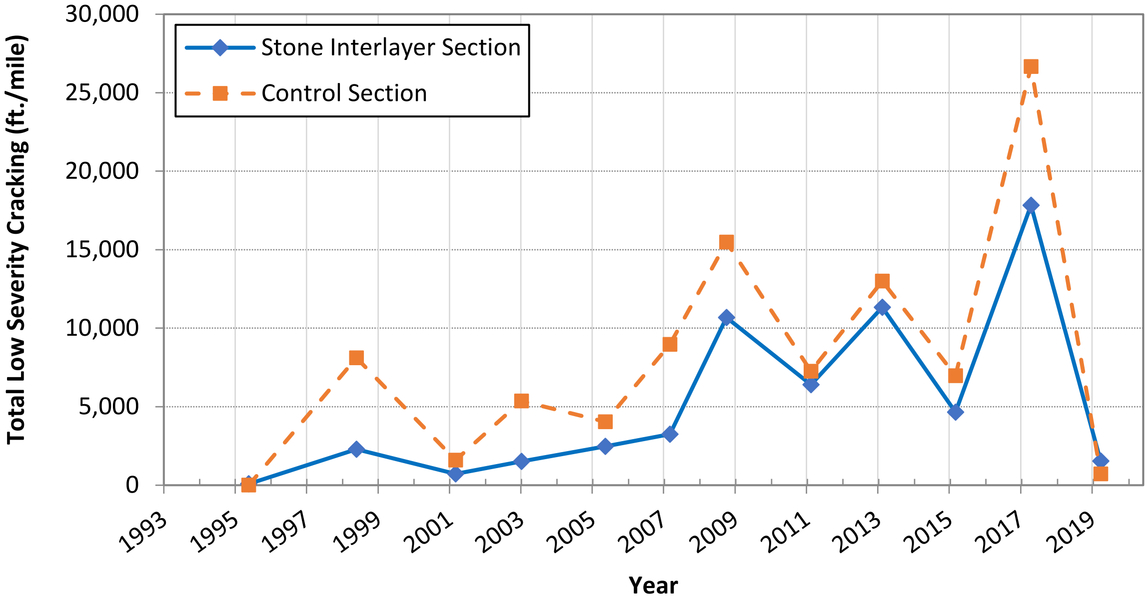
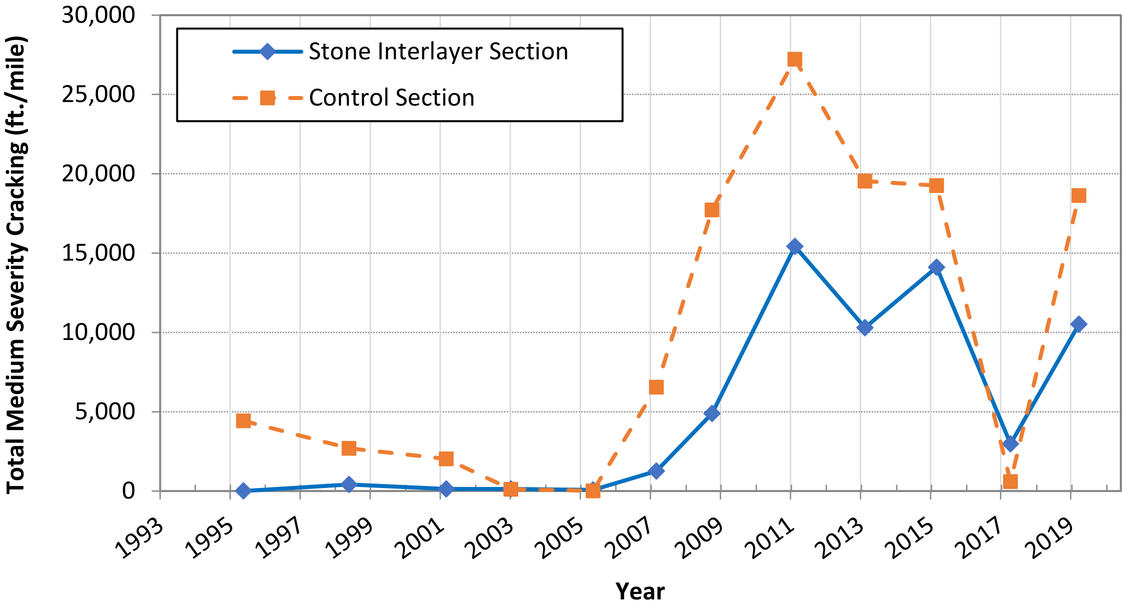


Figure 87. Graph. Average and standard deviation rut depth; LA-97 (data provided by LaDOTD).

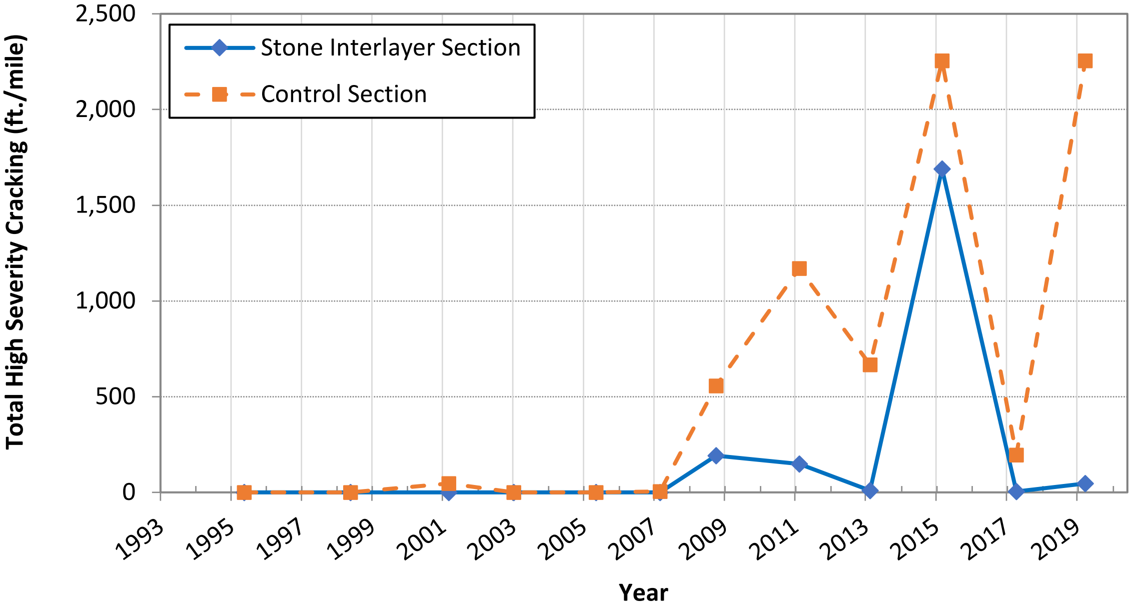
Figure 88 shows the total low-severity, medium-severity, and high-severity cracking, and total cracking density for both sections. The data indicated that the control section had overall more cracking than the stone interlayer section. Medium-severity cracking started increasing after 2005, and high-severity cracking from about 2007 onward.



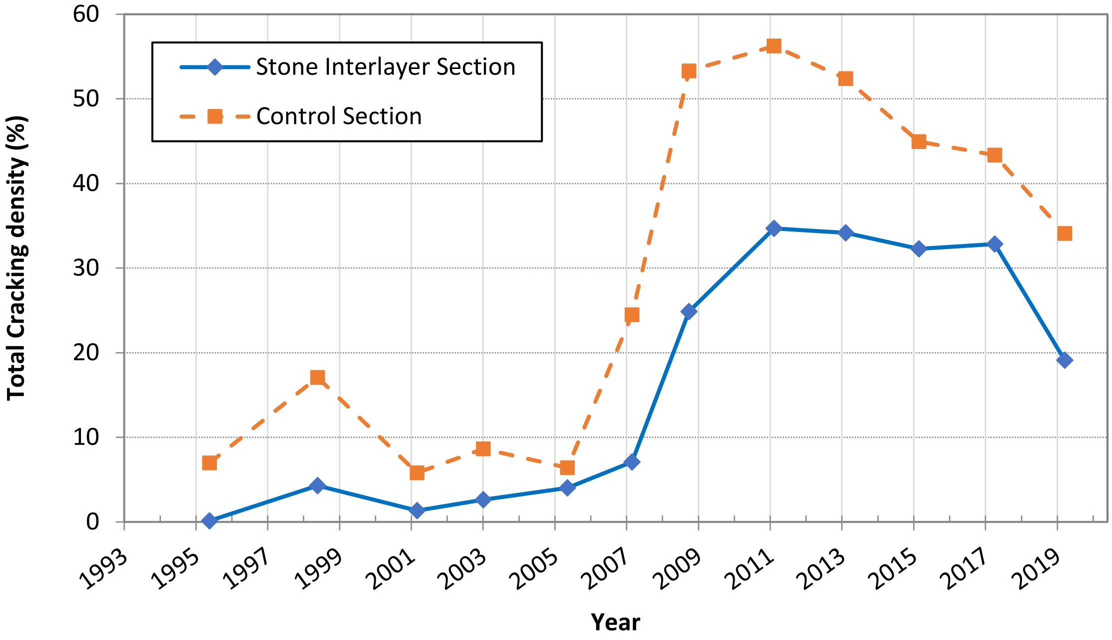
A. Low-severity cracking.



B. Medium-severity cracking.



C. High-severity cracking.



D. Total cracking density.

Figure 88. Graph. Total cracking; LA-97 (data provided by LaDOTD).

Figure 89 shows the composite index (CI) evolution over time. The CI represents the overall condition of the pavement, with 100 representing the best condition and 0 the worst. The control section showed overall inferior performance to the stone interlayer section, although the data of 2017 and 2019 indicated similar performance, with both presenting in poor condition in 2019.

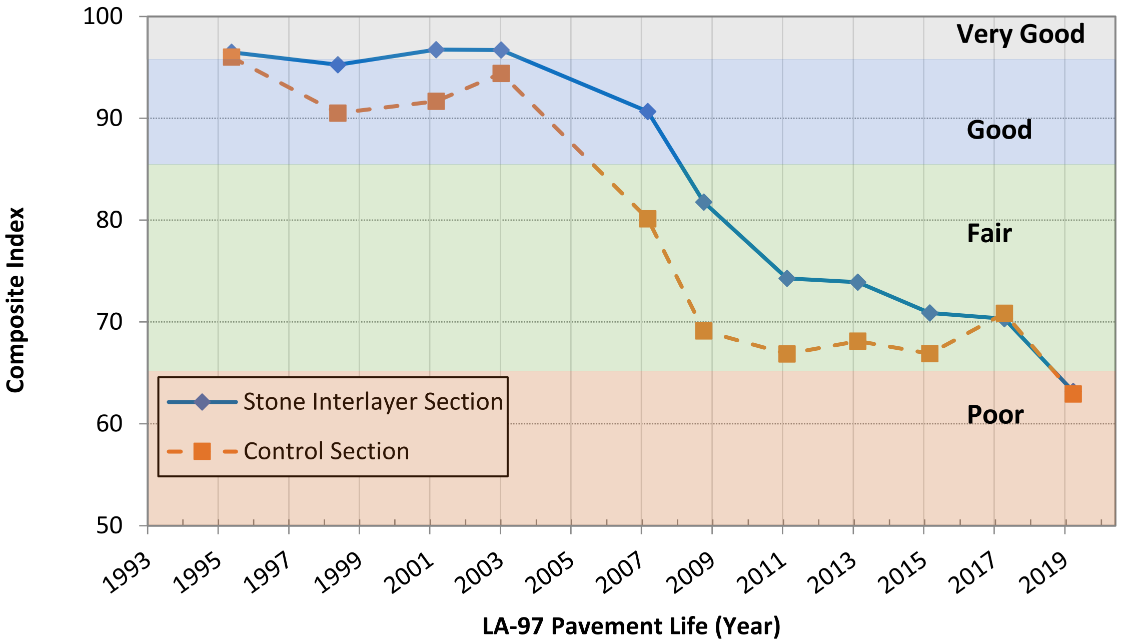


Figure 89. Graph. Composite index; LA-97 (data provided by LaDOTD).

FWD testing carried out in 2008 and 2009 showed that the IP had a relatively higher deflection than the control section. The average maximum deflection for the IP was 7.9 mils (0.2 mm) with a COV of 26.8 percent, whereas for the control section, the average was 4.7 mils (0.12 mm) with a COV of 45 percent (Chen, Zhang, and Lambert 2014). Figure 90 shows a photo of the IP section taken in 2017.

Figure 90. Photo. Inverted pavement section in 2017; LA-97 (provided by LaDOTD).

On the other hand, the APT showed that the IP section (Lane 009) performed better than the soil-cement section (Lane 008). The IP section had 4.7 times the number of ESALs of the soil-cement lane before failure (Rasoulian, Becnel, and Keel 2000; Chen, Zhang, and Lambert 2014).

Cost Assessment

Analysis performed by Titi et al. (2003) indicated that the pavement materials for a conventional soil-cement pavement design would cost \$173,000/mi (\$107,497/km), whereas the stone interlayer pavement (IP), would cost \$208,000/mi (\$129,246/km). According to those authors, the IP would represent an increased load-carrying capacity, as shown by the APT and performance data at the time.

More recent performance data, however, indicate that both pavement types reached poor condition at the same time after 28 years of service (see figure 89). It is noted, however, that the CP received some patching for which records were not available. The life-cycle cost of the pavement depends also on the extent, schedule, and cost of patching activities.

Environmental Sustainability

Results of an environmental assessment conducted in a previous study are included in table 21. The analysis took into consideration the materials and initial construction stages of the two pavement sections; the US-165 will be discussed in the following section but added herein for comparison. A hypothetical control section for US-165 was included for comparison purposes. Energy demand was found to be essentially the same for both pavement sections, though it was noted that the energy demand for IP could had been reduced by a range of about 3 to 5 percent if the source of crushed aggregate used in the base course were located closer to the construction site. GWP for the IP section was reduced by a range of 11 to 13 percent compared to the control section. This was found to be primarily related to the reduced use of cement in the IP section (Ozer and Al-Qadi 2021).

Table 21. Environmental sustainability assessment; US-165 and LA-97 (Ozer and Al-Qadi 2021).

Section		Energy demand, MJ per lane-mile	GWP, kgCO$_2$ per lane-mile
US-165	Inverted pavement	3.54E+06	3.23E+05
	Control (hypothetical)	3.63E+06	3.74E+05
LA-97	Inverted pavement	2.63E+06	2.58E+05
	Control	2.61E+06	2.90E+05

Additional analysis was conducted using FHWA LCA Pave tool. The analysis considered only pavement materials, transportation, and construction stages of the project life. Earthworks prior to subgrade preparation and other road construction features (e.g., drainage, signage, and lighting) were not included in the analysis. Transportation distances and construction activities (e.g., use of construction equipment) were estimated assuming typical construction equipment operation.

Maintenance and rehabilitation activities were not considered in the analysis. The IP developed more rutting and less cracking than the control section, but overall, both sections reached poor condition at the same time after 28 years of service (see figure 89), and the average IRI for both sections was relatively similar (see figure 86). Therefore, it was assumed that maintenance and rehabilitation activities for the IP and CP would be similar, in which case the environmental impacts of this stage would also be similar.

The materials included in the analysis were represented by existing materials in the tool library. The provided AC mix design (for US-165) indicates Ad-here was used as the anti-stripping agent. In the absence of environmental product information for Ad-here, the analysis assumed hydrated lime was used. Water consumption was calculated assuming the subgrade was watered to a moisture content of 18 percent to a depth of 12 inches (300 mm), the CTB to a moisture content of 8 percent, and crushed limestone layers to a moisture content of 8 percent. In the absence of detailed transportation distances, materials were assumed to be transported from 50 miles (80 km) away, except for water, which was assumed to be available onsite. Construction equipment transportation distances were not considered in the analysis. Detail assumptions are included in appendix C.2.

The results of the environmental assessment analysis, normalized by lane-mile (functional unit), are included in table 22. Although the results differed from those presented by Ozer and Al Qadi (2021) using Al-Qadi et al. (2015) inventory data, the general trends were similar. GWP was higher for US-165, followed by the control section in LA-97, and then the IP section in LA-97. Total energy demand was higher for US-165 and similar for the LA-97 control and IP sections. Differences in the values obtained in the previous study and the results presented here are due to the use of different libraries and potential differences in the assumptions made.

Figure 91 shows the impact indicators normalized by lane-mile and by the highest value among the three pavement cross sections considered (US-165 IP, LA-97 IP, and LA-97 CP).

Table 22. Environmental impacts per lane-mile; US-165 and LA-97, Louisiana.

Impact indicator (i)	US-165	LA-97	
	Inverted pavement	Inverted pavement	Control pavement
Use of renewable energy primary energy, excluding renewable primary resources used as raw materials (MJ) (ii)	47,664	37,120	46,032
Use of renewable primary energy resources used as raw materials (MJ) (ii)	67.14	65.43	60.63
Total use of renewable primary resources (MJ) (ii)	47,732	37,186	46,094
Use of nonrenewable primary energy, excluding nonrenewable primary energy resources used as materials (MJ)	4,064,250	2,767,109	2,908,471
Use of nonrenewable primary energy used as raw materials (MJ) (ii)	2,960,689	1,748,145	1,748,145
Total use of nonrenewable primary energy resources (MJ) (ii)	7,024,939	3,949,682	4,091,044
Recycled material usage (short-tons)	428	256	270
Disposed nonhazardous waste (short-tons) (ii)	156	92.85	93.38
Disposed hazardous waste (short-tons) (ii)	11.06	6.53	6.53
Net use of fresh water (m^3) (ii)	1,625	1,438	1,947
Acidification (kg SO_2 eq)	969	1,082	1,148
Ecotoxicity (CTUeco/kg) (ii)	13,051	7,718	7,680
Eutrophication (kg N eq)	228	211	268
Fossil fuel depletion (MJ surplus) (ii)	385,692	227,927	227,885
GWP (kg CO_2 eq)	341,361	256,457	297,334
Human health, cancer (CTU/kg) (ii)	0.0002	8.17E-05	7.54E-05
Human health, noncancer (CTU/kg) (ii)	0.008	0.0047	0.0047
Human health effects, particulates (kg PM2.5 eq) (ii)	46.59	14.15	10.78
Ozone depletion (kg CFC-11 eq)	0.0044	0.0041	0.0055
Smog formation (kg O3 eq)	25,024	27,992	28,468

Notes:

(i) Environmental impacts of the production (A3) stage were assumed as the average of A3 impacts for two plants in Louisiana that have published EPDs for hot mix asphalt (EPDs for plants in Opelousas and Westlake available on the NAPA website). For the US-165 AC mixes, the impacts of transportation of materials (A2) to the asphalt plant were calculated based on estimated travel distances between the plant and the origin of each mixture component as identified in the mix design certificate provided by LADOTD. All materials were assumed to be transported by trucks. For the AC mix used in LA-97, the analysis considered averages of A2 and A3 impacts for two HMA mixes with the same NMAS produced in Louisiana (NAPA EPDs No. 34.99.204 v1 and No. 34.100.205 v1).

(ii) The results presented are LCA Pave outputs, which are calculated based on the available information. Calculations of some impact categories can be incomplete due to missing data.

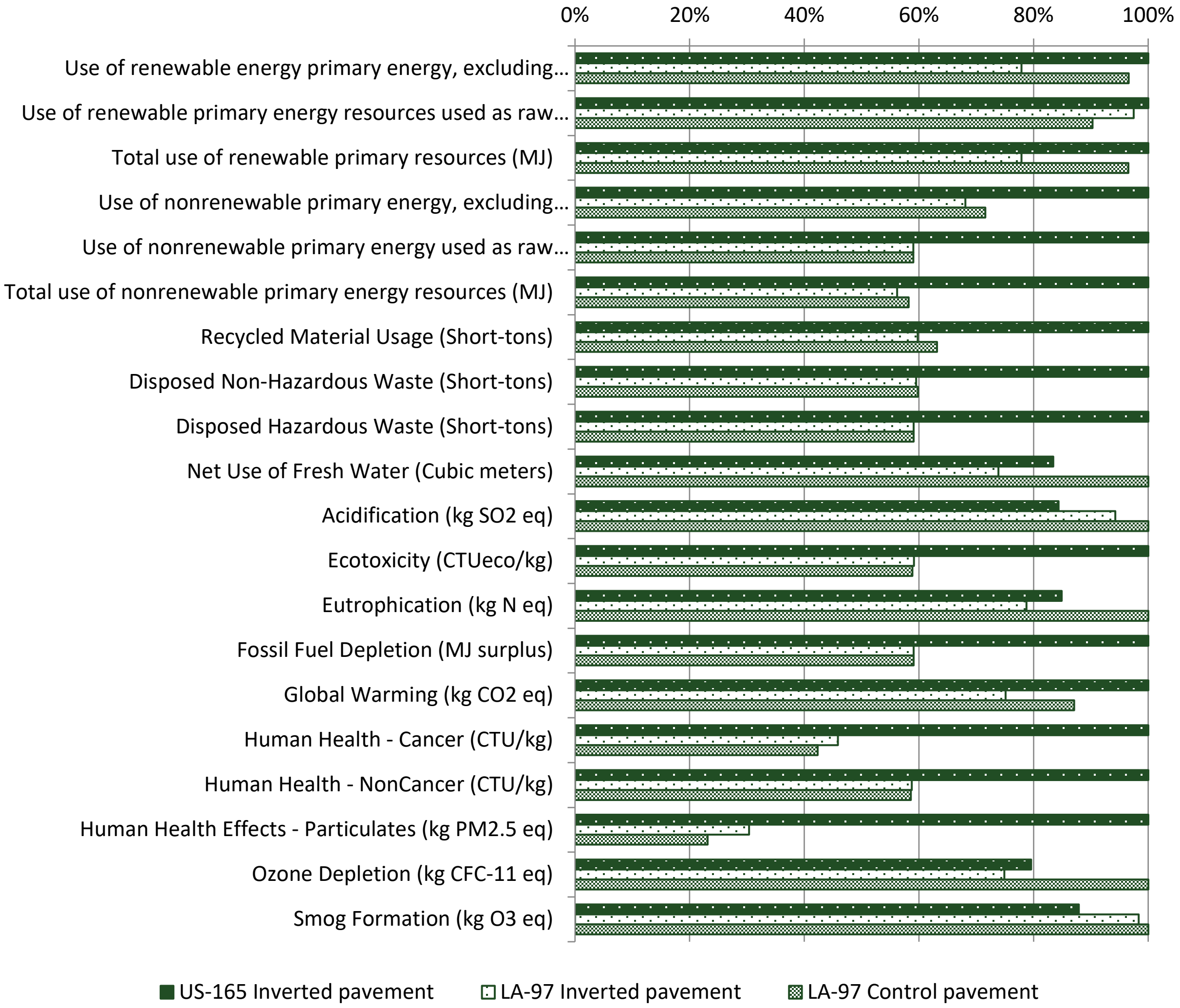


Figure 91. Graph. Comparison of normalized impact indicator values for each pavement section; US 165 and LA-97, Louisiana.

The pavement at US-165 generally represented higher environmental impacts than the LA-97 pavements. However, US-165 has a thicker pavement, which was designed for a design traffic of 3.2 × 10^6 ESALs, whereas LA-97 was designed for 5.7 × 10^5 ESALs. Figure 92 shows the same results presented in figure 91, but further normalized by the design traffic for each section. The plot shows that the environmental impacts of the IP at US-165 per design ESAL were significantly lower than those of sections at LA 97.

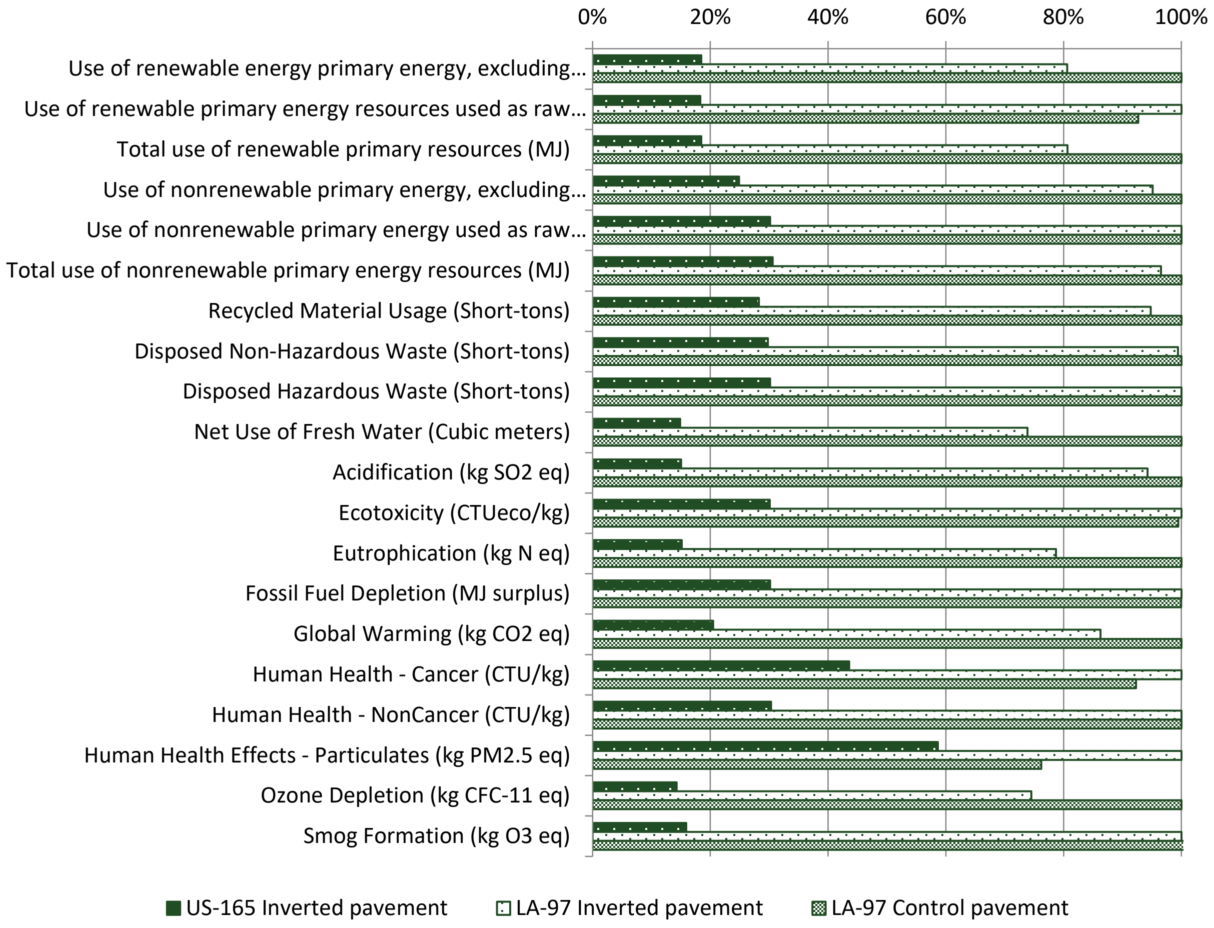
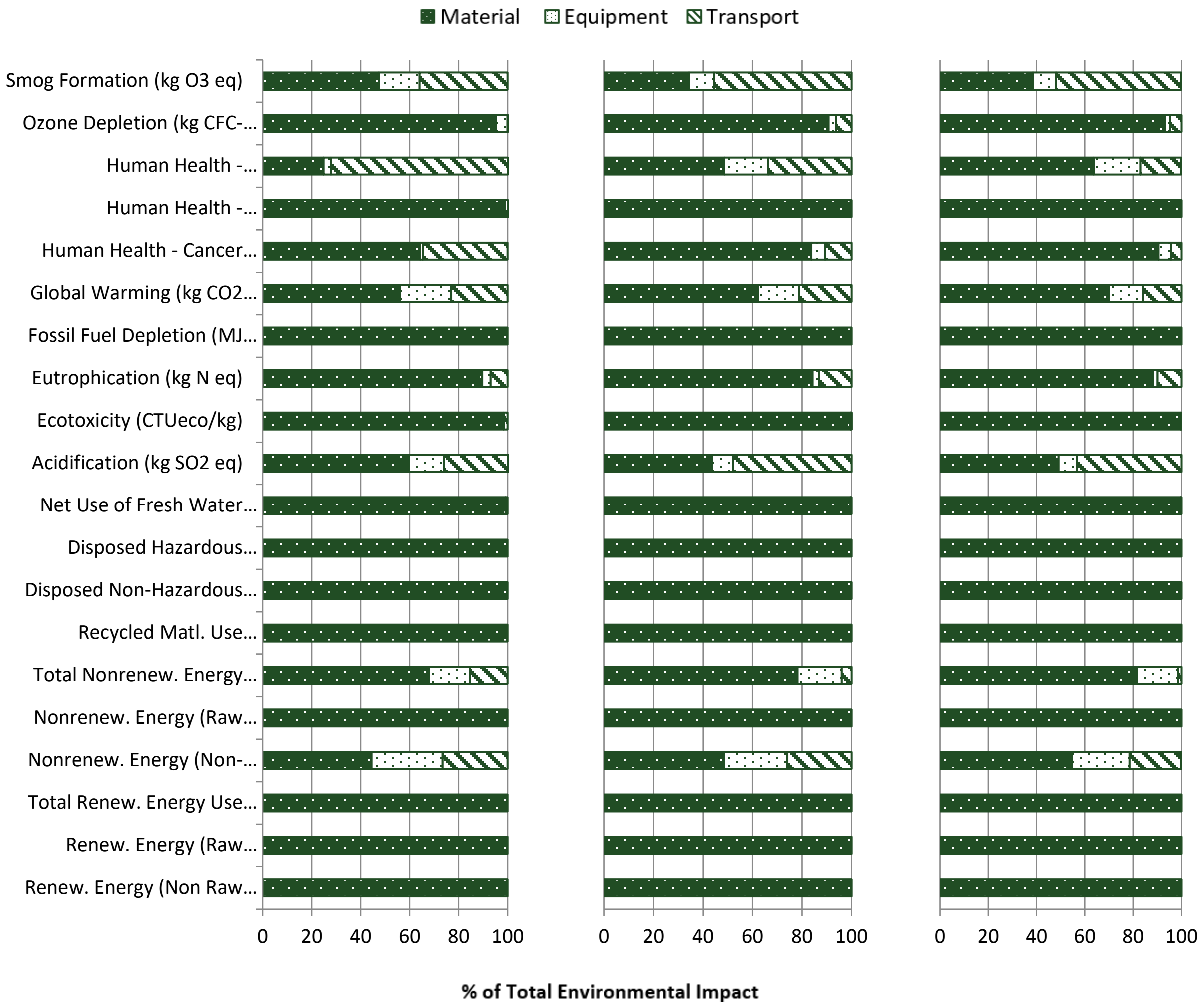


Figure 92. Graph. Comparison of normalized impact indicator values for each pavement section further normalized by design traffic; US-165 and LA-97, Louisiana.

When comparing the IP and control pavement solutions for LA-97, the control pavement generally had a higher impact in most of the categories considered. GWP for the IP was 86 percent that of the control pavement. Total energy demand was 96 percent.

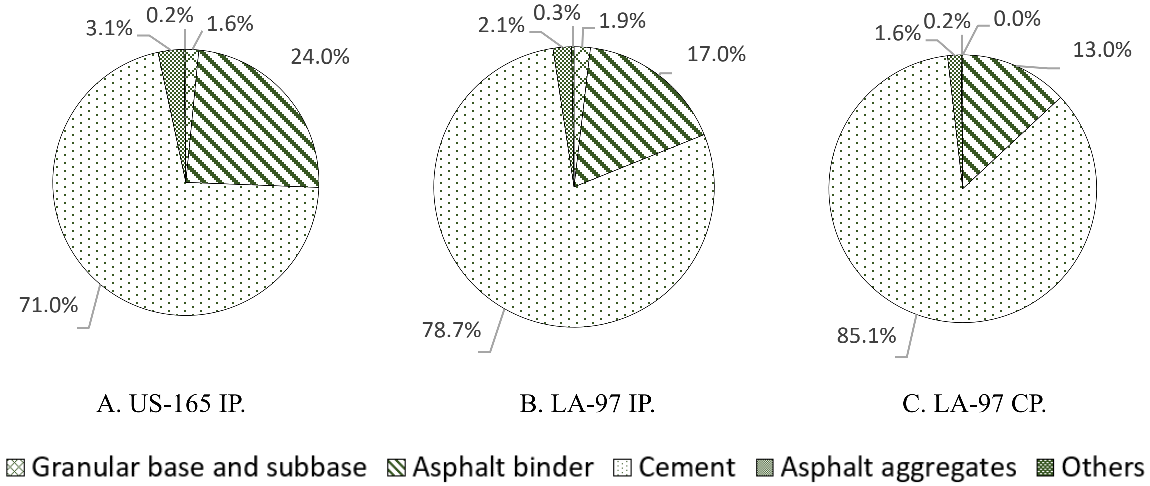
Figure 93 shows the contribution of each process to the impact categories for each pavement section. Most of the GWP originated from the materials phase. Based on the transportation distances assumed, construction equipment operation and materials transport represented similar contributions to GWP.



A. US-165 IP. B. LA-97 IP. C. LA-97 CP.

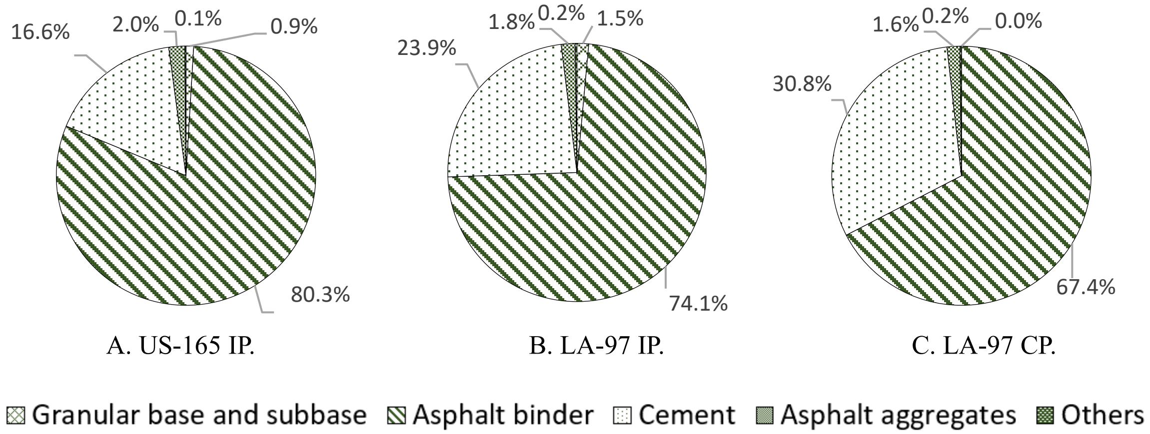
Figure 93. Graph. Comparison of impact indicators by process type for each pavement section; US 165 and LA-97, Louisiana.

Figure 94 and figure 95 show, respectively, the contribution of each material to the total material stage to GWP and to total use of primary energy resources for each pavement section (with transportation and construction stage excluded). The material that most impacted GWP was cement, followed by asphalt binder. The LA 97 IP had a thinner cemented layer than the LA-97 CP, resulting in a reduced contribution of the cement to total GWP. The material that represented most of the energy use was asphalt binder, followed by cement.



A. US-165 IP. B. LA-97 IP. C. LA-97 CP.

Figure 94. Graph. Contribution of each material to GWP (kg CO_2 eq) for each pavement section.



A. US-165 IP. B. LA-97 IP. C. LA-97 CP.

Figure 95. Graph. Contribution of each material to total use of primary energy resources for each pavement section.

Summary and Remarks

The IP and control pavement sections at LA-97 were constructed in 1991. The IP section of LA-97 remained in good to very good condition for about 16 years. The control section presented a slightly poorer performance over time, reaching fair condition roughly a couple of years earlier. Both sections reached a poor condition at the same time—28 years after construction.

The IP generally presented less cracking but more rutting than the control section, confirming the findings of Metcalf et al. (1998). The lower rate of cracking indicated that the stone interlayer was effective in slowing reflective cracking from the cement-stabilized layer to the AC surface. The higher rutting in the IP may be associated with the lower stiffness of the layer directly beneath the AC surface layer. A higher rate of increase in rutting appeared to follow the increase in medium- and high-severity cracking after 2007. This may result in water infiltration, which may have reduced the stiffness of the granular layers and accelerated rutting.

The APT of the pavement configurations similar to the LA-97 showed a better overall performance for the IP section. It lasted 4.7 times longer than the soil-cement section in terms of ESAL repetitions to failure.

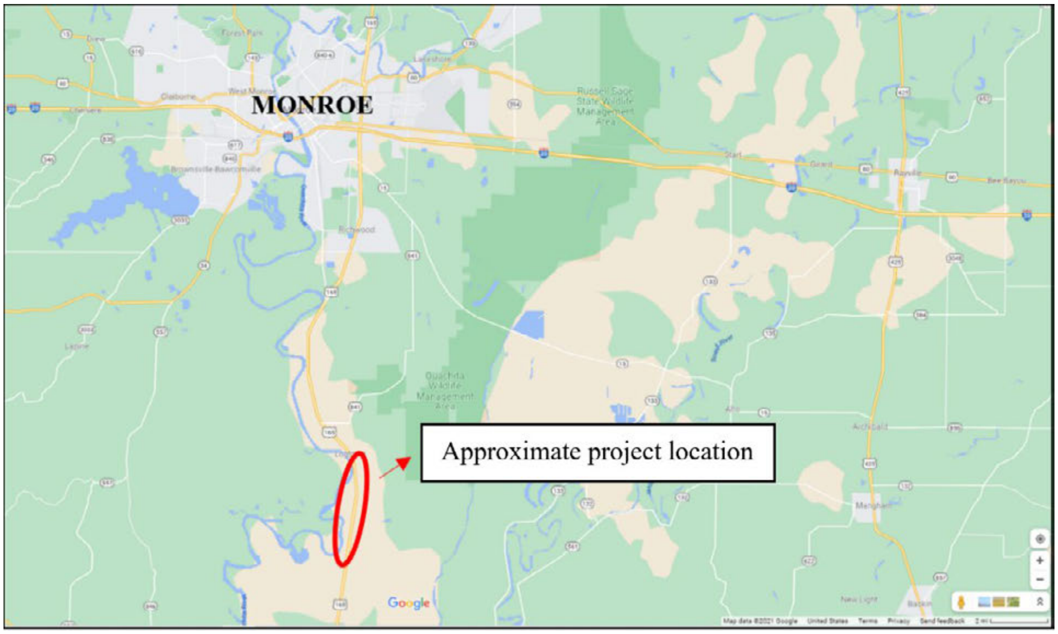
In terms of environmental sustainability, the IP section represented a reduction in GWP compared to the control section. Energy demand was similar for both sections.

In general, the IP solution provided overall similar or better pavement performance, representing a more environmentally and economically sustainable solution than the control section. This project experience led to the adoption of IP as a standard option for other Louisiana roads (Rasoulian 2004).

US ROUTE 165, OUACHITA PARISH, LOUISIANA

Location

The IP on US-165 consists of a 4.4-mi (7.1 km) section located south of Monroe, in Ouachita Parish, Louisiana. The IP section was constructed as the SB pavement where the road went from two lanes with no median to four lanes with median. The approximate location is shown in figure 96.



Original Photos: © 2015 Google® (see Acknowledgements section).

Figure 96. Illustration. US-165, Ouachita Parish, Louisiana.

Pavement Configuration

The IP cross section at US-165 is summarized in table 23.

Table 23. Pavement cross section; US-165.

Pavement layer	Thickness (in)
	Inverted pavement section (US-165)
Superpave AC wearing course	2.0 (50 mm)
Superpave AC binder course	4.0 (100 mm)
Crushed limestone	4.0 (100 mm)
Cement-stabilized base (soil-cement)	8.0 (200 mm)
Lime-treated subgrade	12 (300 mm)
Subgrade	Silty clay LM, A-4, modulus 10 ksi (68.4 MPa)

The pavement was designed using the empirical AASHTO Pavement Design Guidelines (AASHTO 1993). Structural and drainage coefficients assumed for each layer are summarized in Table 24.

Table 24. Structural and drainage coefficients and layer design; US-165 (based on information provided by LaDOTD).

Pavement layer	Structural coefficient	Drainage coefficient	Thickness (in)	Calculated SN (in)
AC surface	0.44	1.0	2	0.88
AC base	0.44	1.0	4	1.76
Crushed lime	0.14	0.9	4	0.50
Cement-stabilized base (soil-cement)	0.14	0.9	8	1.01
TOTAL			18.0	4.15

Construction and Maintenance

The construction of the SB was finalized in June 2006. The NB consists of the previously existing two-lane pavement based on aerial Google Earth imagery. The section is believed to have received an AC overlay around the same time the SB was constructed.

The AC mix used for the binder course had a NMAS of 0.75 inches (19 mm), with optimum binder content 4.6 percent, air void content 3.9 percent, and RAP content 15 percent. A summary of the mix design is included in appendix A.2.

There is no known record of maintenance or rehabilitation activities.

Traffic Loading

US-165 is a rural principal arterial road. The 20-year design traffic was 3.2×10^6 ESALs, with a 2005 ADT of 7,900 and 2025 ADT of 11,700.

Environmental Conditions

Monroe is in a wet non-freeze area in accordance with the FHWA and LTPP classification (see figure 32). Table 25 includes average temperatures, rainfall, and snowfall for Monroe, Louisiana. Monthly rainfall in the area remains between 4.2 and 5.4 inches (107 to 137 mm) from October to June, with the driest months being from July to September, when the monthly rainfall falls to 3.2 to 3.7 inches (81 to 94 mm).

Table 25. Monroe, Louisiana, average temperatures, rainfall, and snowfall (source: NOAA).

Month	Temperature		Rainfall			Snowfall		
	Highs (°F)	Lows (°F)	Days	in	mm	Days	in	mm
Jan	56	36	7	5.0	127	0	0.7	18
Feb	61	40	7	4.6	117	0	0.2	5
Mar	69	47	7	5.4	137	0	0	0
Apr	77	55	6	4.9	124	0	0	0
May	84	63	7	5.1	130	0	0	0
Jun	91	70	7	4.2	107	0	0	0
Jul	93	73	6	3.7	94	0	0	0
Aug	93	72	5	3.2	81	0	0	0
Sep	88	66	5	3.5	89	0	0	0
Oct	79	54	5	4.3	109	0	0	0
Nov	67	45	6	4.4	112	0	0	0
Dec	59	38	7	5.3	135	0	0.1	3
Total			75	53.6	1361	0	1.0	25

Performance

From 2008 through 2019, LaDOTD recorded the following performance indicators on the US 165 IP section: IRI, rut depth, transverse cracking, longitudinal cracking, total cracking, and CI.

Figure 97 shows the average and standard deviation for IRI. Figure 98 shows the average and standard deviation for rut depth. There was a relatively constant increase in IRI and rutting with time, though it appears that, after 2014, the rate of rutting development was slightly faster.

Figure 99 shows low-, medium-, and high-severity cracking. Figure 100 shows total density cracking. The rate of cracking development appears to have accelerated after six years of construction.

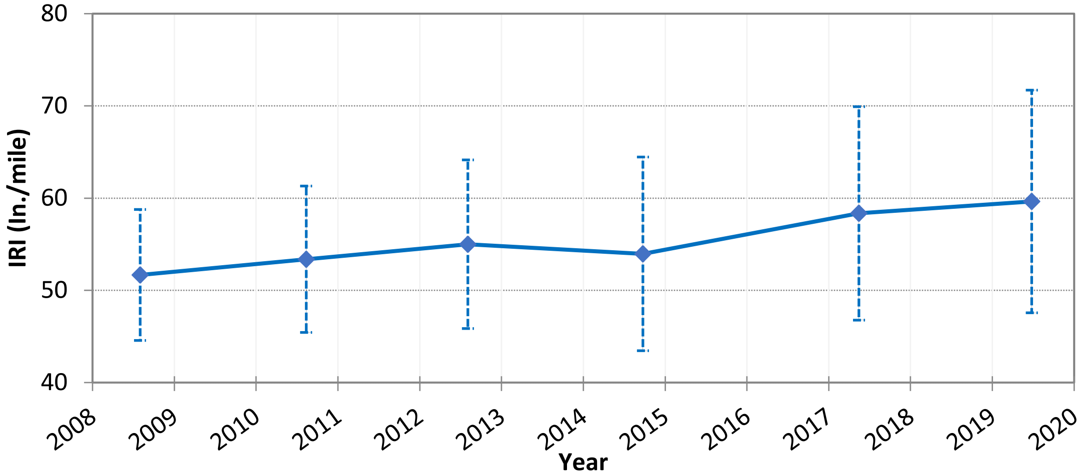


Figure 97. Graph. Average and standard deviation international roughness index; US-165 (data provided by LaDOTD).

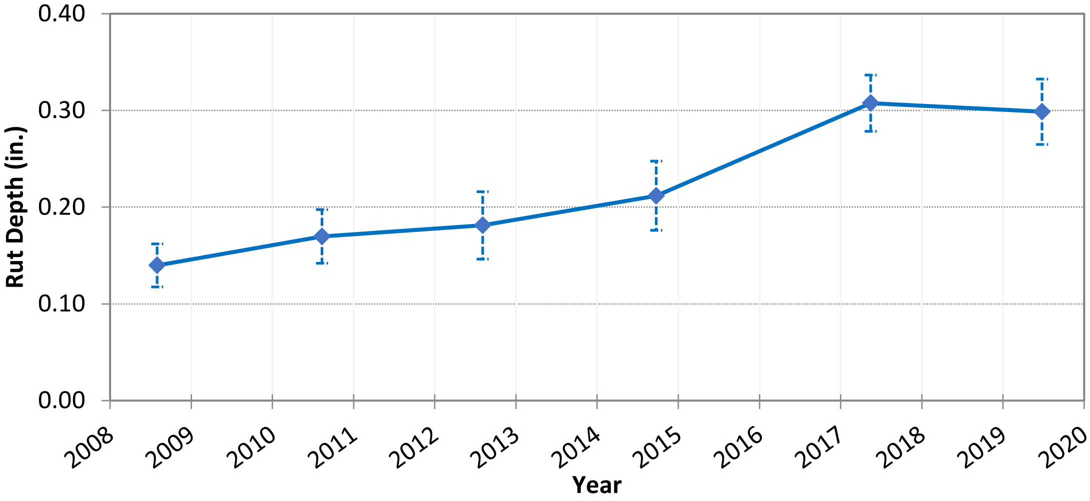


Figure 98. Graph. Average and standard deviation rut depth; US-165 (data provided by LaDOTD).

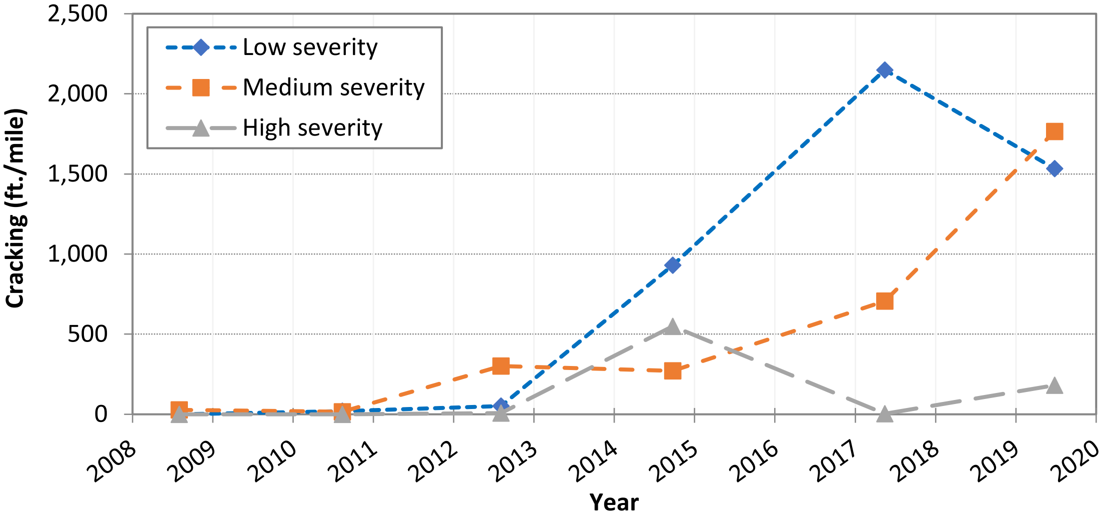


Figure 99. Graph. Low-, medium-, and high-severity cracking; US-165 (data provided by LaDOTD).

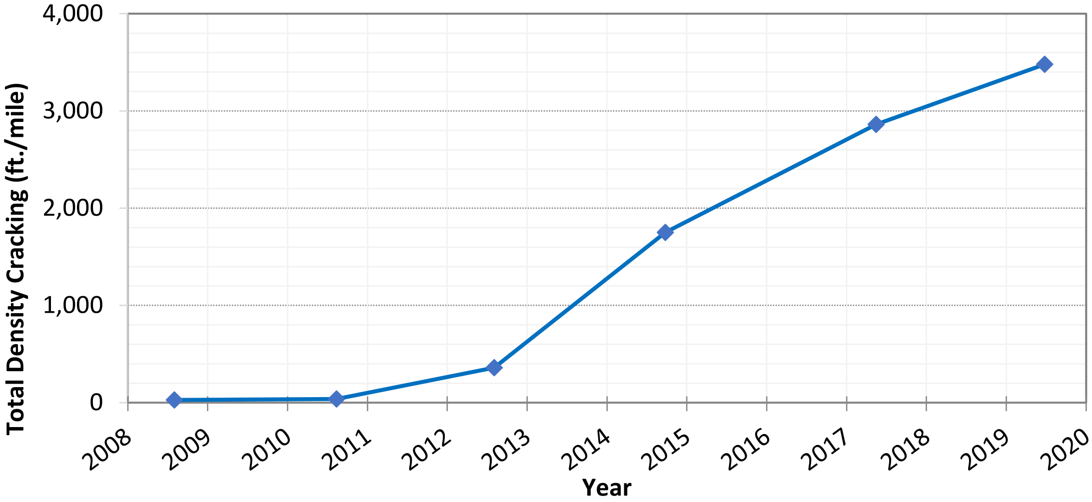


Figure 100. Graph. Total cracking: US-165 (data provided by LaDOTD).

Figure 101 shows the CI evolution. The CI is a unitless measure that takes into consideration the overall pavement condition accounting for rutting, cracking, IRI, patching, etc. It is based on a scale from 0 to 100, with 100 being the perfect condition. Pavement deterioration appears to have slightly accelerated after 2013 (seventh year of pavement life). Nevertheless, the IP section at 13 years of age (year 2019) was still in good condition despite the observed cracking and rutting.

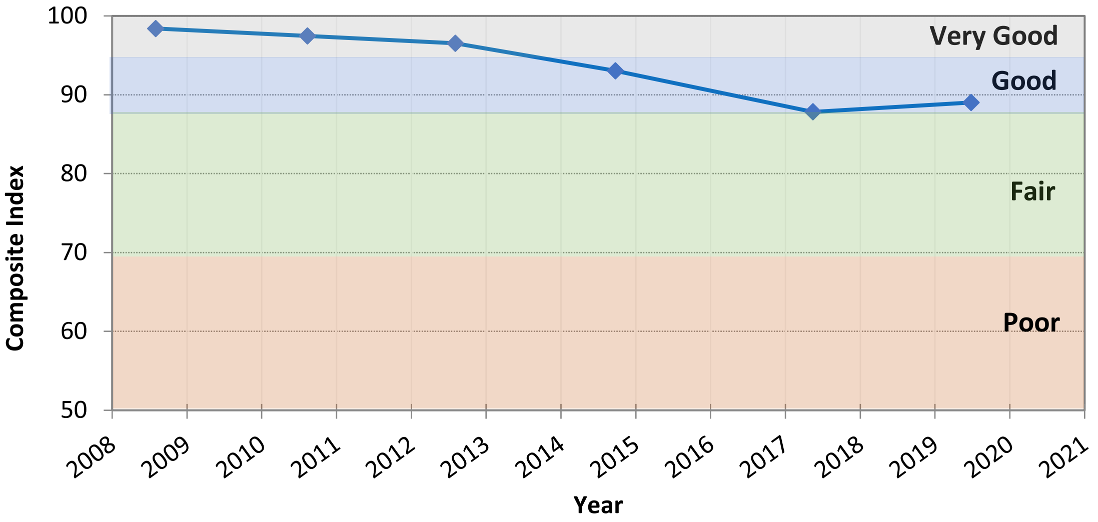


Figure 101. Graph. Composite index, US-165 (data provided by LaDOTD).

FWD Backcalculated Moduli

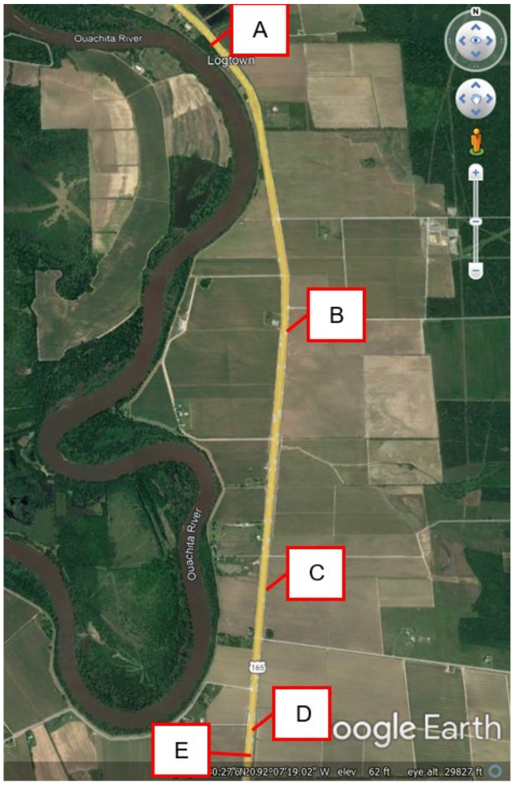
Chen, Zhang, and Lambert (2014) performed backcalculation of layer moduli for the IP section from FWD testing data collected sometime between March 2008 and June 2009 (i.e., two to three years after construction). The authors corrected the AC moduli to a temperature of 77 degrees Fahrenheit (25 degrees Celsius) and adopted a seed modulus value of 45 ksi (310 MPa) for the stone interlayer (i.e., unbound granular layer). Moduli stress dependency of granular layers was not included in the analysis. The backcalculated moduli obtained by the authors are summarized in table 26. A COV of 129.1 percent was obtained for the CSB, with an average modulus of 722 ksi (4,975 MPa) and standard deviation of 932 ksi (6,428 MPa). This significant variation is believed to be due to the presence of discontinuities in the form of cracks in that layer.

Table 26. FWD backcalculated layer moduli (Chen, Zhang, and Lambert 2014).

Pavement layer	FWD backcalculated moduli		
	Average	Standard deviation	COV (%)
AC	404 ksi (2,784 MPa)	86 ksi (593 MPa)	21.2
Crushed limestone interlayer	56 ksi (385 MPa)	17 ksi (116 MPa)	30.2
Cement-stabilized base	722 ksi (4,975 MPa)	932 ksi (6,428 MPa)	129.1
Lime-treated subgrade	19 ksi (129 MPa)	4.3 ksi (30 MPa)	17.9

Site Visit

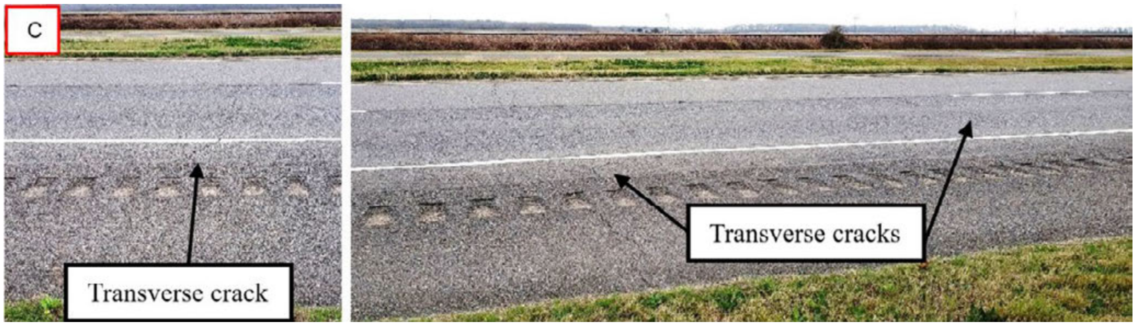
The site was visited on December 29, 2021. The visit consisted of observations taken from a moving vehicle (at around 50 mph [80 km/h]) and visual observations and photographs taken from the side of the road. No traffic control was in place for the visit; therefore, close observation of the pavement was not safely possible. However, the overall ride and visual observations indicated that the pavement was in good riding condition, with some transverse cracking observed at locations, spaced about 10 to 25 ft (3.0 to 7.6 m) apart. The transverse cracking was not evident from a moving vehicle but could be seen from the side of the road. Figure 102 includes photos of the IP in the SB direction taken during the visit, with the locations of a few visible transverse cracks indicated.



Original Photo: © 2015 Google® (see Acknowledgements section).


A


B


C
Transverse crack
Transverse cracks

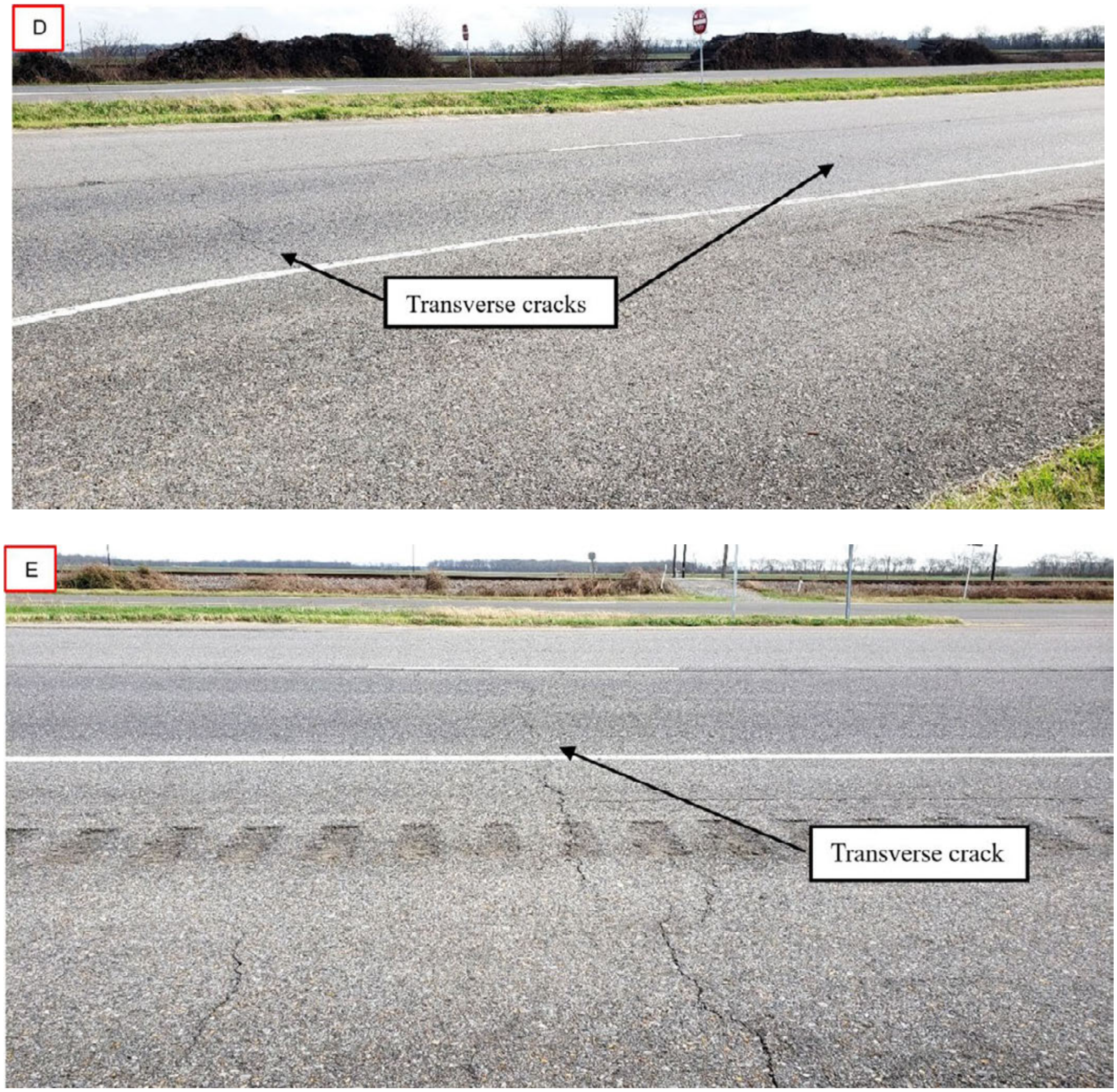


Figure 102. Photo. US-165 inverted pavement site visit photos.

Cost Assessment

The cost of the IP for US-165 per lane-mile was $204,208 (Ozer and Al-Qadi 2021).

Environmental Sustainability Assessment

The environmental sustainability assessment for US-165 is presented with the assessment conducted for LA-97.

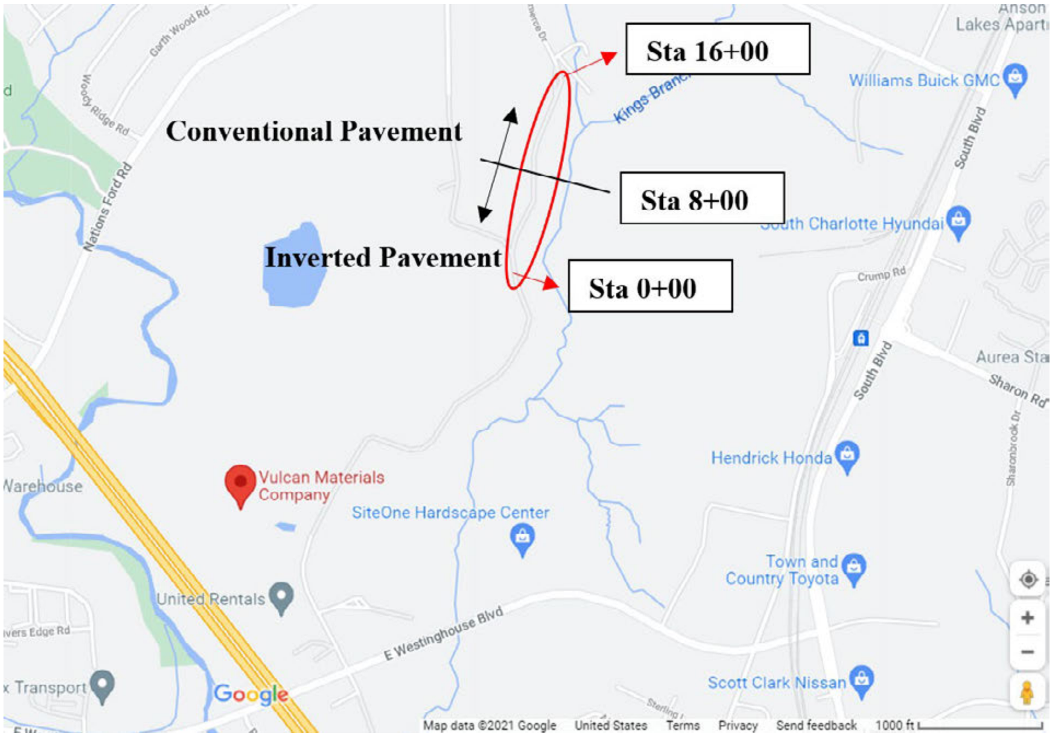
Summary and Remarks

The IP section of US-165, in Ouachita Parish, was constructed in 2006 and has remained in very good or good condition since then. Performance data indicated that the rate of crack density development accelerated after 2012, whereas the rate of rut depth development slightly accelerated after 2014. This may be an indication that water may be infiltrating through the cracks and reducing the support capacity provided by the granular layers underneath the AC, which could accelerate rutting development.

QUARRY ACCESS ROAD, NORTH CAROLINA

Location

The IP section in North Carolina was a relocation of a haul road that gives access to a quarry[3] in North Carolina. The project consisted of two 800-ft (224-m) road sections, one using IP (Station 0 to 8) and one using CP (Station 8 to 16). The location of the project is shown in figure 103.



Original Photo: © 2015 Google® (see Acknowledgements section).

Figure 103. Illustration. Inverted pavement location at Quarry Access Road, North Carolina.

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[3] Vulcan Materials Quary Access Road

Pavement Configuration

The IP and CP cross sections are summarized in table 27. The structural number (SN) for the IP was reported as 3.78 and as 4.04 for the CP (Vaughan 2017).

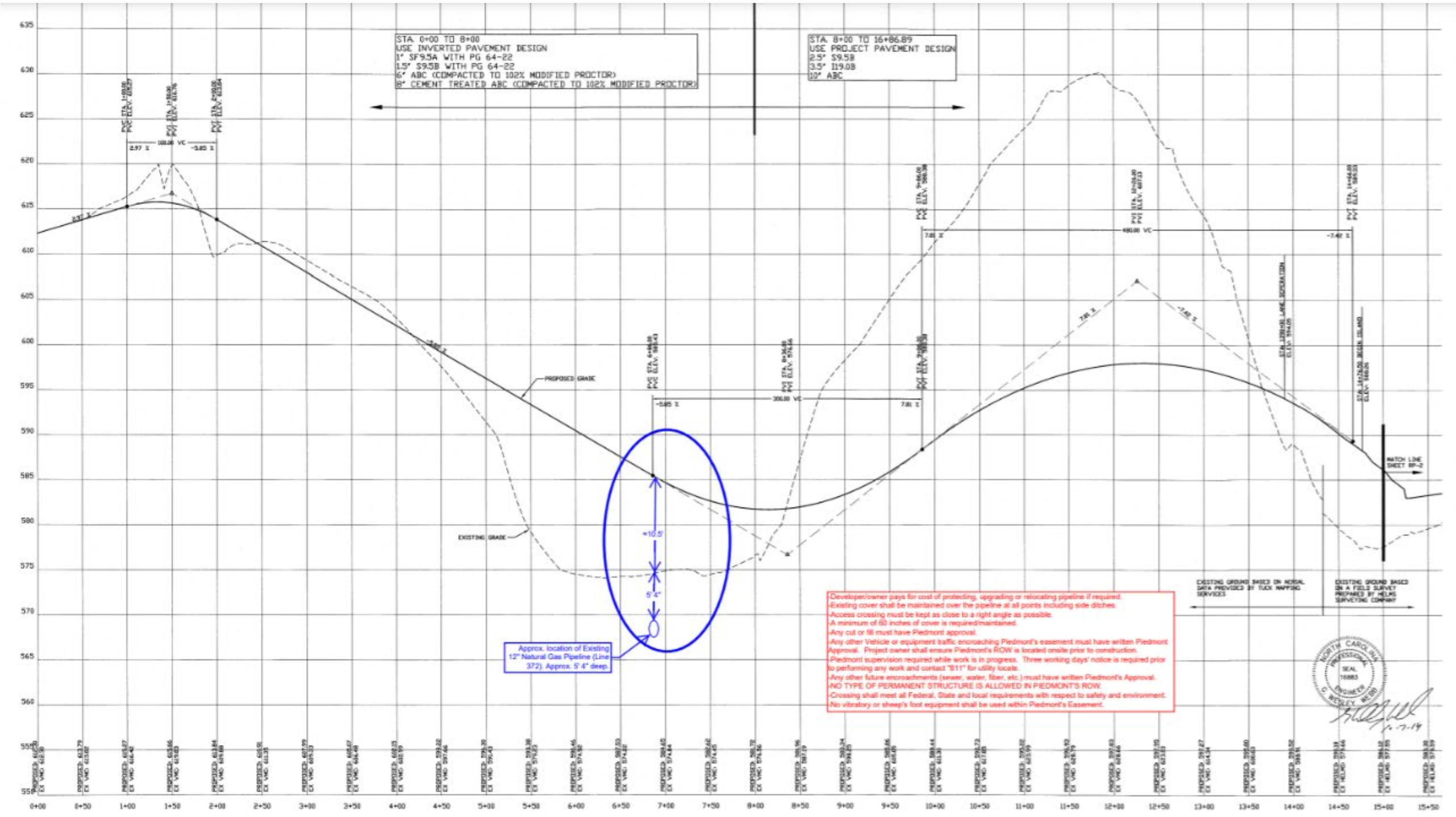
Table 27. Pavement cross section; Quarry Access Road, North Carolina.

Pavement layer	Thickness (in)	
	Inverted pavement (Station 0 to 8)	**Conventional pavement (Station 8 to 16)**
AC 0.37 in (9.5 mm) NMAS	1+1.5 (65 mm total, placed in two lifts)	2.5 (65 mm)
AC 0.75 in (19.0 mm) NMAS	—	3.5 (90 mm)
Unbound granular layer	6.0 (150 mm)	10.0 (250 mm)
Cement-treated aggregate base (2% cement)	8.0 (200 mm)	—
Subgrade	unknown	unknown

Construction

The Quarry Access Road was constructed in 2015. Construction followed NCDOT standards.

The road profile is shown in figure 104, where the left half represents the IP section and the right side the CP section. The pavement has a longitudinal slope up to about 6 percent within the IP section and more than 7 percent in the CP section. The IP level is closer to the existing ground level, except in the proximity of an existing gas pipeline at Station 7+00, where the road is on fill. The CP section, on the other hand, is located mostly in cut, with the deepest cut surpassing 30 feet (9.1 m) in height. Figure 105 shows the subgrade and an aerial image of the site during subgrade preparation.



STA. 0+00 TO 8+00
USE INVERTED PAVEMENT DESIGN
1" SF9.5A WITH PG 64-22
1.5" S9.5B WITH PG 64-22
6" ABC (COMPACTED TO 102% MODIFIED PROCTOR)
8" CEMENT TREATED ABC (COMPACTED TO 102% MODIFIED PROCTOR)

STA. 8+00 TO 16+86.89
USE PROJECT PAVEMENT DESIGN
2.5" S9.5B
3.5" I19.0B
10" ABC

Approx. location of Existing 12" Natural Gas Pipeline (Line 372). Approx. 5' 4" deep.

-Developer/owner pays for cost of protecting, upgrading or relocating pipeline if required.
-Existing cover shall be maintained over the pipeline at all points including side ditches.
-Access crossing must be kept as close to a right angle as possible.
-A minimum of 60 inches of cover is required/maintained.
-Any cut or fill must have Piedmont approval.
-Any other Vehicle or equipment traffic encroaching Piedmont's easement must have written Piedmont Approval. Project owner shall ensure Piedmont's ROW is located onsite prior to construction.
-Piedmont supervision required while work is in progress. Three working days' notice is required prior to performing any work and contact "811" for utility locate.
-Any other future encroachments (sewer, water, fiber, etc.) must have written Piedmont's Approval.
-NO TYPE OF PERMANENT STRUCTURE IS ALLOWED IN PIEDMONT'S ROW.
-Crossing shall meet all Federal, State and local requirements with respect to safety and environment.
-No vibratory or sheep's foot equipment shall be used within Piedmont's Easement.

EXISTING GROUND BASED ON AERIAL DATA PROVIDED BY TUCK MAPPING SERVICES

EXISTING GROUND BASED ON A FIELD SURVEY PREPARED BY HELMS SURVEYING COMPANY

SEAL 16883

Figure 104. Illustration. Road profile; Quarry Access Road, North Carolina (Credit: Vulcan, provided by Kevin Vaughan).

Original Photo: © 2015 Google® (see Acknowledgements section).

Figure 105. Photo. Subgrade; Quarry Access Road, North Carolina (left photo from Vaughan 2017).

The CTB layer in the IP included 2 percent cement, achieving a seven-day compressive strength of 550 psi (3.8 MPa) in the laboratory. In the field, the achieved seven-day UCS was higher, 1400 psi (9.6 MPa), with shrinkage cracks appearing days after curing. A tack coat was applied to the CTB and allowed to cure for seven days (information provided by Shane Underwood). Figure 106 shows photos of the construction of the CTB layer.

The unbound base course layer for the IP and CP sections was compacted at the same time using the same compaction technique. It was noted that compacting the unbound granular base in the IP section was "bouncier" when using vibratory mode. This was thought to be due to the presences of the stiff cement treated layer which didn't absorb the vibrations like the soil subgrade in the CP section. The granular layer in the IP achieved a density of 103.4 percent of the modified Proctor, whereas in the CP, it achieved 99.8 percent. The South African slushing technique was not used (Vaughan 2017). Figure 107 shows photos of the construction of the UAB.

The AC layers were constructed following NCDOT standards, with the IP AC achieving better density on the aggregate base course, 103.4% in comparison to 99.8% on the CP. Figure 108 shows the AC surface.

Figure 106. Photo. Cement-treated base construction; Quarry Access Road, North Carolina (Vaughan 2017).

Figure 107. Photo. Unbound granular base construction; Quarry Access Road, North Carolina (Vaughan 2017).

Figure 108. Photo. AC; Quarry Access Road, North Carolina (Vaughan 2017).

Traffic Loading

The IP section was designed assuming an estimated traffic of 1.5 to 2 million ESALs over 20 years based on sales forecast, mainly heavy trucks (Vaughan 2017 and 2019). Accurate measurements of the truck volume on the roads do not exist CP (information provided by Shane Underwood).

Environmental Conditions

Table 28 includes average temperatures, rainfall, and snowfall for Charlotte, North Carolina. Charlotte is in an area considered wet non-freeze in accordance with the FHWA and LTPP classification (see figure 32).

Table 28. Charlotte, North Carolina, average temperatures, rainfall, and snowfall (source: NOAA).

Month	Temperature		Rainfall			Snowfall		
	Highs (°F)	Lows (°F)	Days	in	mm	Days	in	mm
Jan	51	31	8	3.6	91	1	1.8	46
Feb	56	34	7	3.3	84	0	1.6	41
Mar	64	41	8	4.2	107	0	0.8	20
Apr	73	49	6	3.2	81	0	0	0
May	80	57	7	3.7	94	0	0	0
Jun	86	66	7	3.6	91	0	0	0
Jul	90	69	7	3.9	99	0	0	0
Aug	88	68	7	4.0	102	0	0	0
Sep	82	62	6	3.8	97	0	0	0
Oct	72	50	5	3.3	84	0	0	0
Nov	63	40	6	3.2	81	0	0.1	3
Dec	54	34	7	3.5	89	0	0.5	13
Total			81	43.3	1100	1	4.8	122

Performance

A visit summary from April 2020 (by Shane Underwood and Kevin Vaughan) indicated that both sections were generally in good condition. The IP section presented some cracking, while the CP did not have any cracks. The cracks reported in the visit were (1) transverse cracking, which was believed to be related to shrinkage cracks in the CTB reflecting to the surface; (2) settlement cracking, believed to be related to the settlement of fill because the start and end of the crack coincided with the start and end of the fill section; and (3) longitudinal cracking, reported to be potentially related to loading or a subgrade issue. Figure 109 shows photos of the cracks.

A. Transverse crack. B. Settlement crack. C. Longitudinal crack.

Figure 109. Photo. Cracks observed during a 2020 site visit; Quarry Access Road, North Carolina (credit: Shane Underwood and Kevin Vaughan).

A subsequent visit performed in August 2021 by Shane Underwood and his team found that cracking had started appearing in the CP as well, as shown in figure 110 and detailed in table 29. The cracks in the IP section were mostly transverse cracks (probably reflected from the CTB), with the NB section presenting slightly more transverse cracks than the SB. The cracking in the CP was more diverse, with signs of transverse, longitudinal, fatigue, edge, and random cracking reported. Fatigue cracks from low to medium severity was reported in the SB CP section.

The PCR for the IP and CP remained relatively similar and constant from 2021 to 2022. The IP presented a PCR of 95 in both years, the CP SB section a PCR of 96.7 in 2021 and 96.2 in 2022, and the CP NB a PCR of 100 both years (Underwood et al. 2022).

A. Transverse crack (IP, Station 4+91). B. Longitudinal crack (IP, Station 5+50).

C. Edge cracking/deterioration (CP, Station 10+00). D. Fatigue cracking (CP, Station 14+50).

Figure 110. Photo. Cracks observed during a 2021 site visit; Quarry Access Road, North Carolina (provided by Shane Underwood).

Table 29. August 2021 pavement performance survey; Quarry Access Road, North Carolina (provided by Shane Underwood).

Section		Station	Distress	Extent	Severity	Note
Inverted	SB	0+35	Transverse crack	2 ft (0.6 m)	Low	Sealed
		2+12	Transverse crack	12 ft (3.7 m)	Low	Sealed
		2+68	Transverse crack	4 ft (1.2 m)	Low	Sealed
		2+97	Transverse crack	3 ft (0.9 m)	Low	Unsealed
		3+40	Transverse crack	4 ft (1.2 m)	Low	Partially sealed
		3+85	Transverse crack	1.5 ft (0.5 m)	Low	Unsealed
		4+91	Transverse crack	9 ft (2.7 m)	Low	Sealed
		5+50	Longitudinal crack	250 ft (76.2 m)	Low	Sealed
		6+62	Transverse crack	6 ft (1.8 m)	Low	Unsealed
		7+71	Transverse crack	2 ft (0.6 m)	Low	Unsealed
	NB	7+68	Transverse crack	6 ft (1.8 m)	Low	Unsealed
		7+00	Transverse crack	6 ft (1.8 m)	Low	Unsealed
		6+62	Shoulder deterioration	62 ft (18.9 m)		
		5+71	Transverse crack	8 ft (2.4 m)	Low	Unsealed
		5+41	Transverse crack	6 ft (1.8 m)	Low	Unsealed
		4+92	Transverse crack	6 ft (1.8 m)	Low	Unsealed
		3+87	Transverse crack	6 ft (1.8 m)	Low	Unsealed
		3+40	Transverse crack	8 ft (2.4 m)	Low	Sealed
		2+97	Transverse crack	6 ft (1.8 m)	Low	Unsealed
		2+60	Transverse crack	10 ft (3.0 m)	Low	Sealed
		2+12	Transverse crack	12 ft (3.6 m)	Low	Sealed
		1+47	Transverse crack	5 ft (1.5 m)	Low	Unsealed
		1+13	Transverse crack	6 ft (1.8 m)	Low	Unsealed
Conventional	SB	10+00	Edge crack	44 ft (13.4 m)	Low	Unsealed
		11+25	Shoulder deterioration	225 ft (68.6 m)		
		12+46	Transverse crack	6 ft (1.8 m)	Low	Unsealed
		14+25	Longitudinal crack	20 ft (6.1 m)	Low	Unsealed
		14+50	Fatigue cracking	36 ft^2 (3.3 m^2)	Low	Unsealed
		14+50	Fatigue cracking	36 ft^2 (3.3 m^2)	Medium	Unsealed
		15+00	Fatigue cracking	81 ft^2 (7.5 m^2)	Low	Unsealed
		16+00	Fatigue cracking	12 ft^2 (1.1 m^2)	Low	Unsealed
	NB	15+50	Shoulder deterioration	172 ft (52.4 m)		
		13+90	Transverse crack	1 ft (0.3 m)	Low	Unsealed
		11+47	Shoulder deterioration	97 ft (29.6 m)		
		9+87	Edge crack	2 ft (0.6 m)	Medium	Unsealed
		9+75	Random cracking	74 ft^2 (6.9 m^2)	Low	Unsealed
		8+32	Random cracking	36 ft^2 (3.3 m^2)	Low	Unsealed

FWD Backcalculated Moduli

Figure 111, figure 112, figure 113, figure 114, and figure 115 show, respectively, FWD maximum deflections, RoC, BLI, MLI, and LLI, as defined by Horak (2008) and summarized in table 11. It is noted that the geophone spacing in the FWD used differed slightly from the typical South African spacings, for which the indices shown were developed. The deflections assumed for D200, D300, D600, and D900 were the deflections at spacings from the load of, respectively, 8 inches (203 mm), 12 inches (305 mm), 24 inches (610 mm), and 36 inches (914 mm) rather than 7.9 inches (200 mm), 11.8 inches (300 mm), 23.6 inches (600 mm), and 35.4 inches (900 mm).

Horak's structural condition rating, represented by the colors green (sound), yellow (warning), and red (severe), have been included in the plots in figure 111 through figure 115. Limits for the granular base course pavement were considered for the IP section, and limits for the AC base pavement for the CP section (see table 11).

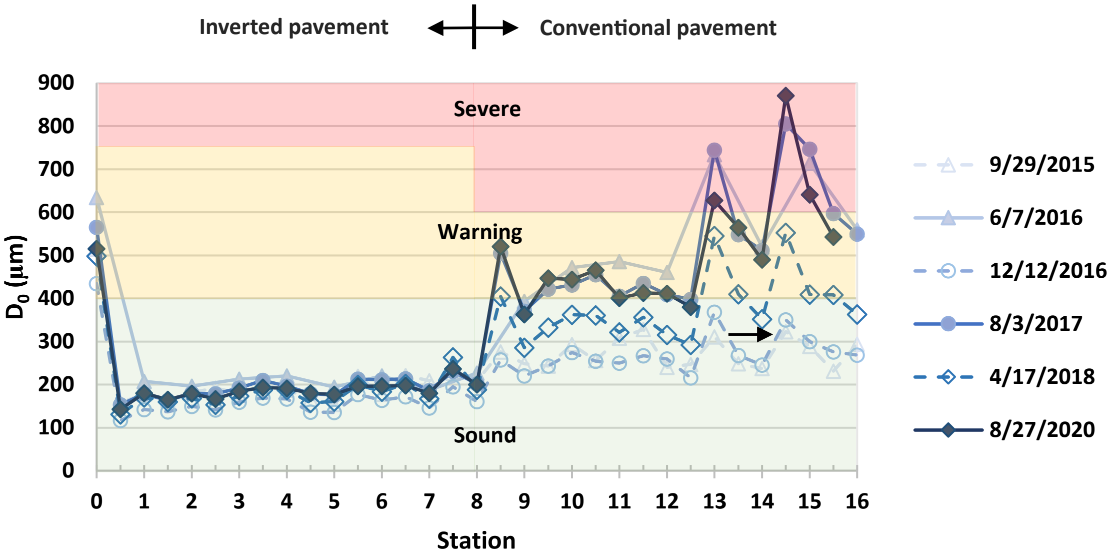


Figure 111. Graph. Maximum deflection: Quarry Access Road, North Carolina.

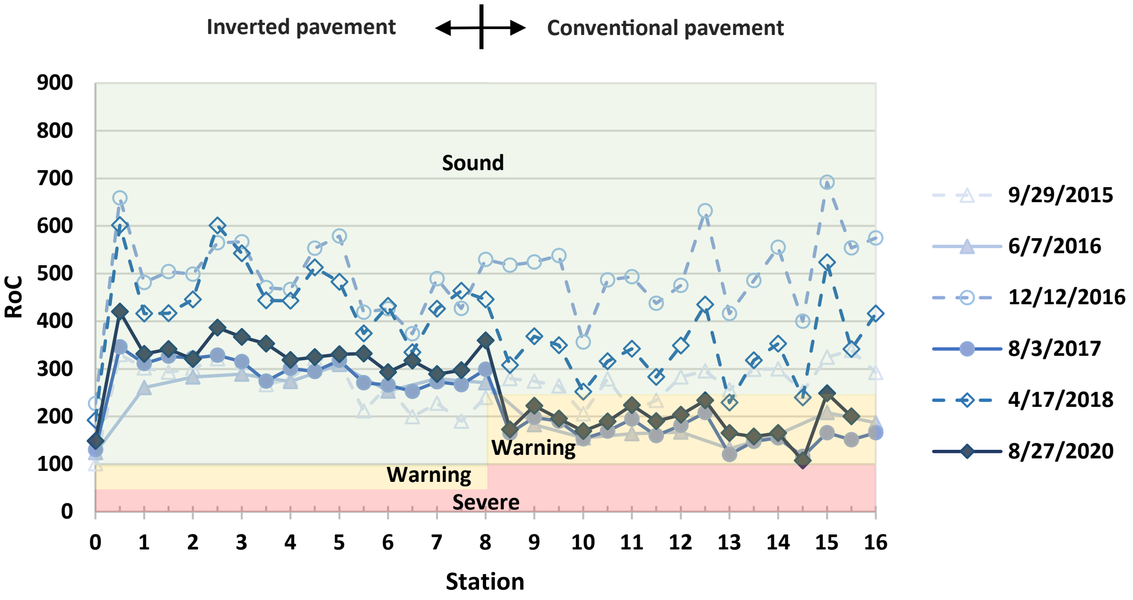


Figure 112. Graph. Radius of curvature; Quarry Access Road, North Carolina.

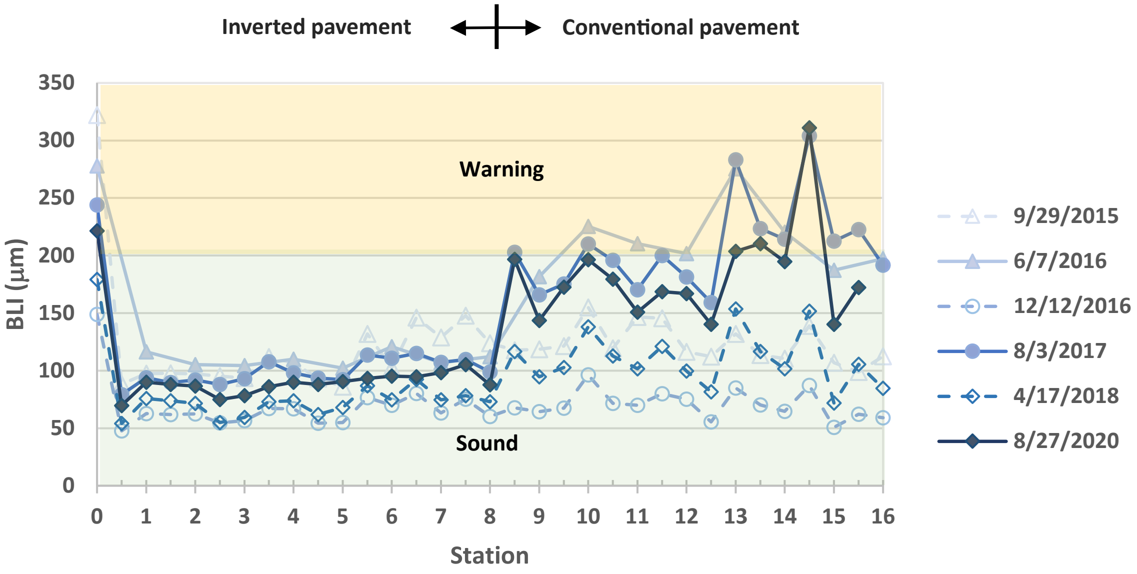


Figure 113. Graph. Base layer index: Quarry Access Road, North Carolina.

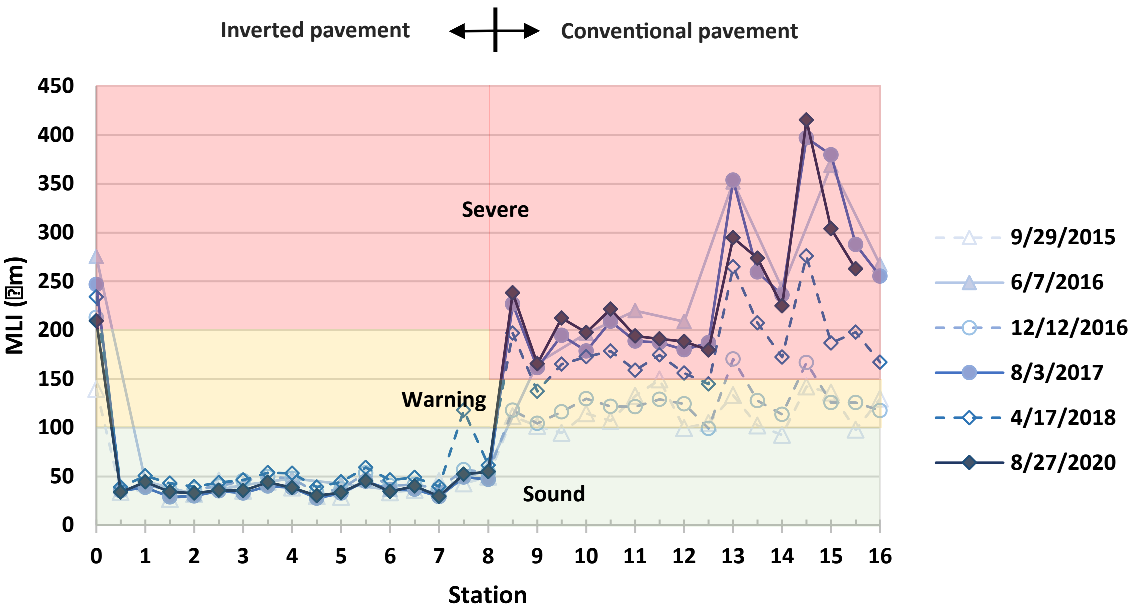


Figure 114. Graph. Middle layer index: Quarry Access Road, North Carolina.

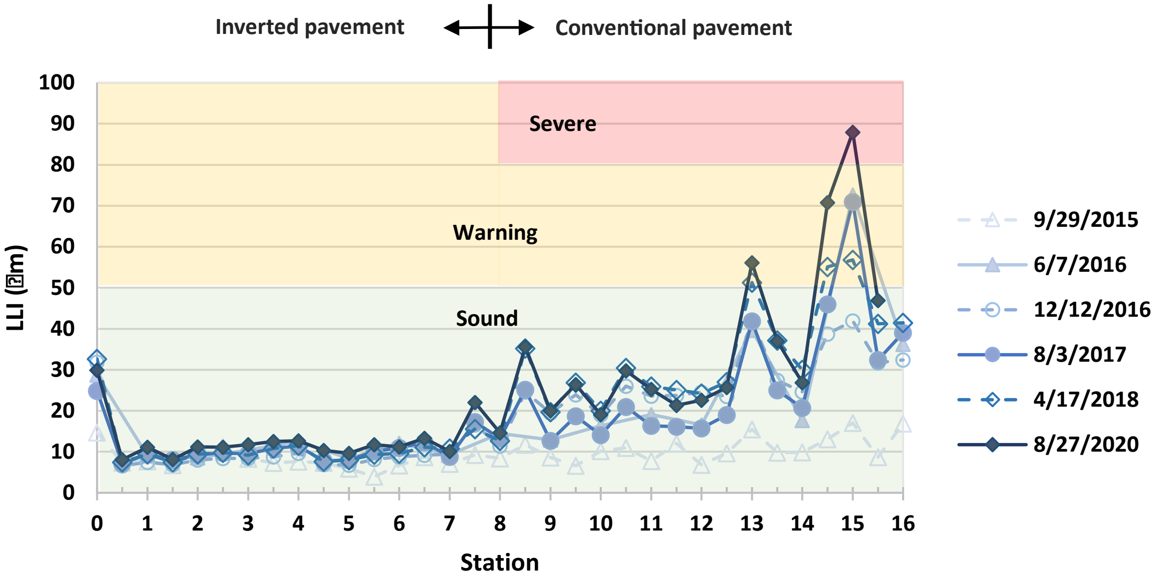


Figure 115. Graph. Lower layer index; Quarry Access Road, North Carolina.

The IP section (Station 0 to 8) generally fell within sound condition limits, except for at the very start of the section (Station 0), which may have been affected by the adjacent pavement. Maximum deflection, BLI, MLI, and LLI within the IP section remained relatively unchanged from year to year, whereas a more prominent variation was observed for RoC. The variation in RoC appeared to be more related to pavement temperature than to a progression in time because higher RoC values were observed in the colder months of December and April.

The CP section (Station 8 to 16) appeared in a worse condition compared to the IP section. Most of the maximum deflection fell within a sound condition in cold months. During the warmer months, most of the maximum deflection fell within warning (Station 8 to 13) to severe (Station 13 to 16) conditions, even though the maximum deflections measured during colder months indicated sound to warning conditions. The RoC for warmer months indicated a warning condition, whereas for colder months it indicated a sound condition. The BLI and LLI generally indicated a sound condition, with some measurements from Station 13 onward in warmer months indicating a warning condition. The most concerning index was the MLI, which was in severe condition for most of the measurements conducted in 2016, 2017, 2018, and 2020, which also include a measurement in April when the pavement temperature was relatively cold. According to Horak (2008), MLI correlates mostly with the subbase layer. In the case of the CP, this would be the unbound aggregate layer and/or the upper subgrade.

The data also indicate that except for the first FWD measurements, which were taken in September 2015 when the surface temperature was around 75 degrees Fahrenheit (24 degrees Celsius), the deflection measurements at the CP section appeared to be more sensitive to the time of year when the measurements were taken. This is believed to be due to the thicker AC layer in the CP, because the AC becomes less viscous at higher temperatures. The surface temperature during the measurements taken in December 2016 and in April 2017 were, respectively, 49 degrees Fahrenheit (9 degrees Celsius) and degrees Fahrenheit (14 degrees Celsius), whereas during the measurements taken in June 2016, August 2017, and August 2020 they were, respectively, 102 degrees Fahrenheit (39 degrees Celsius), 95 degrees Fahrenheit (35 degrees Celsius), and 83 to 93 degrees Fahrenheit (28 to 34 degrees Celsius). Apart from the first measurements in 2015, D_0 was generally greater at higher surface temperatures; the opposite trend was observed for RoC.

Figure 116 shows the surface modulus differential. The SMD values indicated a difference between the behavior of the subgrade within the IP and CP sections. Within the IP section, the SMD indicated a stress-stiffening behavior, whereas within the CP section, the SMD indicated a linear elastic or stress softening.

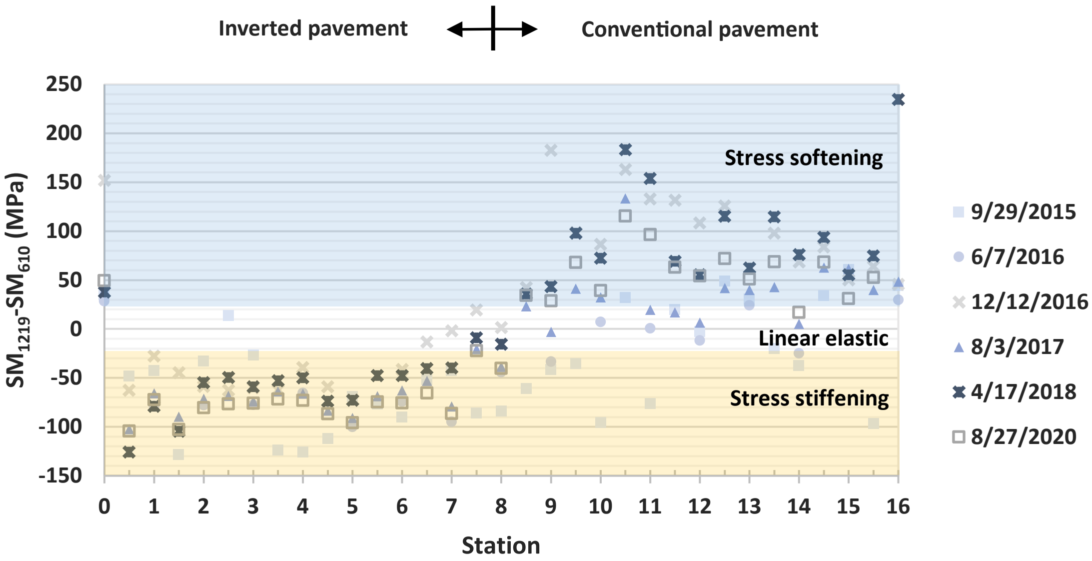


Figure 116. Graph. Surface modulus differential: Quarry Access Road, North Carolina.

FWD deflections were used to obtain backcalculated moduli values for the different pavement layers and subgrade using Dynatest ELMOD 6.0 software, similar to the analysis conducted for the New Mexico I-25 case study.

Material input parameters for the backcalculation analysis are summarized in table 30 and were chosen based on engineering judgment and available reasonable ranges in the literature (Luo and Prozzi 2008; Pierce et al. 2017; Stubstad, Jiang, and Lukanen 2006). The two layers of AC were modeled as one single layer because of limitations of the backcalculation method (i.e., backcalculation of thin layers can result in unrealistic values).

Table 30. Assumed layer mechanical properties for backcalculation; Quarry Access Road, North Carolina.

Pavement layer	Poisson's ratio	Seed modulus value	Allowable modulus range	
			Min.	Max.
AC layers	0.35	600 ksi (4,135 MPa)	50 ksi (345 MPa)	3,650 ksi (25,165 MPa)
Unbound granular layer	0.35	90 ksi (620 MPa)	15 ksi (105 MPa)	220 ksi (1,515 MPa)
CTB	0.25	300 ksi (2,070 MPa)	15 ksi (105 MPa)	1,160 ksi (8,000 MPa)
Subgrade	0.45	15 ksi (105 MPa)	5 ksi (35 MPa)	70 ksi (485 MPa)

Stress dependency was considered in the unbound granular pavement layers and the subgrade. The model used for stress-dependent layers is the same as presented for the New Mexico I-25 case study.

Figure 117 shows the average and standard deviation backcalculated moduli for each layer of the IP and CP over time (with outliers removed). Figure 118 shows the average and standard deviation backcalculated moduli of the CTB in the IP. Figure 119 shows the average and standard deviation backcalculated moduli for the lower moduli layers: the unbound granular layer (base course) and the subgrade. Appendix B includes plots showing the variation in individual backcalculated moduli across the entire section (per milepost) for each year of measurement. For the layers assumed to have stress-dependent behavior, the backcalculated values indicate the moduli at the top of the layer.

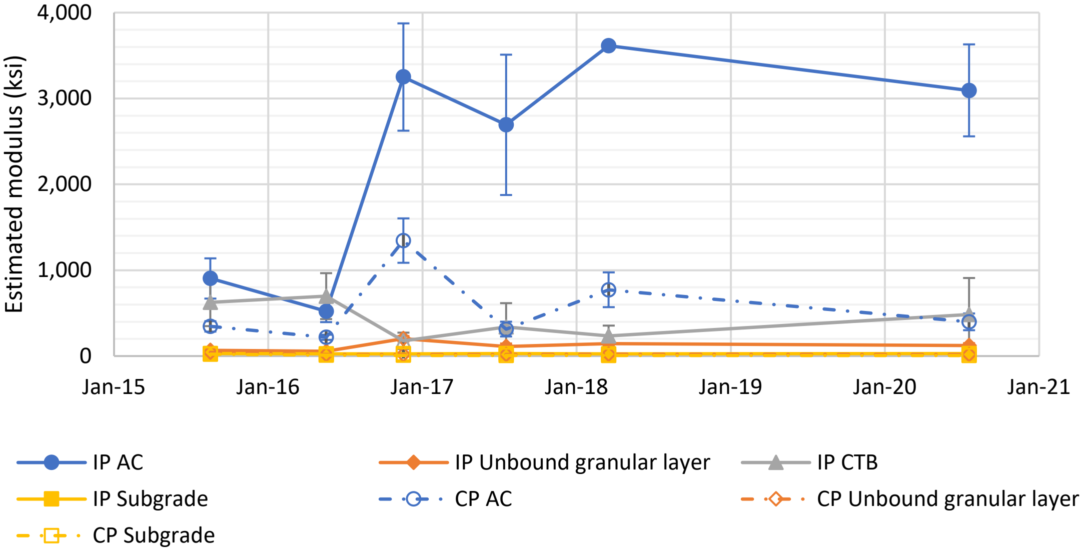


Figure 117. Graph. Average and standard deviation backcalculated moduli for each layer; Quarry Access Road, North Carolina.

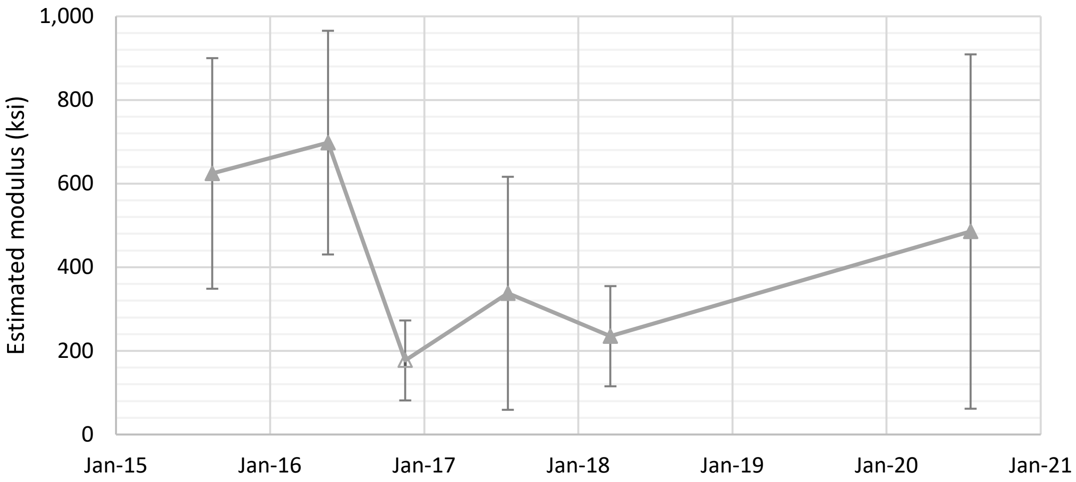


Figure 118. Graph. Average and standard deviation backcalculated layer moduli of the inverted pavement cement-treated subbase; Quarry Access Road, North Carolina.

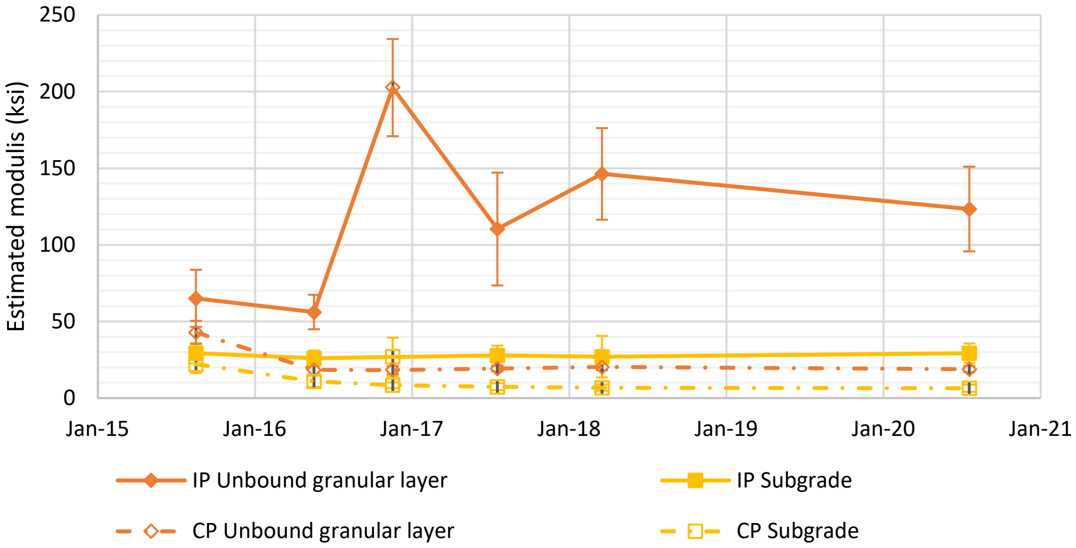


Figure 119. Graph. Average and standard deviation backcalculated layer moduli for the unbound granular layer and subgrade; Quarry Access Road, North Carolina.

The AC backcalculated moduli were higher in the IP section, with the modulus generally increasing with time. The higher modulus in the IP section was confirmed by geophysical measurements conducted by North Carolina State University. Provided data showed that AC modulus of the IP was 2,506 ksi (17,278 MPa), whereas the modulus reported for the AC in the CP was 1,362 ksi (9,391 MPa). The results from mechanical tests on lab cores were somewhat different. These results suggested considerable lateral variation in the moduli and also large differences between the CP surface layer (a 9.5 mm NMAS mixture) and the bottom asphalt layer in the CP section (a 19.0 mm NMAS mixture). The surface layer modulus from cores taken in the center of the lane were higher in the CP than in the IP, but the moduli from cores taken in the other wheel path were higher in the case of the IP (information provided by Shane Underwood).

CTB average backcalculated moduli values in 2015 and 2016 were between 700 and 800 ksi (4,826 and 5,516 MPa), dropping to values between 200 and 400 ksi (1,379 and 2,758 MPa) in 2016, 2017, and 2018 and then increasing to an average backcalculated value of close to 500 ksi (3,447 MPa) in 2020. Both the AC and CTB layers exhibited relatively variable results for backcalculated moduli. This may be partly due to the presence of cracks in those layers at some of the testing locations.

The backcalculated moduli of the unbound granular layer were higher for the IP, as expected. Generally, the modulus of this layer increased with time in the IP, with the estimation for the measurements taken in winter resulting in the higher values. The unbound granular layer in the CP may not have experienced the same increase in moduli because the layer is further from the traffic loading, and therefore, the stresses experienced in this layer are smaller compared to the stresses in the IP unbound granular layer.

In December 2016, the backcalculated moduli of the IP unbound granular layer, for most of the testing locations, reached the maximum value allowed in the backcalculation procedure. This could be an indication that part of the pavement may have been frozen at the time of testing. Testing was conducted on December 12, 2016, at 7:31 am. According to historical data[4] for the Charlotte Douglas Airport Station, the low temperatures in the previous two days were 18 degrees Fahrenheit (-7.8 degrees Celsius) and 22 degrees Fahrenheit (-5.6 degrees Celsius).

The backcalculated subgrade moduli were higher in the IP section, where average values ranged between 25 and 30 ksi (172 and 207 MPa). In the CP section, the average value in 2015 was 22 ksi (152 MPa), reduced to values between 5 and 10 ksi (34 and 69 MPa) from 2016 through 2020. The difference in moduli is believed to be related to the fact that the IP level was relatively close to the natural ground levels, whereas the CP section is in a section of relatively deep cut.

In the CP section, the backcalculated moduli of the unbound granular layer and the subgrade both reduced after the first year. Considering that this section is in a cut, it is possible that moisture accumulated in those layers and caused a reduction in moduli.

Figure 120 shows the variation of average and standard deviation backcalculated C and n coefficients stress dependent materials was modeled: unbound granular (base course) and subgrade. In the IP, n-values for the unbound granular layer started negative and became positive, whereas in the CP, n-values were constantly positive.

The n-values for the subgrade in the IP were close to 0, indicating limited variation in modulus with stress. For the CP, the subgrade n-values were negative and lower, indicating that the subgrade presents a stress softening behavior. Figure 122 shows the variation of vertical resilient moduli (M_{RV}) with stresses for the unbound granular layer based on the average backcalculated C- and n-values.

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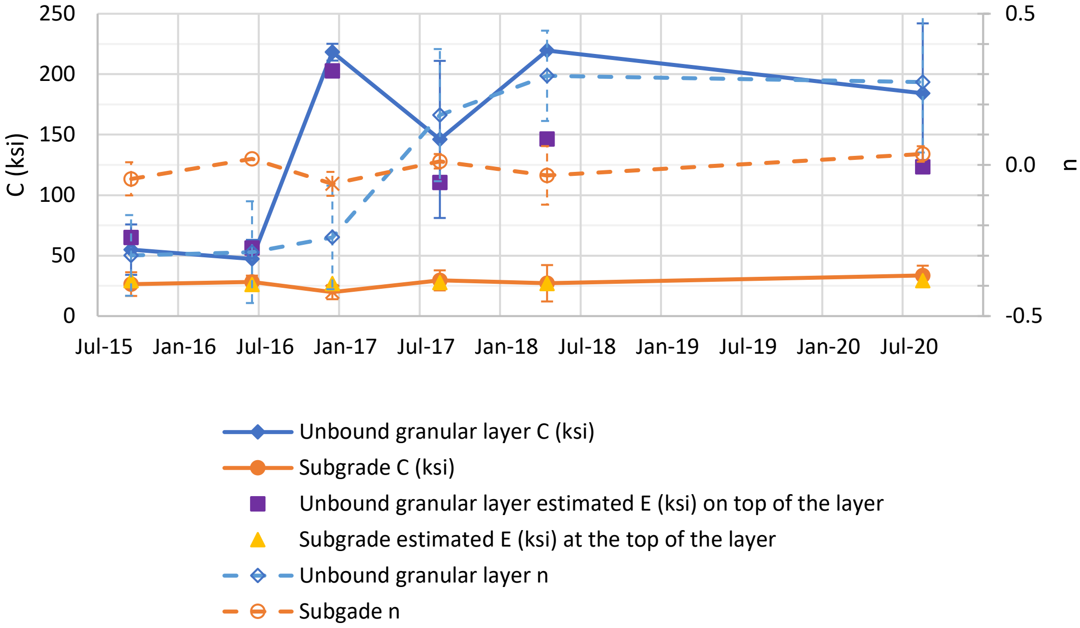
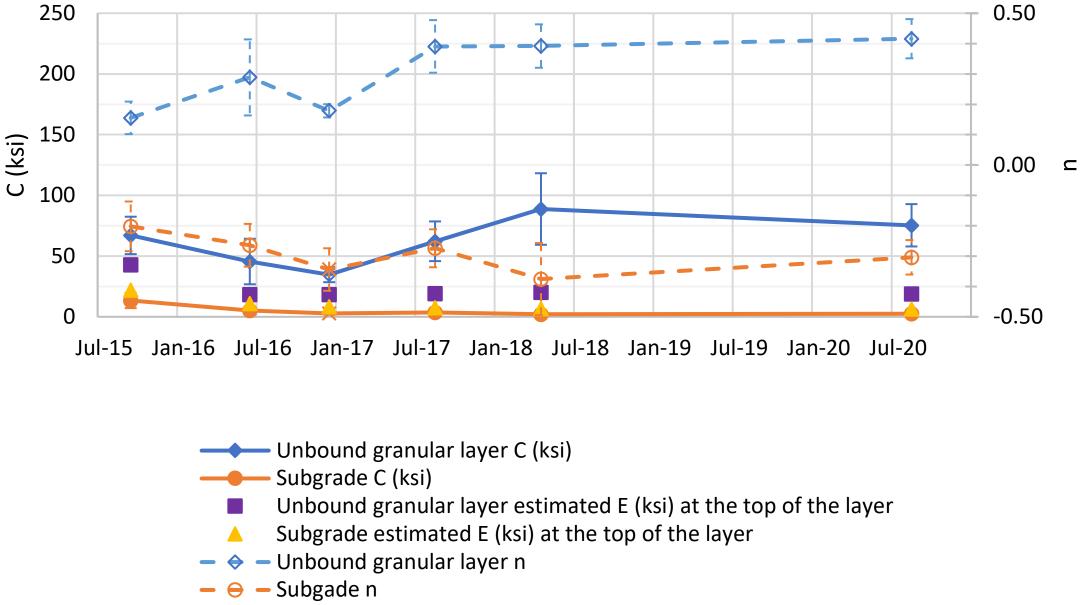
[4] https://www.ncdc.noaa.gov/



A. Inverted pavement.



B. Conventional pavement.

Figure 120. Graph. Backcalculated C and n for the unbound granular layer and subgrade; Quarry Access Road, North Carolina.

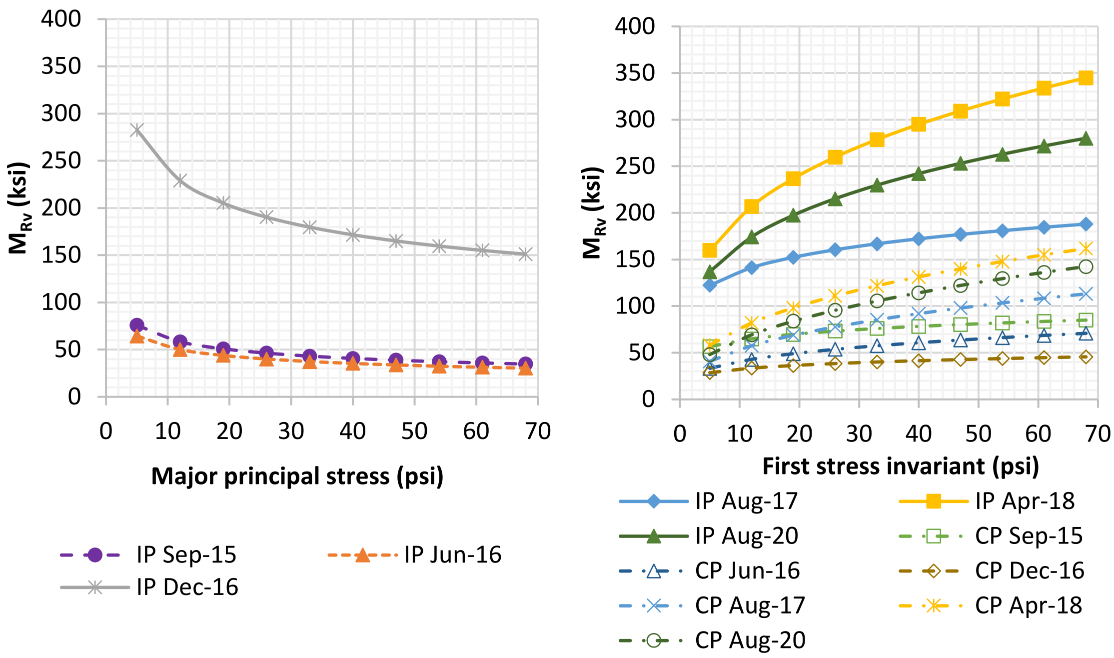


Figure 121. Graph. Backcalculated moduli for the unbound granular base; Quarry Access Road, North Carolina.

Cost Assessment

The IP cost was \$35.92/yd^2 (\$42.95/m^2), while the CP cost \$40.51/yd^2 (\$48.45/m^2) (12.8 percent more expensive; Vaughan 2017 & 2019). Normalized by the previously reported SN of each section (SN of 3.78 for the IP and 4.04 for the CP based on Vaughan 2017), the cost of the IP was \$9.50/ yd^2/SN (\$11.36/m^2/SN), and the cost of the CP was \$10.03/yd^2/SN (\$11.99/m^2/SN) (5.5 percent more expensive).

The backcalculated pavement layer module indicates that the overall strength of the IP is significantly higher than the overall strength of the CP. The summation of the product of thickness and average backcalculated moduli (based on September 2015 FWD data) for the IP is about three times higher than that of the CP. Considering a ratio of SN for the inverted pavement to SN for the conventional pavement of three, the cost of the CP per square yard per SN would be more than three times higher than the cost of the IP.

Environmental Sustainability Assessment

A comparative environmental assessment analysis of the IP and CP was conducted using the FHWA LCA Pave tool. The analysis considered the materials stage, transportation distances, and initial construction. Records indicated that both pavement sections were in good condition as of April 2020, with both sections presenting mostly low-severity cracking in 2021. Therefore, there was no indication as to when and how often each section may require maintenance, rehabilitation, or reconstruction activities in the future. For this reason, the analysis took into consideration materials, transportation, and construction activities related only to the initial pavement construction (year 0) rather than the entire life-cycle of the pavement.

In the absence of detailed information on material origins, transportation distances were assumed to be 50 mi (80 km) for all materials. Transportation of construction equipment to the construction site was omitted from the analysis. Earthworks prior to subgrade preparation and other road construction features (e.g., drainage, signage, and lighting) were not included in the analysis. Water was assumed available at the site. Detailed assumptions are included in appendix C.1.

The results of the LCA analysis, normalized by lane-mile, are included in table 31. Figure 122 shows the impact indicators normalized by lane-mile and by the highest value between the two pavement cross sections considered (IP and CP).

Table 31. Environmental impacts per lane-mile; Quarry Access Road, North Carolina.

Impact indicator (i)	**Inverted Pavement**	**Conventional Pavement**
Use of renewable energy primary energy, excluding renewable primary resources used as raw materials (MJ) (ii)	28,704	35,762
Use of renewable primary energy resources used as raw materials (MJ) (ii)	29.2	20.76
Total use of renewable primary resources (MJ) (ii)	28,734	35,784
Use of nonrenewable primary energy, excluding nonrenewable primary energy resources used as materials (MJ)	2,026,514	2,984,067
Use of nonrenewable primary energy used as raw materials (MJ) (ii)	2,260,315	4,868,697
Total use of nonrenewable primary energy resources (MJ) (ii)	4,286,829	7,852,764
Recycled material usage (short-tons)	13.56	0.7025
Disposed nonhazardous waste (short-tons) (ii)	119	254
Disposed hazardous waste (short-tons) (ii)	8.44	18.17
Net use of fresh water (m^3) (ii)	719	344
Acidification (kg SO_2 eq)	558	600
Ecotoxicity (CTUeco/kg) (ii)	10,150	21,594
Eutrophication (kg N eq)	111	73.59
Fossil fuel depletion (MJ surplus) (ii)	293,538	631,902
GWP (kg CO_2 eq)	155,629	174,454
Human health, cancer (CTU/kg) (ii)	0.0001	0.0002
Human health, noncancer (CTU/kg) (ii)	0.0061	0.013
Human health effects, particulates (kg $PM_{2.5}$ eq) (ii)	25.19	33.96
Ozone depletion (kg CFC-11 eq)	0.0018	0.0007
Smog formation (kg O_3 eq)	14,654	16,160

Notes:

(i) AC mixing was assumed as the average of the production stage (A3) from NAPA EPDs for four plants in North Carolina (in Burlington, Greensboro, Pineville, and Raleigh). The transportation distance of the AC mix from the plant to the construction site was assumed to be 20 mi (32 km).

(ii) The results presented are LCA Pave outputs, which are calculated based on the available information. Calculations of some impact categories can be incomplete due to missing data.

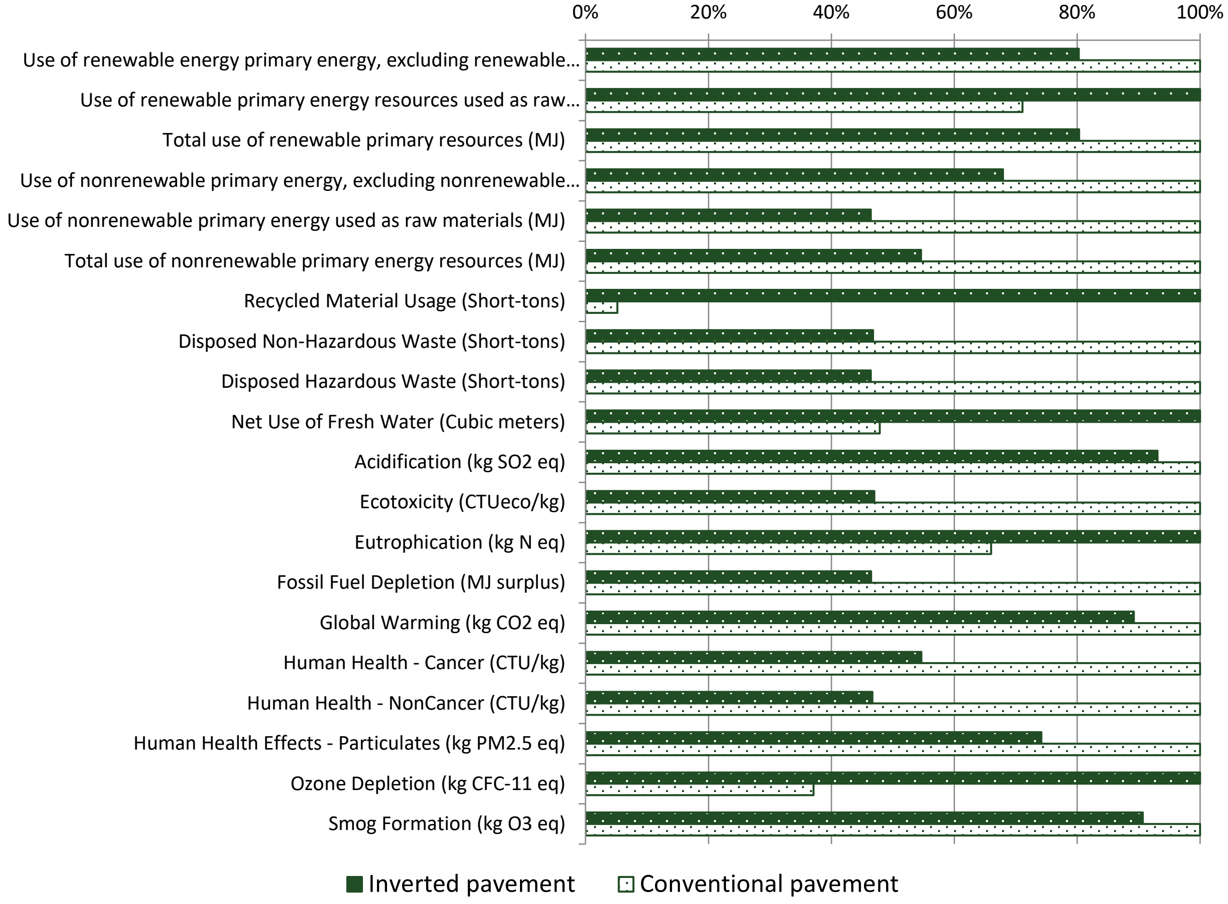


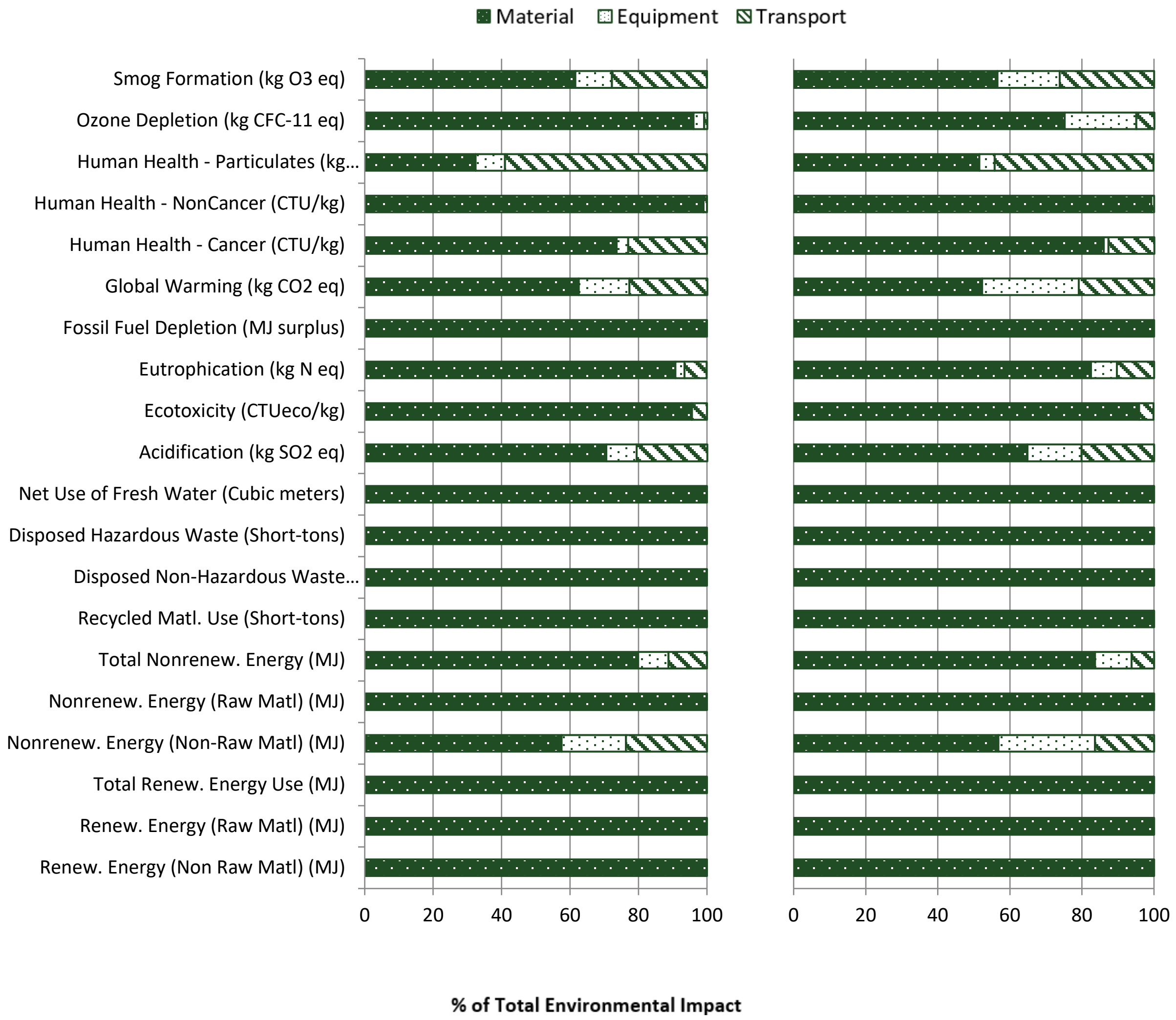
Figure 122. Graph. Comparison of normalized impact indicator values for each pavement section; Quarry Access Road, North Carolina.

The differences in the environmental impact results mainly reflect the use of a cement-stabilized layer in the IP section, which was not present in the CP, versus the use of a thicker AC layer in the CP section.

The CP generally represented higher environmental impacts, except for categories where cement plays a more important role, such as ozone depletion, net use of fresh water, and eutrophication.

In terms of GWP, the impact of the IP was 89 percent that of CP. In terms of total use of nonrenewable energy, the IP section represented only 55 percent of the energy use of the CP.

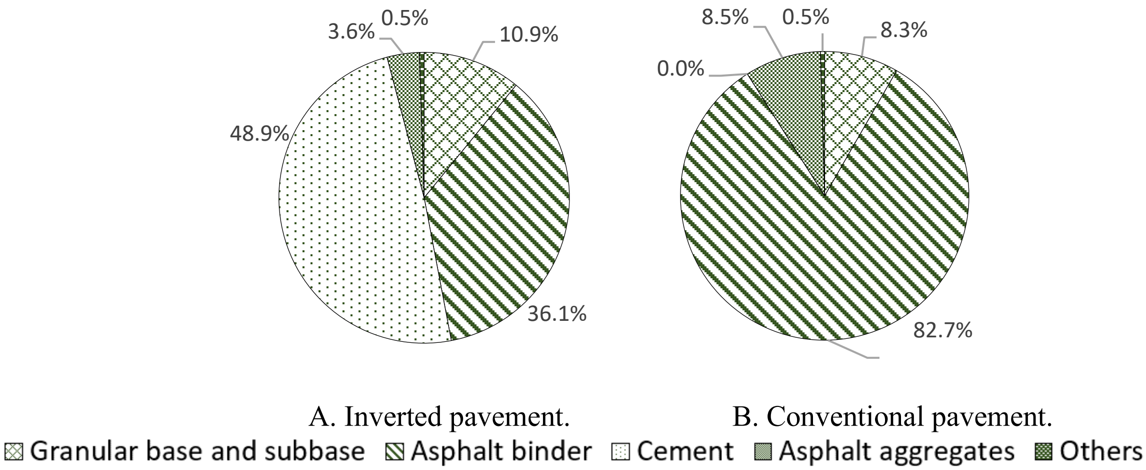
Figure 123 shows the distribution of each impact indicator by process type. Most of the GWP originated from the materials phase, followed by transportation. It was noted, however, that the total transportation contribution was based on an assumed hauling distance rather than actual transportation distances.



A. Inverted pavement. B. Conventional pavement.

Figure 123. Graph. Comparison of impact indicators by process type for each pavement section; Quarry Access Road, North Carolina.

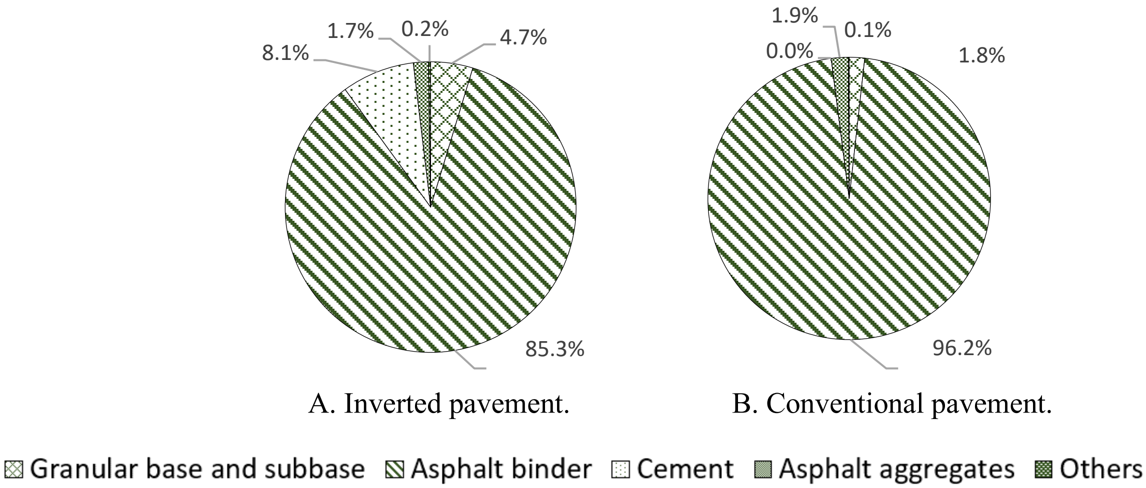
Figure 124 shows the contribution of each material to the total GWP related to the materials stage (excluding transportation and construction). For the IP, the material that impacted GWP the most was cement (48.9 percent), followed by asphalt binder (36.1 percent). The CP did not incorporate a cement-treated layer but has a thicker AC layer. The production of asphalt binder represented 82.7 percent of the total GWP.



A. Inverted pavement. B. Conventional pavement.

Figure 124. Graph. Contribution of each material to GWP (kg CO_2 eq) for each pavement section; Quarry Access Road, North Carolina.

Figure 125 shows the contribution of each material to the total use of primary energy (renewable plus nonrenewable) for each pavement section. Asphalt binder is responsible for most of the energy consumption.



A. Inverted pavement. B. Conventional pavement.

Figure 125. Graph. Contribution of each material to total use of primary energy resources for each pavement section; Quarry Access Road, North Carolina.

Summary and Remarks

The IP section was constructed generally near or above the previously existing ground level, whereas the CP was constructed mostly in cut. The IP section at the Quarry Access Road in North Carolina consists of 3.5 inches (90 mm) of AC, 6.0 inches (150 mm) of an unbound granular layer, and 8 inches (200 mm) of CTB. The control section consists of 6.0 inches (150 mm) of AC over 10.0 inches (250 mm) of an unbound granular layer. Both sections were constructed in 2015. The South African slushing technique was not used.

In April 2020, the pavement was reported to be generally in good condition. The IP section presented some cracks, while the CP did not have any cracks. At a later visit, performed in August 2021, cracks had begun to appear in the (information provided by Shane Underwood).

Analysis of FWD data indicated that the IP subgrade behaved more as a stress-hardening material, whereas the subgrade in the CP section behaved more like a stress-softening (cohesive) material. Backcalculation analysis indicated that the IP subgrade modulus was greater than that of the CP. In addition, FWD analysis suggested that the IP structural condition, based on MLI, is better than that of the CP. The MLI for the first is classified as sound, whereas for the later as severe. The MLI is said to correlate mainly with subbase layer.

Construction of the IP was 11.1 percent cheaper than the CP. In addition, the construction of the IP had generally less environmental impacts than construction of the CP (11 percent less GWP and 45 percent less total use of nonrenewable primary energy resources).

Additional details on this case study, including traffic speed deflectometer and impact resonance testing data analysis, can be found in Underwood et al. (2022).

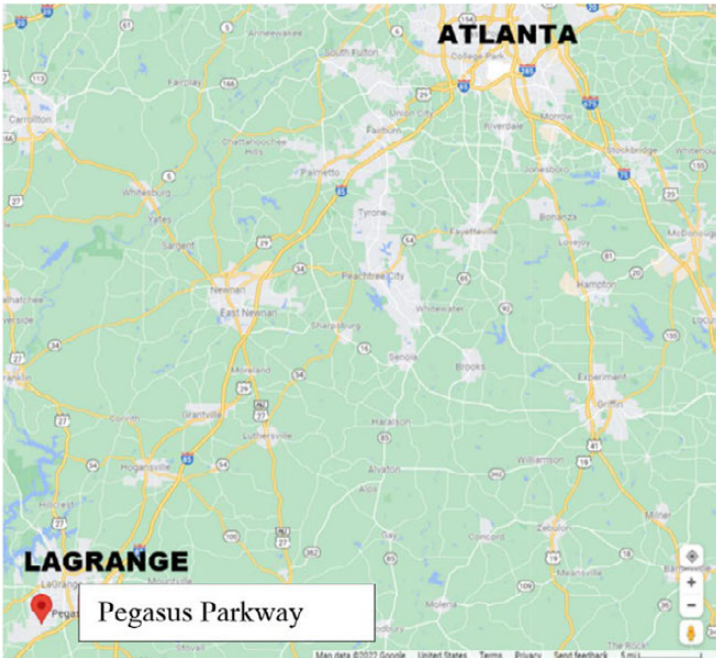
LAGRANGE BYPASS, PEGASUS PARKWAY, GEORGIA

Location

The LaGrange Bypass Road case study consists of a 3,400-feet (1,036 m) long two-lane section on Pegasus Parkway off Whitesville Road, Exit 13 on I-85 in LaGrange, Troup County, Georgia. The road is located near the LaGrange Callaway Airport. The test section extends from Station 280+00 to Station 314+00. The IP section was constructed between Stations 280+00 and 314+34, between two PCC pavement sections. The locations of Pegasus Parkway and of the test sections are indicated in figure 126.

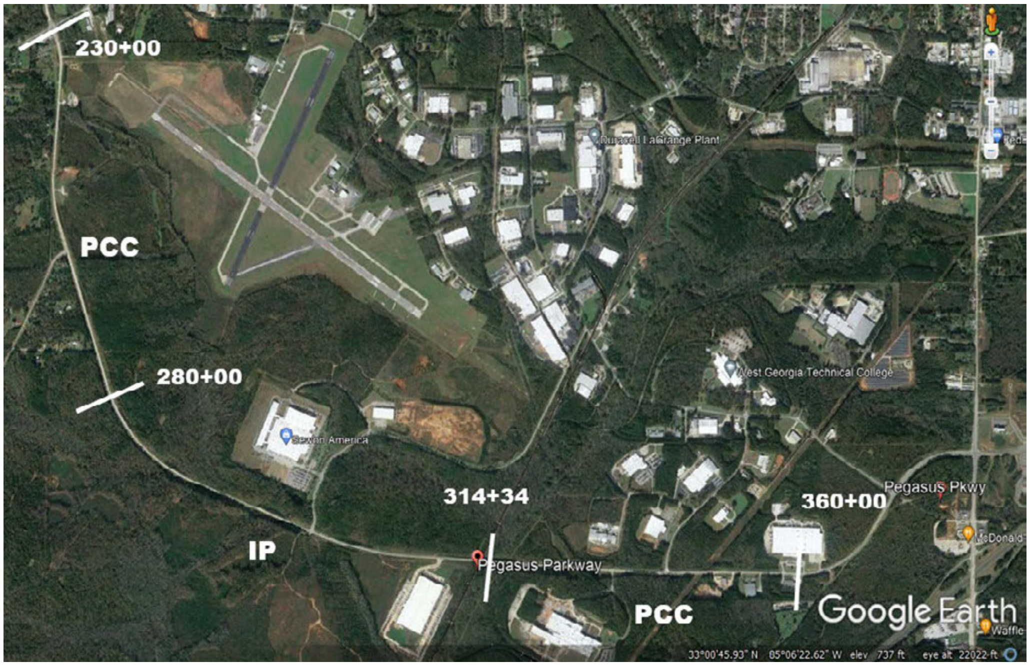
Pavement Configuration

Pavement cross sections are summarized in table 32.



Original Photo: © 2015 Google® (see Acknowledgements section).

A. Site location.



Original Photo: © 2015 Google® (see Acknowledgements section).

B. Location of test sections.

Figure 126. Illustration. LaGrange Bypass Road, Georgia.

Table 32. Pavement cross section; LaGrange Bypass Road, Georgia.

Pavement layer	Thickness (in)	
	Inverted pavement	Portland cement concrete pavement
AC: 0.5 in (12.5 mm) NMAS Superpave	1.5 (40 mm)	—
AC: 0.75 in (19 mm) NMAS Superpave	2.0 (50 mm)	—
Portland cement concrete	—	9.5 (240 mm)
UAB	6 (“special”) (150 mm)	10 (250 mm)
CTB (4% cement by weight, compacted to 90% of maximum dry density modified Proctor, min. UCS 450 psi [3.1 MPa])	10 (250 mm)	—
Stabilized subgrade	6 (150 mm)	6 (150 mm)
In situ subgrade	Residual soils from the Georgia Piedmont geologic formation	Residual soils from the Georgia Piedmont geologic formation

Construction and Maintenance

Construction of this section started in January 2008 and was completed in April 2009 (Cortes and Santamarina, n.d.).

The minimum required CTB strength was 300 psi (2.1 MPa). CTB cores taken after seven days of curing presented UCS varying from 446 psi (3.1 MPa) to 723 psi (5 MPa) (Lewis et al. 2012).

Extensive apparent gravity testing of the granular unbound base course layer was performed prior to construction to ensure appropriate compaction levels. Variables tested included the use of the South African slushing technique, water temperature, soaking period, and sample weight. The difference between the apparent gravity with and without the South African slushing technique applied was minimal (apparent gravity was 166.9 pcf [2,673 kg/m^3] using the slushing technique and 165.4 pcf [2,649 kg/m^3] without) (Lewis et al. 2012). The UAB was constructed using standard construction techniques at 100 to 120 percent OMC. The UAB could be compacted to achieve more than 86 percent of the apparent solid density as required by GDOT using conventional methods.

Traffic Loading

Initial one-way annual average traffic of LaGrange Bypass Road was 7,000 vehicles per day, projected to grow to 11,700 by the end of its service life. Truck traffic was estimated at 7 percent, consisting of 3 percent multi-unit and 4 percent single-unit trucks (Cortes and Santamarina, n.d.). Donovan (2022) reported an approximated calculated traffic of 1.3 million ESALs.

Environmental Conditions

Table 33 includes average temperatures, rainfall, and snowfall for LaGrange, Georgia. LaGrange is in an area considered wet non-freeze in accordance with the FHWA and LTPP classification (see figure 32).

Table 33. LaGrange, Georgia, average temperatures, rainfall, and snowfall (source: NOAA).

Month	**Temperature**		**Rainfall**			**Snowfall**		
	Highs (°F)	**Lows (°F)**	**Days**	**in**	**mm**	**Days**	**in**	**mm**
Jan	55	33	9	5.0	127	0	0.3	8
Feb	60	36	7	4.8	122	0	0.1	3
Mar	69	42	8	6.2	157	0	0.1	3
Apr	76	48	6	4.2	107	0	0	0
May	83	57	7	3.5	89	0	0	0
Jun	88	65	7	3.9	99	0	0	0
Jul	91	69	8	5.0	127	0	0	0
Aug	89	68	7	3.7	94	0	0	0
Sep	84	62	6	3.4	86	0	0	0
Oct	75	50	5	3.1	79	0	0	0
Nov	67	41	6	3.8	97	0	0	0
Dec	58	35	7	4.8	122	0	0	0
Total			83	51.4	1306	0	0.5	13

Findings of Earlier Studies

Cortes (2010) and Cortes and Santamarina (2013) conducted pre- and post-compaction sieve analyses of aggregate samples collected from the UAB and reported inconclusive data about the extent of particle crushing. By digging trenches through the AC layers to expose the UAB and subsequently processing the grain skeleton photographs through digital image analysis, they found evidence of compaction-induced anisotropy in the UAB as the coarse aggregate particles were found to preferentially align their major axis parallel to the horizontal plane. Through FE analyses of the test sections, they observed that both vertical and radial stresses in the UAB layer remained in compression throughout the layer depth.

Cortes and Santamarina (2013) developed new field test methods to characterize the stress-dependent stiffness of UAB layers in these IP test sections. Cortes (2010) and Cortes, Shin, and Santamarina (2012) analyzed the aforementioned IPs using a nonlinear and anisotropic base course. The study concluded that accurate characterization of unbound aggregate layers plays an important role in the prediction of IP responses, and that IPs can provide enhanced structural capacity both in rutting and fatigue compared to other typical road types considered.

Lewis et al. (2012) reported that the test sections showed excellent structural capacities and long remaining lives based on results from FWD testing immediately after construction. The as-built IP structure of the LaGrange Bypass exhibited pronounced stiffness profile contrasts among successive layers: 4,351 ksi (30,000 MPa) at the AC, 72 ksi (500 MPa) for the UAB (unloaded), 3,190 ksi (22,000 MPa) for the CTB, and 22 ksi (150 MPa) for the compacted subgrade. This unconventional high-low-high-low stiffness sequence was reported as a salient characteristic of IP systems. They reported that IP sections could exceed the structural capacities of conventional flexible pavement designs, while at the same time bringing savings of up to 40 percent of the initial construction costs.

Recent research at Georgia Tech developed a suite of in situ shear-wave velocity measurement devices to assess the in-situ stress-dependent small-strain stiffness of UAB under controlled load comparing wave velocity in different pavement sections (Papadopoulos 2014; Papadopoulos, Cortes, and Santamarina 2015). Two testing methodologies (cross-hole and up-hole) were developed. The methodology was applied to LaGrange Bypass project using two field measurement configurations to determine the stress-dependent stiffness and anisotropy of as-built UABs in pavements.

Variations in the vertical and horizontal P-wave velocities under different normal stresses indicated definite trends of anisotropy in small-strain stiffness properties. Accordingly, it was possible to measure in situ granular base layer stiffness and detect stress sensitivity and anisotropy compared to the techniques used for laboratory-compacted specimens. Results suggested that the effect of suction on the stiffness of coarse-grained granular bases was insignificant due to non-dry base conditions.

The follow-up work by Papadopoulos and Santamarina (2016) considered the field-measured trends of vertical and horizontal stiffnesses and developed nonlinear anisotropic modulus characterization models to analyze IPs with thin AC surface courses. Three-dimensional FE simulations were conducted to assess the mechanical performance of different inverted base pavement structures. The AC layer was assumed as a membrane (Papadopoulos and Santamarina 2016), which is unrealistic for AC pavement modeling (Hernandez, Gamez, and Al-Qadi 2016).

More recently, Sha et al. (2020) investigated optimal structural thickness combinations for IP structures through three-dimensional FE analyses and concluded that 4 inches (100 mm) aggregate base thickness was enough to prevent the CTB crack propagating to the surface. Further, a 2-inches-thick (50 mm) AC and a 4-inches-thick (100 mm) UAB combination was suggested to provide low critical AC fatigue strains similar to a thicker 5.9 inches (150 mm) AC and a thin 3.9 inches (100 mm) base if the stiffnesses of the AC and base could be maintained at 1,040 ksi (7,175 MPa) and 52 ksi (358 MPa), respectively, or higher. A major limitation of the analysis was considering the AC as elastic material and independent of temperature and loading rate, which are crucial to predict the response and performance of AC materials (Gamez et al. 2018).

Performance

Figure 127 shows the GDOT Pavement Condition Evaluation System (PACES) rating of the IP, based on data collected in 2016 and 2022. The PACES rating considers rutting, load cracking, block/transverse cracking, reflection cracking, raveling, edge distress, bleeding and flushing, corrugation and pushing, loss of pavement section, and patches and potholes. The rating varies from 0 to 100, with 100 representing a pavement with no visible distresses and 70 being a trigger indicating the need for pavement resurfacing (Frost 2017).

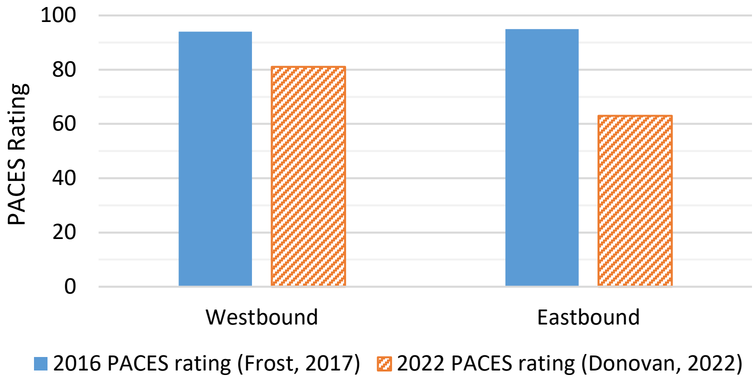


Figure 127. Graph. 2016 and 2022 Pavement Condition Evaluation System ratings; LaGrange Bypass Road, Georgia (data from Frost 2017 and Donovan 2022).

In 2016, Frost (2017) reported that the IP section was performing well, with an average PACES rating of 94.7 after seven years of service. The pavement presented low-severity load cracking and block/transverse cracking, and moderate rutting. The westbound (WB) lane was reported to exhibit more block/transverse cracking and more rutting than the eastbound (EB) lane.

In 2022, however, a more significant reduction in the PACES rating of the EB lane was observed. The PACES rating for the WB was 81 and was 63 for the EB. The reasons for the difference between the EB and WB performances are unknown. The EB developed more rutting in the LWP, more block cracking, and more load cracking than the WB. The distresses observed were low-severity load cracking, low-severity block cracking, and low rutting, with the EB lane showing more widespread and severe load cracking (Donovan 2022, Frost 2023).

The 2009 average FWD maximum deflection reported by Lewis et al. (2012) was 8.5 mils (216 µm) compared to 7.2 mils (183 µm) reported by Donovan (2022) in 2022, indicating that the overall stiffness of the pavement did not significantly change from 2009 to 2022.

Site Visit

In May 2022, a site visit to the LaGrange Bypass Road was held. In addition to visual observations of the site, the performance data presented above was collected.

Figure 128 shows photos taken from the EB lane side, and figure 129 shows photos taken from the WB lane side.

Figure 128. Photo. Inverted pavement eastbound lane in May 2022; LaGrange Bypass Road, Georgia.

Figure 129. Photo. Inverted pavement westbound lane also showing FWD test setup in May 2022; LaGrange Bypass Road, Georgia.

Cost Assessment

Buchanan (2010a) compared the LCCA for the LaGrange Bypass IP sections with a rigid pavement designed to carry the same traffic level. The rigid pavement comprised a 9.5-inches-thick (240 mm) PCC slab over a 10-inches-thick (250 mm) UAB over a 6-inches-thick (150 mm) prepared subgrade with a minimum soil support value of 5. Table 34 lists the comparative cost estimates over a 30-year life-cycle as presented by Buchanan (2010a). As can be seen from the table, the IP section resulted in net savings of $139,000/lane-mile ($86,875/lane-km), which is 25 percent over a 30-year period.

Table 34. Life-cycle cost comparison for LaGrange Bypass inverted pavement section with a rigid pavement section designed to sustain the same traffic level over a 30-year period (Buchanan 2010a).

Event	Cost ($/lane-km)	
	Inverted pavement	PCC pavement
Installation cost	213,750	365,000
10-year maintenance	63,125	
20-year maintenance	76,875	
20–30-year maintenance		75,625
30-year life-cycle cost	353,750	440,625
Net savings	86,875	

Environmental Sustainability

The FHWA LCA Pave tool was used for environmental assessment analysis. The analysis considered only pavement materials and construction stages. This includes materials, transportation to the construction site, and use of construction equipment. Earthworks prior to pavement construction, including construction of the stabilized subgrade, as well as other road construction features (drainage, signage, and lighting), were not included in the analysis.

In the absence of detailed information on material origins, transportation distances were assumed to be 50 mi (80 km) for all materials, except for water. Maintenance and rehabilitation activities were not considered. The materials included in the analysis were represented by the existing materials in the tool library. No additional materials were included. Detail assumptions are included in appendix C.5.

The results of the LCA analysis, normalized by lane-mile (functional unit), are included in table 35. Figure 130 shows the impact indicators normalized by lane-mile and by the highest value among the two pavement cross sections considered.

GWP for the IP was only 53 percent that of the JPCP section. On the other hand, the IP showed a slightly higher total use of nonrenewable primary energy, with the JPCP section having 82 percent of the total energy use of the IP.

Table 35. Environmental impacts per lane-mile; LaGrange Bypass, Georgia.

Impact indicator (i)	Inverted pavement	JPCP
Use of renewable energy primary energy, excluding renewable primary resources used as raw materials (MJ) (ii)	46,952	120,874
Use of renewable primary energy resources used as raw materials (MJ) (ii)	34.77	684
Total use of renewable primary resources (MJ) (ii)	46,988	121,556
Use of nonrenewable primary energy, excluding nonrenewable primary energy resources used as materials (MJ)	3,033,602	4,572,459
Use of nonrenewable primary energy used as raw materials (MJ) (ii)	2,572,675	0
Total use of nonrenewable primary energy resources (MJ) (ii)	5,606,277	4,572,459
Recycled material usage (short-tons)	36.85	118
Disposed nonhazardous waste (short-tons) (ii)	136	7.11
Disposed hazardous waste (short-tons) (ii)	9.61	0.0404
Net use of fresh water (m^3) (ii)	1,624	90,448
Acidification (kg SO_2 eq)	890	1,517
Ecotoxicity (CTUeco/kg) (ii)	11,165	2,784
Eutrophication (kg N eq)	225	647
Fossil fuel depletion (MJ surplus) (ii)	334,114	15,552
GWP (kg CO_2 eq)	271,871	516,193
Human Health, cancer (CTU/kg) (ii)	0.0001	5.70E-05
Human Health, noncancer (CTU/kg) (ii)	0.0069	0.0004
Human health effects, particulates (kg $PM_{2.5}$ eq) (ii)	30.56	21.22
Ozone depletion (kg CFC-11 eq)	0.0041	0.0137
Smog formation (kg O_3 eq)	22,259	32,139

Notes:

(i) AC mixing was assumed as the average of the production phase (A3) from available NAPA EPDs for two plants in Georgia (in Garden City and Hahira). Transportation of the AC mix from the plant to the construction site was assumed to be 20 mi (32 km).

(ii) The results presented are LCA Pave outputs, which are calculated based on the available information. Calculations of some impact categories can be incomplete due to missing data.

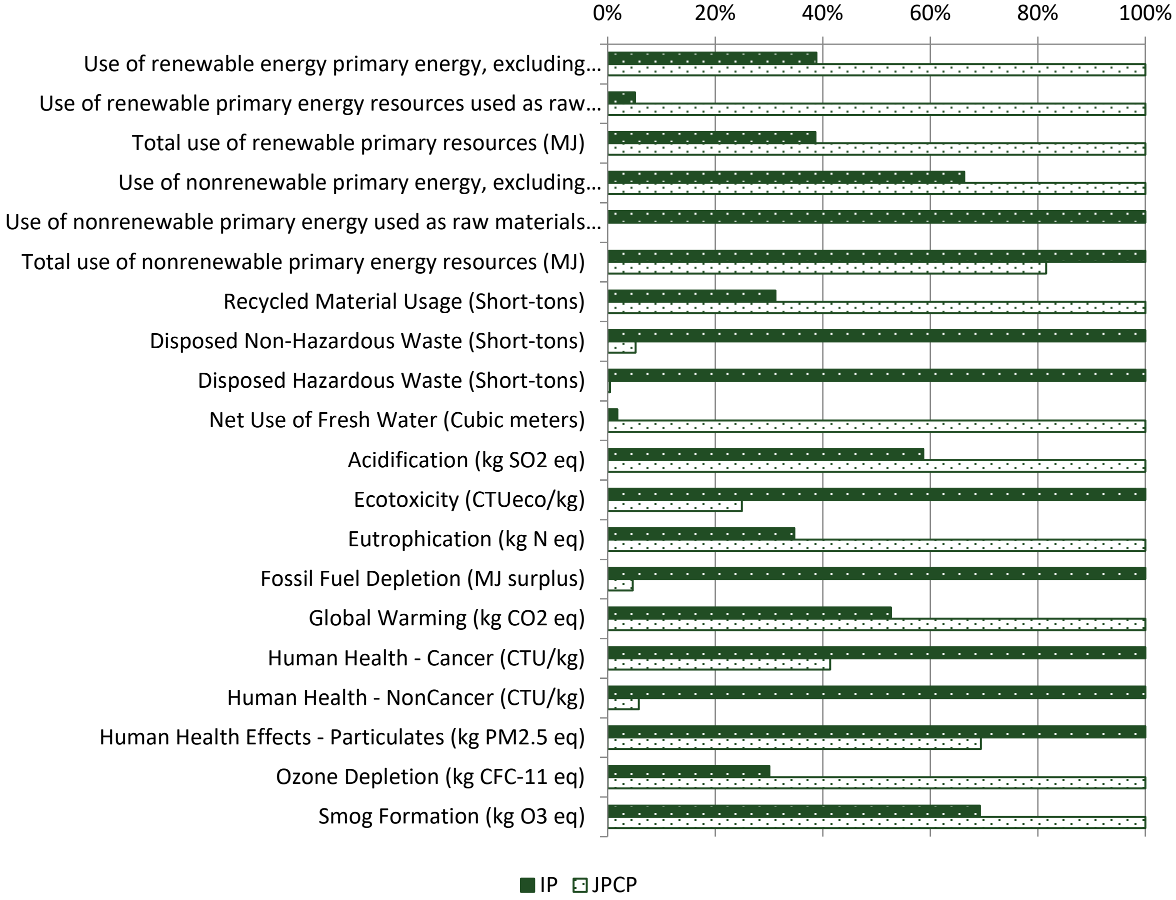
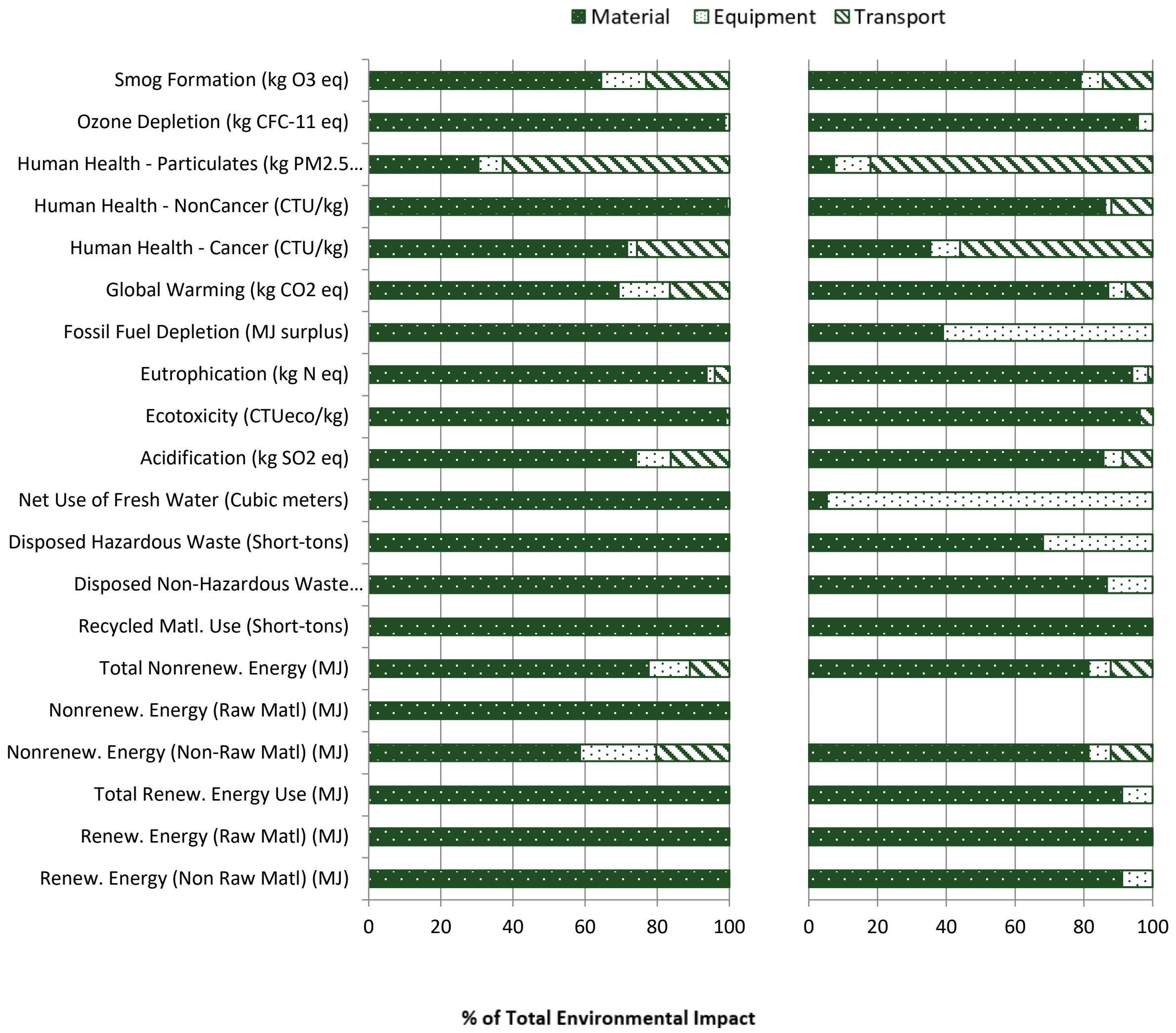


Figure 130. Graph. Comparison of normalized impact indicator values for each pavement section; LaGrange Bypass, Georgia.

Figure 131 shows the distribution of each impact indicator by process type. Material production was responsible for most of the GWP, especially in the JPCP.

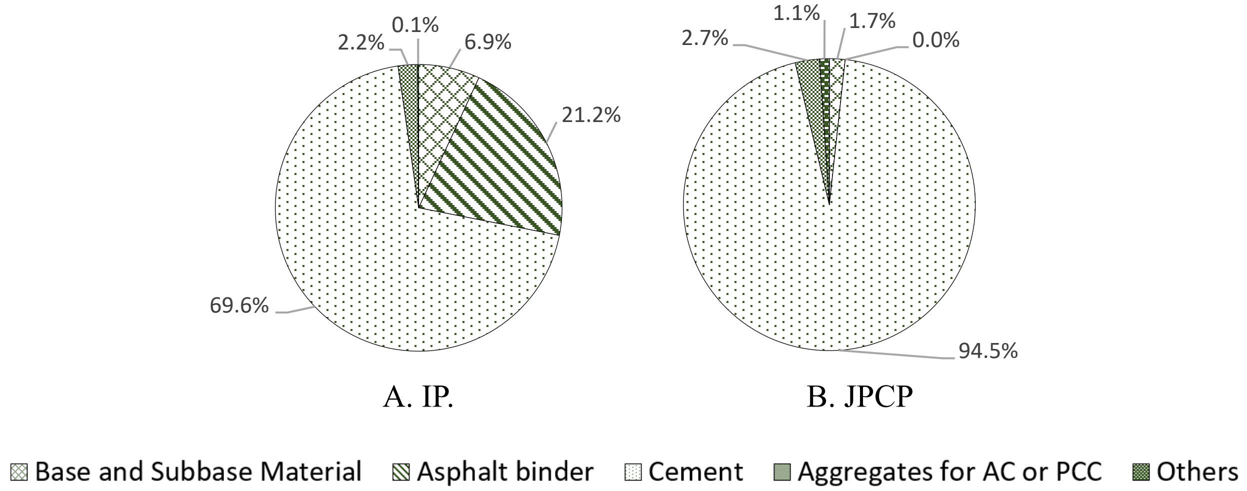


A.IP.

B. JPCP.

Figure 131. Graph. Comparison of impact indicators by process type for each pavement section; LaGrange Bypass, Georgia.

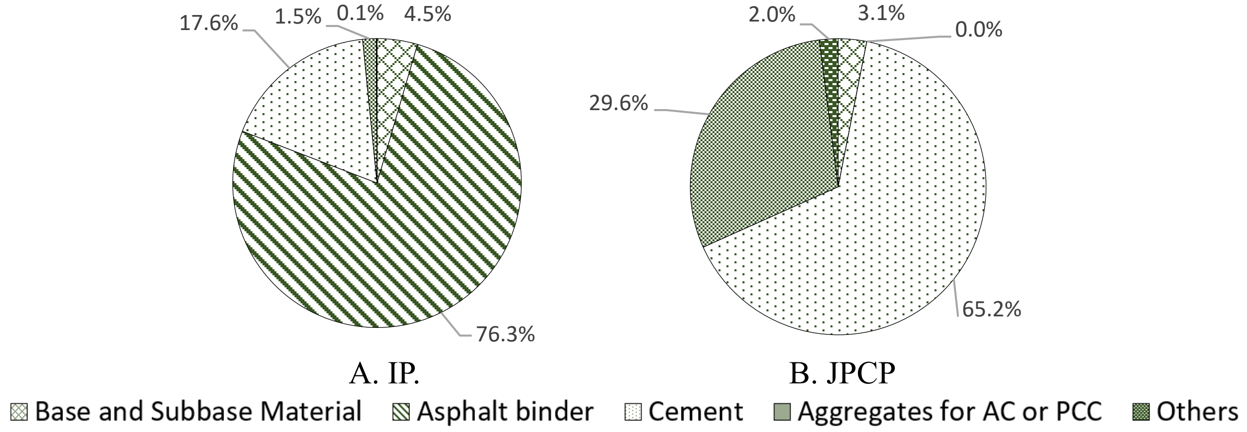
Figure 132 shows the contribution of each material to GWP related to the materials stage (excluding transportation and construction). Cement production was the material with the greatest impact, followed by base and subbase material in the IP.


A. IP.

B. JPCP

Figure 132. Graph. Contribution of each material to GWP (kg CO_2 eq) for each pavement section; LaGrange Bypass, Georgia.

Figure 133 shows the contribution of each material to total use of energy related to the materials stage (excluding transportation and construction). Asphalt binder represented most of the energy used in the IP, followed by cement used in the CTB. In the JPCP, cement represented most of the energy used, followed by concrete aggregates.


A. IP.

B. JPCP

Figure 133. Graph. Contribution of each material to total use of primary energy resources for each pavement section; LaGrange Bypass, Georgia.

Summary and Remarks

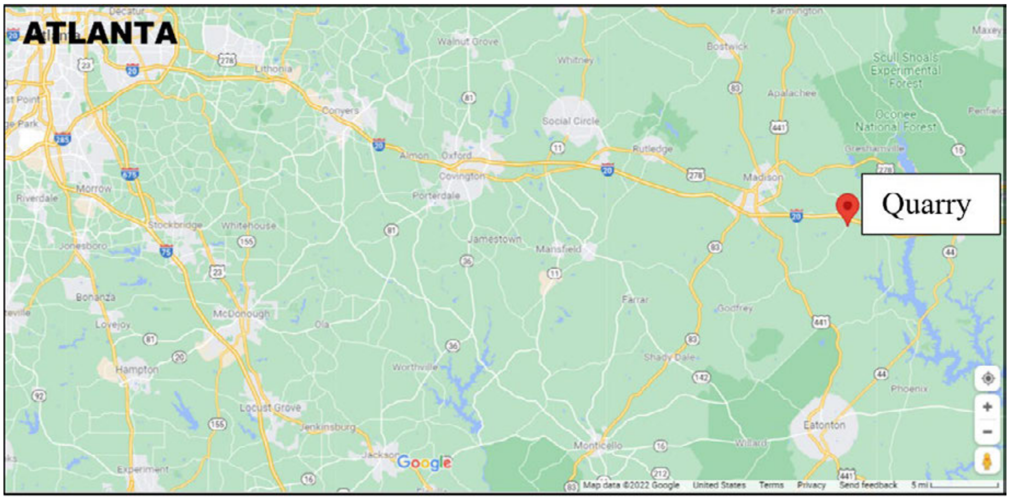
Construction of the LaGrange Bypass pavement was completed in 2009, consisting of an IP section between two sections of JPCP. After 13 years, the pavement was performing relatively well in the WB lane. The EB Lane presented more widespread and severe cracking than the WB lane did. The reason for this behavior is unclear.

In addition to LCCA, where IP showed more cost effectiveness, environmental impact assessment was conducted considering the materials and construction stages, including transportation. For GWP, the IP is only 53 percent that of the JPCP. For use of total nonrenewable primary energy, the JPCP represented 82 percent of the IP impact. In general, impact categories that are affected primarily by the production of cement were higher in the JPCP, whereas impact categories more affected by the production of AC were higher in the IP.

QUARRY ACCESS ROAD, MORGAN COUNTY, GEORGIA

Location

The Quarry[5] Access Road entrance is located near I-20, Exit 121 off the 7-Island Road, in Madison. The test section consists of three subsections, referred to as South African inverted pavement (South African IP), Georgia inverted pavement (Georgia IP), and conventional pavement (CP). The length of each IP section is 400 ft, and the length of the control section is 1,000 ft. The location of the test sections is indicated in figure 134.



Original Photo: © 2015 Google® (see Acknowledgements section).

A. Quarry location.

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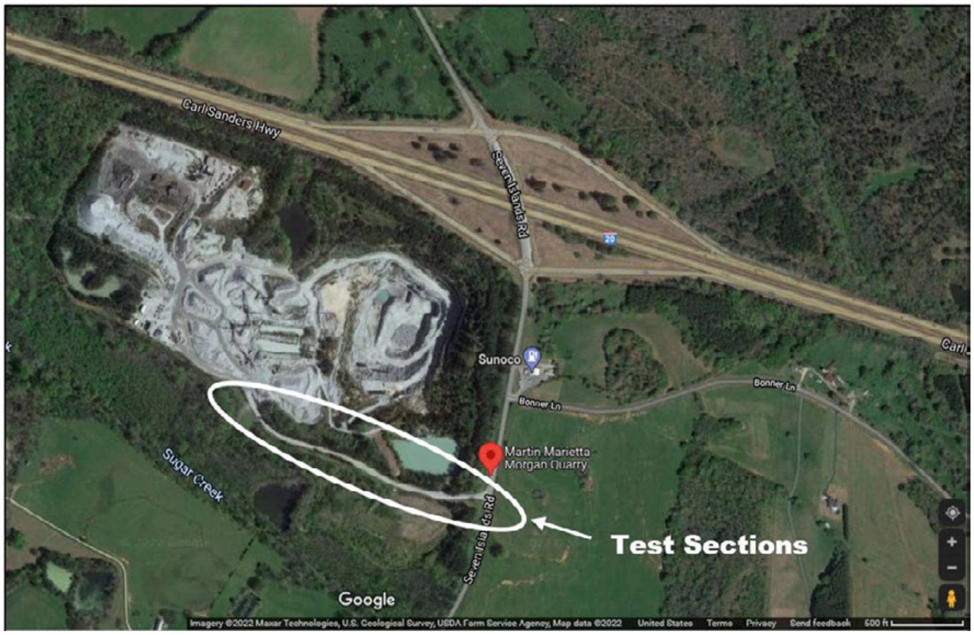
[5] Martin Marrietta Quarry



Original Photo: © 2015 Google® (see Acknowledgements section).

B. Test sections location in relation to the quarry and adjacent roads.

Original Photo: © 2015 Google® (see Acknowledgements section).

C. Location of each test section.

Figure 134. Illustration. Morgan County Quarry Access Road.

Pavement Configuration

The pavement cross sections are summarized in table 36. A control section comprising a CP was built from Station 0+00 to 10+00. The South African IP was built from Station 10+00 to 14+00 and the Georgia IP from Station 14+00 to 18+00. The pavement configuration for the South African and Georgia IP sections was the same. The difference between them was the technique used for finalizing the construction of the granular base layer. In the South African IP, the slushing technique was used, whereas in the Georgia IP, it was not.

Table 36. Pavement cross sections; Morgan County Quarry Access Road, Georgia.

Pavement layer	**Thickness (in)**	
	South African inverted pavement (Station 10+00 to 14+00) and Georgia inverted pavement (Station 14+00 to 18+00)	**Conventional pavement (Station 0+00 to 10+00)**
AC	3 (75 mm)	3 (75 mm)
Granular base	6 (150 mm)	8 (200 mm)
CTB (5% Type I portland, 145 to 435 psi [1 to 3 MPa])	8 (200 mm)	—
Crushed stone	—	6 (150 mm)
Graded aggregate base (filler)	2 (50 mm)	2 (50 mm)
Subgrade	Waste aggregate fill with min CBR 15% (pit overburden and weathered rock)	Waste aggregate fill with min CBR 15% (pit overburden and weathered rock)

Construction and Maintenance

The road was constructed in 2001. In the South African IP, the slushing technique was employed by wetting the pavement and compacting it using common construction equipment.

The pavement was compacted until air bubbles could no longer be seen behind the roller (Lewis et al. 2012). Both IP sections, with and without the slushing technique, achieved similar compaction levels. Figure 135 shows the constructed road in 2001.

Figure 135. Photo. Inverted pavement section constructed in Morgan County, Georgia, in 2001 (TRB Webinar 2016).

Terrell et al. (2003a,b) conducted miniaturized versions of traditional cross-hole and down-hole seismic tests to determine the stiffnesses of each base layer. Horizontally propagating compression and shear waves were measured under four different loading conditions to determine Young's moduli and Poisson's ratios of the base. An increase in stiffness with an increase in load was measured. The vertical base modulus was more than 690 MPa compared to much lower base moduli reported in conventional flexible pavement base courses. Additionally, it was found that the Georgia and South Africa sections had similar stiffness, while the traditional section was found to be stiffer (Terrell et al. 2003b).

Traffic Loading

The traffic consisted of empty haul trucks entering the quarry and loaded trucks leaving the quarry (Frost 2017). The pavement was designed for 1.3×10^6 ESALs. By the first five years of life, 63.4 percent of the design traffic had already been observed (Lewis 2008).
Though no pavement design analysis details were available, it was noted that in the CP, the 8 inches (200 mm) of CTB present in the IP sections was replaced by the same thickness of less structurally robust materials (2 inches [50 mm] of granular base and 6 inches [150 mm] of compacted crushed stone). If the same structural coefficients adopted in the design of the I-25 IP in New Mexico had been used, the SN of the Morgan Quarry Access Road CP would be about 0.32 less than the SN of the IP sections (i.e., 0.22 t 8 inches minus 0.18 × 8 inches).

Environmental Conditions

Table 37 includes average temperatures, rainfall, and snowfall for Buckhead, Georgia, where the quarry is located. Buckhead is in an area considered wet non-freeze in accordance with the FHWA and LTPP classification (figure 32).

Table 37. Buckhead, Georgia, average temperatures, rainfall, and snowfall (source: NOAA).

Month	Temperature		Rainfall			Snowfall		
	Highs (°F)	Lows (°F)	Days	in	mm	Days	in	mm
Jan	57	38	9	4.8	122	0	0	0
Feb	61	11	6	4.6	117	0	0.3	8
Mar	68	46	8	5.5	140	0	0.1	3
Apr	76	54	5	3.7	94	0	0	0
May	83	61	6	3.9	99	0	0	0
Jun	90	68	6	3.7	94	0	0	0
Jul	91	71	7	4.1	104	0	0	0
Aug	90	71	7	4.3	109	0	0	0
Sep	86	65	6	3.0	76	0	0	0
Oct	76	55	4	3.1	79	0	0	0
Nov	66	45	5	3.3	84	0	0	0
Dec	59	41	7	3.7	94	0	0	0
Total			76	47.7	1212	0	0.4	10

Performance

Visual inspection in 2003 and 2006 indicated that the IP sections did not present any cracking, whereas the CP section showed extensive cracking, especially in the EB (or outbound) lane, where loaded trucks stop at the quarry gate (Lewis et al. 2012).

According to Lewis et al. (2012) the two IP test sections performed well for over ten years, with no significant rut accumulation, whereas the conventional section presented cracking and rutting problems.

Performance measurements taken in 2016 and reported by Frost (2017) indicated overall good performance, with the IP sections generally showing fewer signs of rutting than the CP section. The CP showed more cracking, especially in the EB direction, where loaded trucks leave the quarry. It was noted that the CP near the quarry entrance (Station 0 to 300) underwent some repairs prior to the 2016 measurement.

The performance data collected in 2022 was reported by Donovan (2022) and Frost (2023). Figure 136 shows GDOT PACES ratings based on data collected in 2016 and 2022. In general, the outbound (EB) lanes, where the trucks are loaded, were found to be in worse condition than the inbound (WB) lanes, where trucks arrived empty. The figure indicates that, in 2016, the overall condition of the CP required or was close to requiring a thin pavement surfacing because some sections already presented a PACES rating less than 70. The IP sections were both performing more satisfactorily and similarly, with a PACES rating around 80. In 2022, the performance of the CP, especially in the outbound lanes, presented a significantly reduced PACES rating compared to the 2016 rating. Moreover, the Georgia IP also suffered a significant reduction in PACES rating, no longer presenting a performance similar to the South African IP.

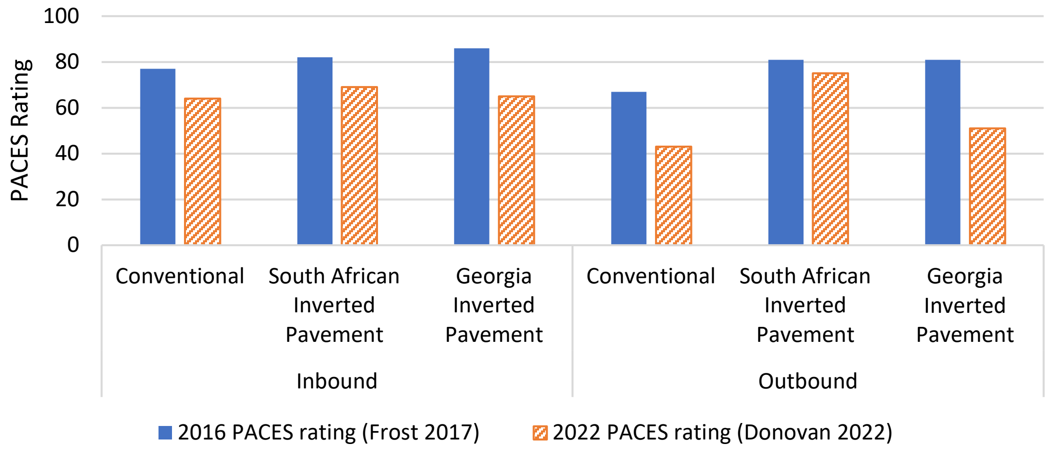


Figure 136. Graph. 2016 and 2022 average Pavement Condition Evaluation System rating in inbound (westbound) and outbound (eastbound); Morgan County Quarry Access Road, Georgia (data from Donovan 2022, and Frost 2017).

The 2022 measurement indicated severe load-associated cracking in the CP pavement, while the South Africa and Georgia IP sections showed less severe load cracking (low in the South Africa section and low to medium in the Georgia section) and some block cracking. Rutting was close to zero in the LWP of the entire section (CP and IP), with higher rutting in the RWP potentially associated with edge distress related to poor compaction or water infiltration (Donovan 2022).

FWD data collected in November 2007 indicated that both IP sections presented similar average maximum deflections, representing only 22 to 35 percent of the average maximum deflections in the CP (Donovan 2022, Lewis et al 2012). FWD data collected in 2022 compared to the 2007 data showed an increase in the average maximum deflection of 72 percent in the CP, while for the IP sections, the increase in deflection ranged from negligible to 19 percent, indicating less structural damage in the IP (Donovan 2022). A summary of the 2022 average maximum is shown in Table 38.

Table 38. Average maximum FWD deflection; Morgan County Quarry Access Road, Georgia (data from Donovan 2022).

Pavement Section	2022 Average maximum deflection	
	Inbound	Outbound
CP (excluding first 300 ft)	20.38 mils (518 µm)	40.01 mils (1016 µm)
South African IP	7.73 mils (196 µm)	12.15 mils (309 µm)
Georgia IP	7.12 mils (181 µm)	8.82 mils (224 µm)

Site Visit

In May 2022, a site visit took place. Figure 137 through Figure 142 show, respectively, the inbound and outbound CP, the inbound and outbound South African IP, and the inbound and outbound Georgia IP on the day of the visit. Frost (2023) noted that some of the poor performance locations had water ponding on the side of the pavement.

Figure 137. Photo. Conventional pavement in the inbound lane in May 2022; Morgan County Quarry Access Road, Georgia.

Figure 138. Photo. Conventional pavement in the outbound lane in May 2022; Morgan County Quarry Access Road, Georgia.

Figure 139. Photo. South African inverted pavement in the inbound lane in May 2022; Morgan County Quarry Access Road, Georgia.

Figure 140. Photo. South African inverted pavement in the outbound lane in May 2022; Morgan County Quarry Access Road, Georgia.

Figure 141. Photo. Georgia inverted pavement in the inbound lane in May 2022; Morgan County Quarry Access Road, Georgia.

Figure 142. Photo. Georgia inverted pavement in the outbound lane in May 2022; Morgan County Quarry Access Road, Georgia.

Environmental Sustainability

Environmental assessment analysis was conducted using FHWA LCA Pave tool. The analysis considered only the pavement construction phase of the project, including materials, transportation to the construction site, and use of construction equipment. Earthworks prior to pavement construction, including placement and compaction of fill, as well as other road construction features (such as drainage, signage, lighting, etc.) were not included in the analysis.

In the absence of detailed information on material origins, transportation distances were assumed to be 50 mi (80 km) for all materials except for water, which was assumed to be available on site. Maintenance and rehabilitation activities were not considered. The materials included in the analysis were represented by the existing materials in the tool library. Detail assumptions are included in appendix C.4.

The results of the LCA analysis, normalized by lane-mile, are included in table 39. Figure 143 shows the impact indicators normalized by lane-mile and by the highest value among the three pavement cross sections considered.

Table 39. Environmental impacts per lane-mile; Morgan County Quarry Access Road, Georgia.

Impact indicator (i)	Conventional pavement	Inverted pavement	
		South African	Georgia
Use of renewable energy primary energy, excluding renewable primary resources used as raw materials (MJ) (ii)	17,946	41,657	41,654
Use of renewable primary energy resources used as raw materials (MJ) (ii)	20.79	32.7	31.75
Total use of renewable primary resources (MJ) (ii)	17,968	41,690	41,687
Use of nonrenewable primary energy, excluding nonrenewable primary energy resources used as materials (MJ)	1,850,464	2,638,265	2,630,013
Use of nonrenewable primary energy used as raw materials (MJ) (ii)	2,206,680	2,206,680	2,206,680
Total use of nonrenewable primary energy resources (MJ) (ii)	4,057,144	4,844,946	4,836,694
Recycled material usage (short-tons)	0.3486	33.65	33.65
Disposed nonhazardous waste (short-tons) (ii)	115	117	117
Disposed hazardous waste (short-tons) (ii)	8.23	8.24	8.24
Net use of fresh water (m^3) (ii)	214	1,468	1,468
Acidification (kg SO_2 eq)	439	782	780
Ecotoxicity (CTUeco/kg) (ii)	9,822	9,884	9,879
Eutrophication (kg N eq)	49.2	202	202
Fossil fuel depletion (MJ surplus) (ii)	286,502	286,607	286,599
GWP (kg CO_2 eq)	113,028	240,418	239,817
Human health, cancer (CTU/kg) (ii)	0.0001	0.0001	0.0001
Human health, noncancer (CTU/kg) (ii)	0.0059	0.0059	0.0059
Human health effects, particulates (kg $PM_{2.5}$ eq) (ii)	23.35	25.98	25.72
Ozone depletion (kg CFC-11 eq)	0.0004	0.0038	0.0038
Smog formation (kg O_3 eq)	12,517	19,429	19,361

Notes:

(i) AC mixing was assumed as the average of the production stage (A3) from available NAPA EPDs for two plants in Georgia (in Garden City and Hahira). The transportation distance of the AC mix from the plant to the construction site was assumed to be 20 mi (32 km).

(ii) The results presented are LCA Pave outputs, which are calculated based on the available information. Calculations of some impact categories can be incomplete due to missing data.

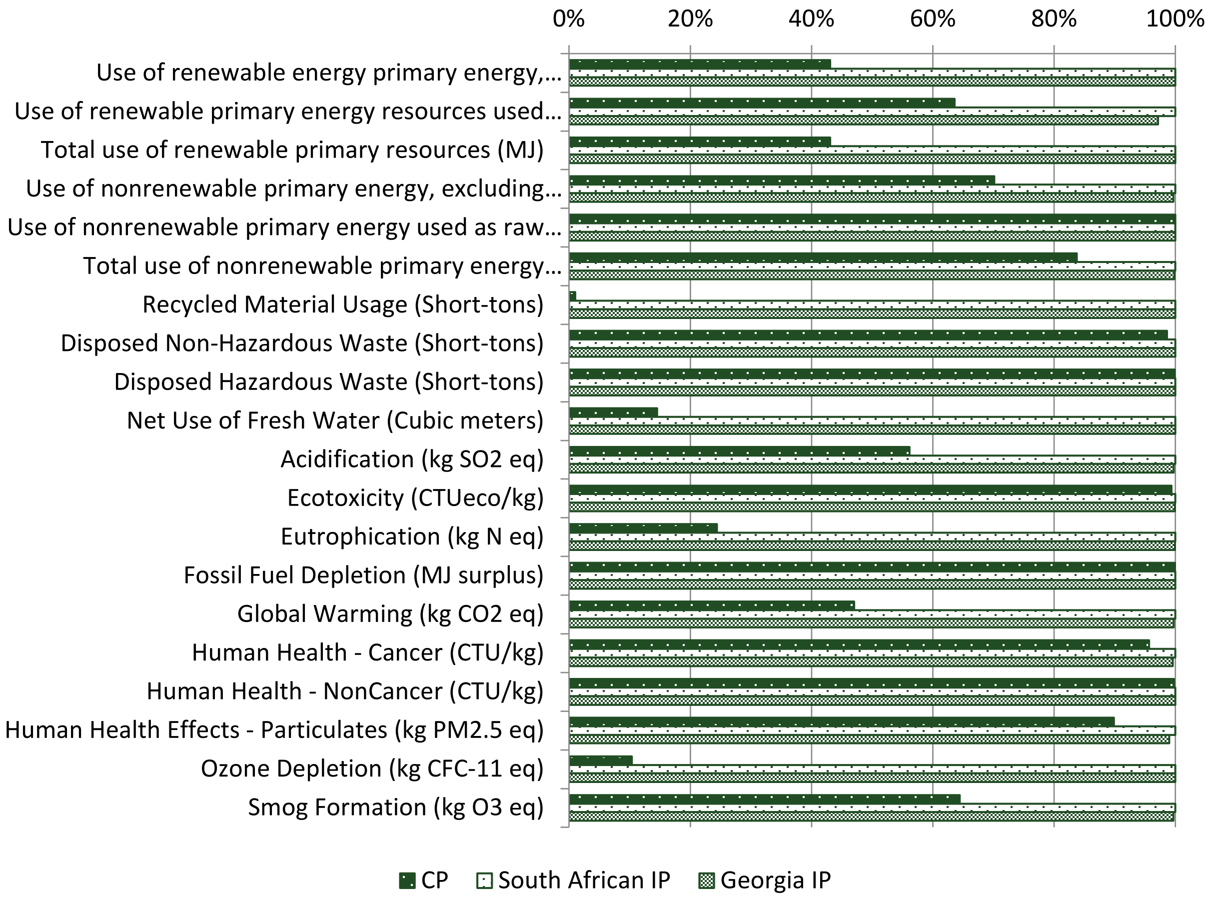
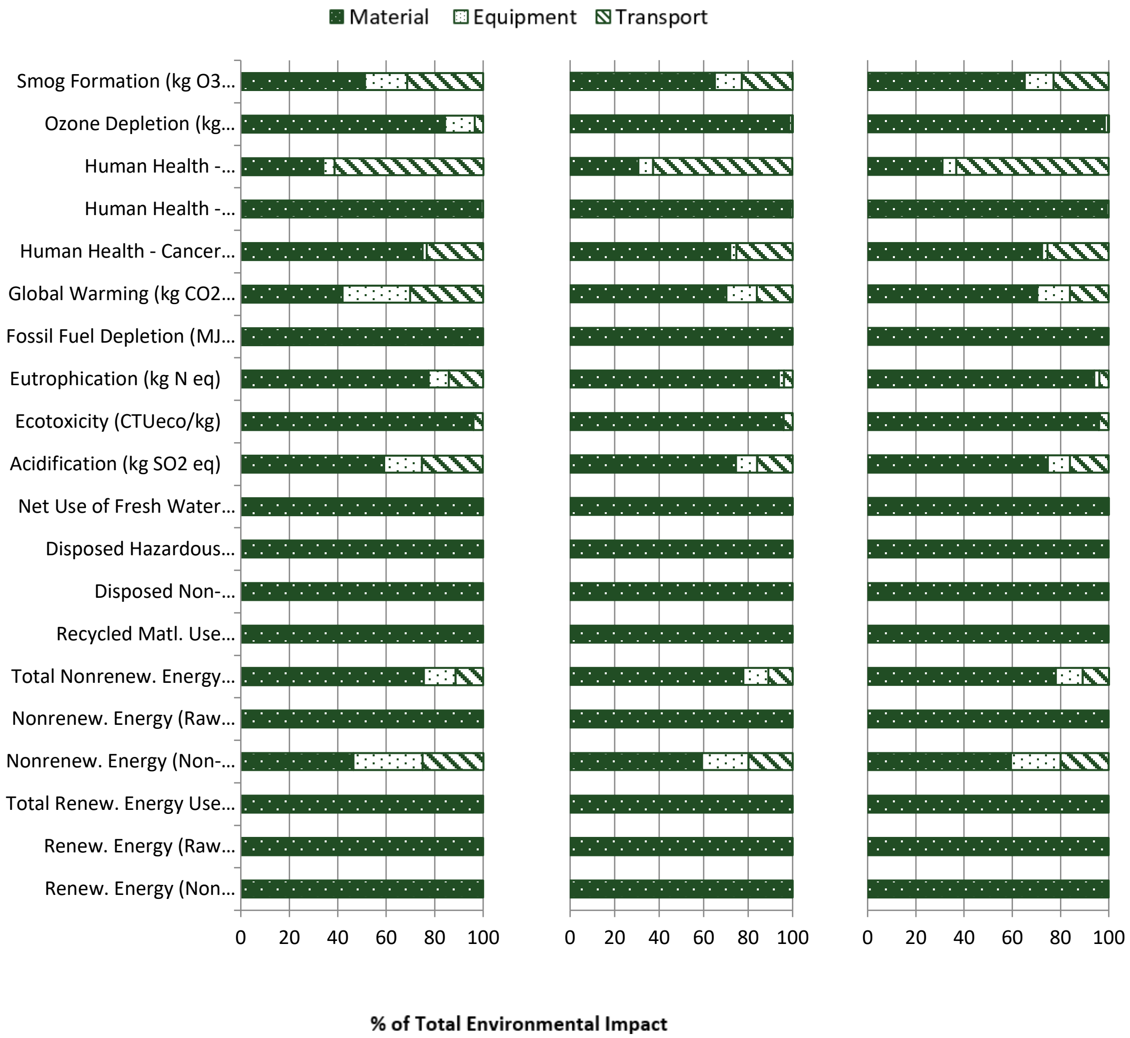


Figure 143. Comparison of normalized impact indicator values for each pavement section; Morgan Quarry Access Road, Georgia.

The IP sections represented higher environmental impacts in all categories considered. The environmental impacts for the South Africa and Georgia IP sections were similar, which was expected because the only difference between them was the use of the South African slushing technique (i.e., slightly more use of construction equipment time and water used in construction).

In terms of GWP, the impact of the CP was 47 percent that of IP. In terms of total use of nonrenewable primary energy, the CP represented only 84 percent of the energy use of the IP.

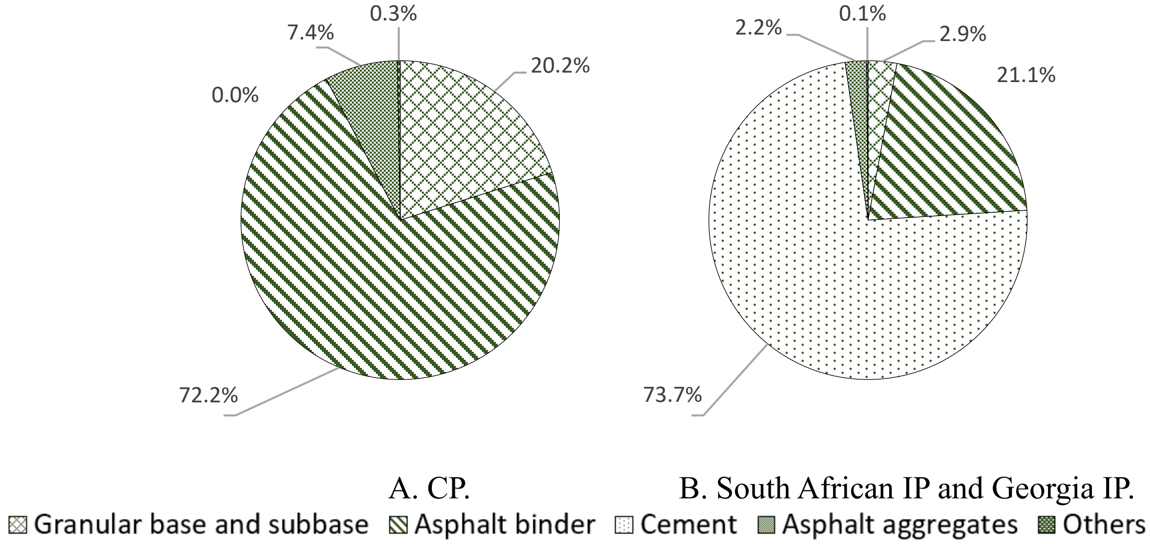
Figure 144 shows the distribution of each impact indicator by process type. Most of the GWP originated from the materials phase.



A. CP B. South African IP C. Georgia IP

Figure 144. Comparison of impact indicators by process type for each pavement section; Morgan County Quarry Access Road, Georgia.

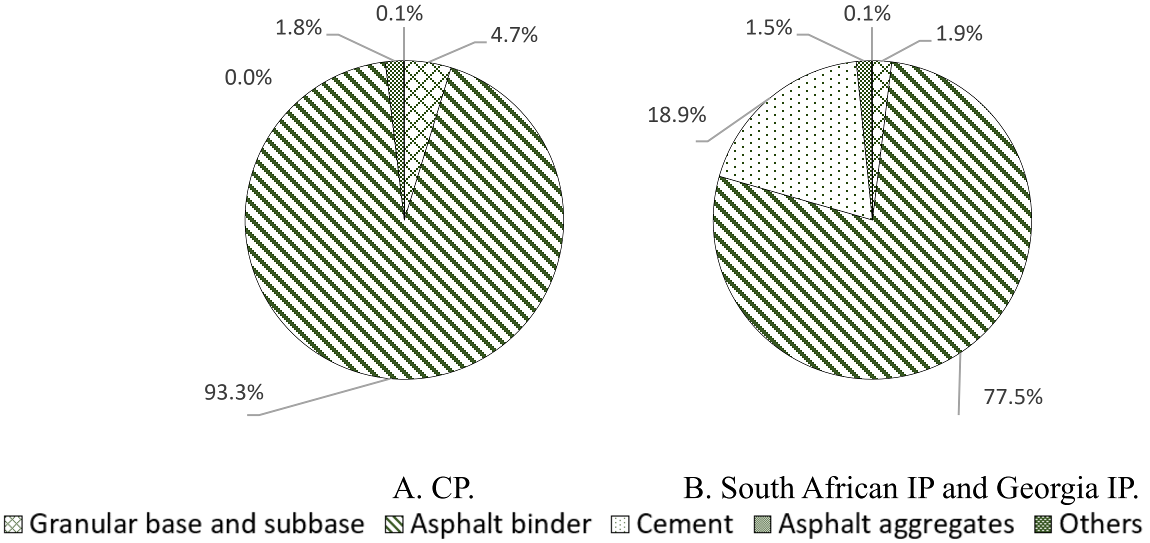
Figure 145 shows the contribution of each material to total GWP related to materials used in each pavement section (transportation and construction are not included). The production of cement was responsible for most of the GWP in the IP sections. In the conventional pavement, where cement is not included, asphalt binder is the main material impacting GWP, followed by granular base material.



A. CP. B. South African IP and Georgia IP.

Figure 145. Graph. Contribution of each material to GWP (kg CO_2 eq) for each pavement section; Morgan County Quarry Access Road, Georgia.

Figure 146 shows the contribution of each material to total use of primary energy resources related to materials of each pavement section. Asphalt binder, which was present in all pavement sections in the same quantity, is the main material contributing to total use of primary energy resources.



A. CP. B. South African IP and Georgia IP.

Figure 146. Graph. Contribution of each material to total use of primary energy resources for each pavement section; Morgan County Quarry Access Road, Georgia.

Although no maintenance and rehabilitation were considered in the environmental assessment presented above, performance data indicated that the CP pavement deteriorated significantly faster than the conventional pavement. The conventional pavement was close to or in need of a thin resurfacing when the pavement was about 15 years old, whereas the IP sections were still performing satisfactorily then. Figure 147 presents the ratio of the environmental impact of the conventional pavement relative to the Impact of the IP normalized by the pavement age until it requires the first resurfacing (i.e., PACES rating reaches 70). The plot assumes that the conventional pavement is 15 years old when it reaches a PACES rating of 70. The age at which the IP reaches the same rating varies along the horizontal axis of the plot. For the total use of nonrenewable primary energy of the IP normalized by year until first resurfacing to become less than the impact of the conventional pavement, the IP would need to last for about 18 years until it reaches a PACES rating of 70. Regarding GWP, the IP would need to last for about 32 years until it reaches a PACES rating of 70. The PACES rating collected in 2022 indicated a rating of 75 for the South African IP, with a pavement age of 21 years. It is possible that the section will last 25 years before it reaches a PACES rating of 70. The Georgia IP section, however, presented a PACES rating of 51 in 2022 and about 82 in 2016. A PACES rating of 70 was probably reached around 2018, when the pavement was about 17 years of age.

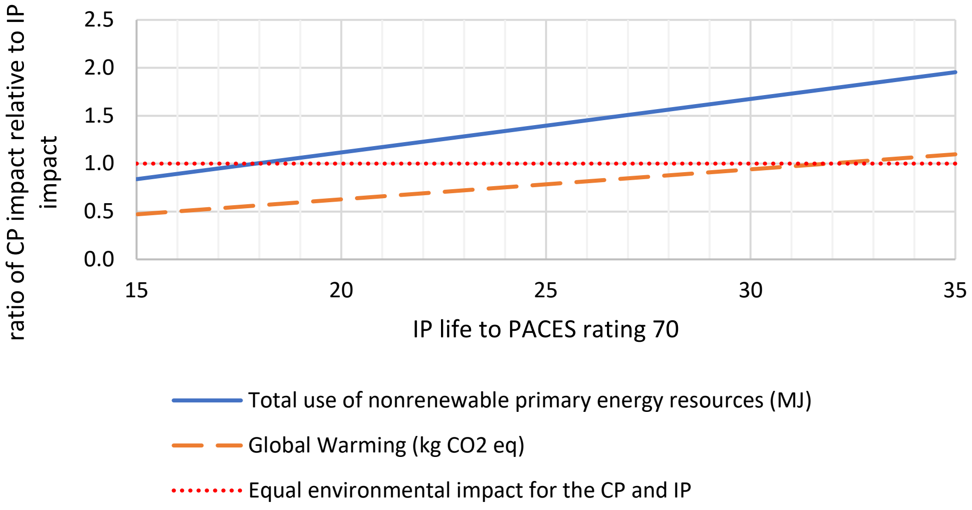


Figure 147. Graph. Ratio of relative impact of conventional pavement and inverted pavement normalized to pavement age until first resurfacing required, Georgia.

Summary and Remarks

The Morgan County Quarry Access Road IP consists of 3 inches (75 mm) of AC, 6 inches (150 mm) of a granular aggregate base, and 8 inches (200 mm) of CTB. The conventional pavement consists of the same thickness of AC overlying 8 inches (200 mm) of granular aggregate base and 6 inches (150 mm) of compacted crushed stone. The pavement was constructed in 2001.

Performance data collected in 2016 indicate that both IP sections were performing similarly, and better than the conventional pavement section. Six years later, in 2022, the performance of the South African IP was superior to that of the Georgia IP, suggesting that the use of the South African slushing technique is effective in improving long-term performance. A clear difference in the performance of the outbound (eastbound) and inbound (westbound) pavements was observed, with the outbound pavement, where the trucks travel loaded, showing poorer performance (Donovan 2022, Frost 2023).

The environmental impact assessment of the materials, transportation, and construction phases indicate that the conventional pavement represents a lesser overall environmental impact. It should be noted, however, that the conventional pavement is structurally less robust and deteriorated faster than the IP sections.

Cost information was not available. Based on the materials used, the conventional pavement is also expected to have been cheaper to construct. When compared to the IP sections, the conventional pavement has an additional 2 inches (50 mm) of thickness of UAB layer and 6 inches (150 mm) of crushed stone but lacks the entire 8 inches-thick (200 mm) stiff cement-treated layer present in the IP sections.

It is noted that the AC thickness in this case study, similar to other case studies in the United States, was higher than the usual AC thickness used in South African IP. The CP was constructed with the same thickness of AC as the IP.

VIRGINIA STATE ROUTE 659, VIRGINIA

Location

The IP at Virginia State Route 659 (VA-659) is located in Chantilly, Virginia, approximately 35 miles west of Washington, DC. The project involved a relocated road bypassing a quarry[6]. It consisted of two instrumented pavement sections, one with a CP, also referred to as the original section, and one IP section, each 500 feet (152 m) in length.

Figure 148 shows the project location and the location of each test section.

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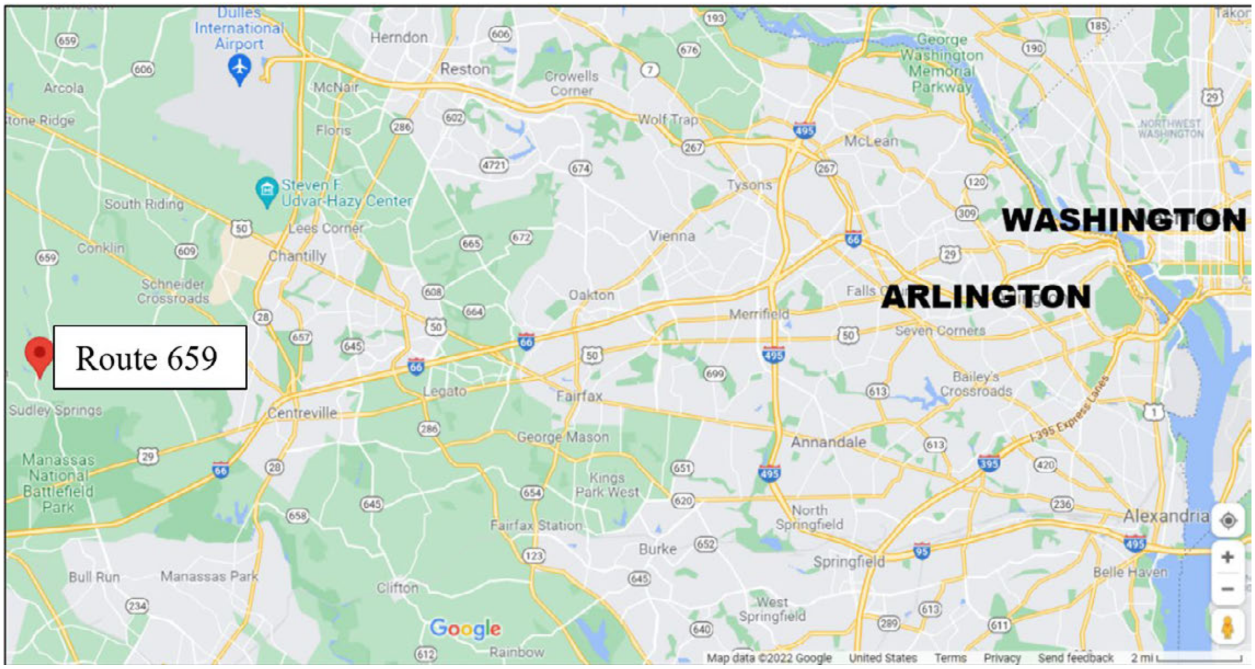
[6] Luck Stone Bull Run Quarry



Original Photo: © 2015 Google® (see Acknowledgements section).

A. Site location.

Original Photo: © 2015 Google® (see Acknowledgements section).

B. Location of test sections.

Figure 148. Illustration. VA-659, Virginia.

Pavement Configuration

The pavement cross sections are summarized in table 40.

Table 40. Pavement cross section; VA-659, Virginia.

Pavement layer	Thickness	
	Inverted pavement	**Conventional pavement**
AC	1 in (50 mm) (surface)	1.5 in (40 mm) (SM 9.5D)
AC	3 in (75 mm) (intermediate)	2.0 (50 mm) (IM 19.0A)
AC		7.5 (190 mm) (BM 25.0)
Open-graded drainage layer	—	3 (75 mm)
Unbound aggregate base	6 in (150 mm)	—
CTB	10 in (250 mm)	8 (200 mm)
Subgrade	Untreated subgrade 10,000 psi (69 MPa)	CBR 5%

Pavement Design

The pavement was designed using the International Center for Aggregates Research (ICAR) model and compared to the latest MEPDG AASHTO model at the time. The ICAR model considers the UAB a nonlinear, anisotropic, and stress-sensitive granular material, providing a more realistic model of the layer's mechanistic behavior (Weingart 2012).

The design rutting and fatigue models adopted are presented, respectively, in equations in figure 149 and figure 150:

$$N_d = 1.365 \times 10^{-9}(\varepsilon_c)^{-4.477}$$

Figure 149. Equation. Design rutting model.

$$N_f = 0.0796(\varepsilon_{ct})^{-3.291}(E_{AC})^{-0.854}$$

Figure 150. Equation. Design fatigue models.

where:

N_d = number of load applications to subgrade failure.
N_f = number of load applications to fatigue failure.
ε_c = vertical compressive strain at the top of the subgrade.
ε_{ct} = horizontal tensile strain at the bottom of the AC layer.
E_{AC} = modulus of the AC layer (psi).

These equations consider the failure criteria are a rut depth of 0.5 inches (12.7 mm) and 20 percent cracking.

The layer configuration of the test section was designed and analyzed using a hybrid combination of pavement responses (stress, strain, deflection) from laboratory mechanistic materials characterization for a stress-dependent, cross-anisotropic base course resilient modulus implemented in TTI-PAVE, which was then passed to the above listed empirical Asphalt Institute design equations to assess pavement life predictions for AC fatigue-cracking and subgrade rutting.

Construction and Maintenance

The pavement was completed May 2012. The sections were instrumented with multidepth deflectometers, pressure cells, strain gauges, moisture sensors, and thermocouples. Unfortunately, data collected by these instruments were not available.

Historical aerial images from Google Earth indicate that a new AC surfacing layer was constructed in both test sections (control and IP sections) sometime between April 2018 and October 2019, when the access to the quarry from the CP test section was constructed. Based on the limited pavement performance data available for the test sections, it is inferred that the work took place in 2018 because the 2018 IRI measurements are generally lower than the 2016 measurements.

Traffic Loading

The 30-year design traffic for this section was 1.79×10^7 ESALs. The road is classified by VDOT as a minor arterial road, with recorded AADT varying from 11,434 to 12,952.

Environmental Conditions

Table 41 includes average temperatures, rainfall, and snowfall for Chantilly, Virginia. Chantilly is in an area considered wet-freeze in accordance with the FHWA and LTPP classification (figure 32).

Table 41. Chantilly, Virginia, average temperatures, rainfall, and snowfall (source: NOAA).

Month	Temperature		Rainfall			Snowfall		
	Highs (°F)	Lows (°F)	Days	in	mm	Days	in	mm
Jan	44	23	7	2.5	64	3	7.6	193
Feb	48	25	7	2.5	64	2	7.6	193
Mar	57	32	7	2.4	61	1	3.5	89
Apr	69	41	7	3.1	79	0	0.2	5
May	77	51	10	3.9	99	0	0	0
Jun	85	60	9	4.7	119	0	0	0
Jul	89	64	7	4.3	109	0	0	0
Aug	87	63	7	3.1	79	0	0	0
Sep	81	56	7	3.3	84	0	0	0
Oct	70	44	7	4.1	104	0	0	0
Nov	59	35	6	2.6	66	0	0.4	10
Dec	48	27	8	3.5	89	1	2.3	58
Total			89	40.0	1016	7	21.6	549

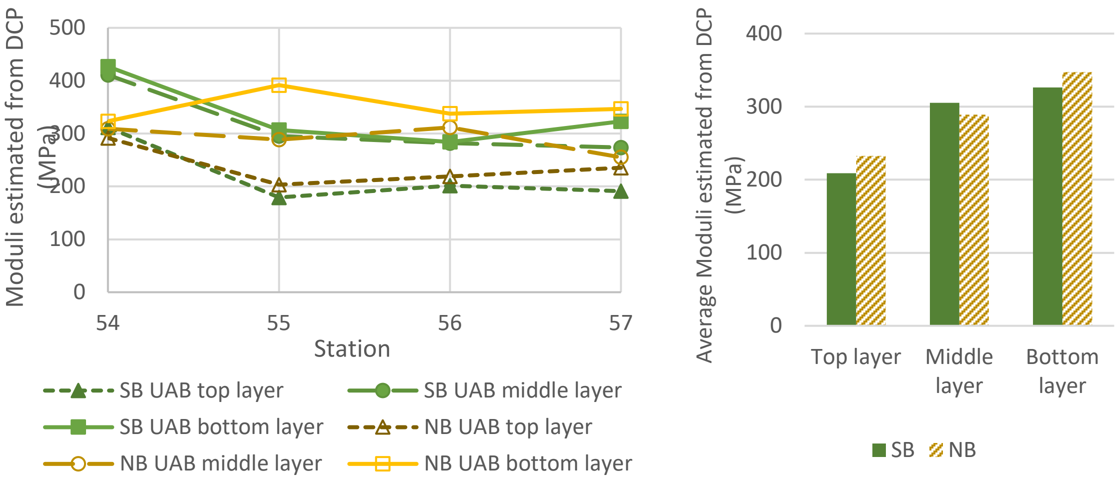
Performance

Table 42 summarizes modulus values for each layer backcalculated from FWD measurements taken in July and August 2011. The backcalculated values indicated that the subgrade, CTB, and AC layers in the CP and IP sections achieved relatively similar moduli following construction.

Table 42. FWD Backcalculated moduli –VA-659, Virginia (prepared from values provided by Edgar Rodriguez and Reza Ashtiani).

Pavement Layer	Inverted Pavement		Conventional Pavement	
	Thickness	Modulus	Thickness	Modulus
AC	5 in (127 mm)	340 ksi (2,345 MPa)	1.5 in (38 mm)	263 ksi (1,815 MPa)
AC	-	-	2.0 in (51 mm)	316 ksi (2,180 MPa)
AC	-	-	7.5 in (190 mm)	351 ksi (2,420 MPa)
Open graded drainage layer	-	-	3 in (76 mm)	Not reported
Unbound aggregate base	6 in (152 mm)	67 ksi (460 MPa)	-	-
CTB	10 in (254 mm)	412 ksi (2840 MPa)	8 in (203 mm)	408 ksi (2815 MPa)

UAB moduli calculated with a dynamic cone penetrometer (DCP) are summarized in figure 151. The data indicated values lower than the backcalculated moduli, with the modulus estimated for the top of the UAB varying from 26 to 45 ksi (180 to 310 MPa), for the middle layer from 37 to 60 ksi (255 to 410 MPa), and for the bottom layer 41 to 62 ksi (285 to 425 MPa).



A. Values estimated for each location.

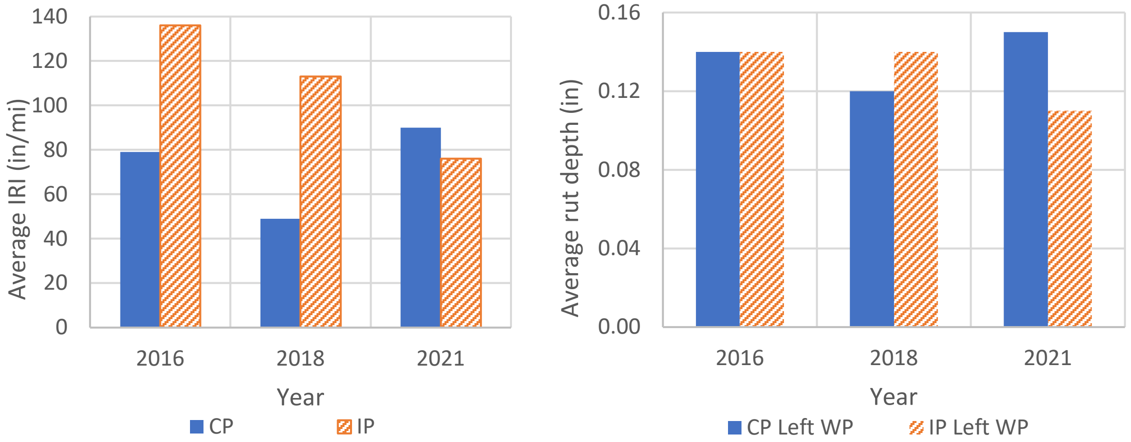
B. Average values.

Figure 151. Graph. Inverted pavement unground aggregate base moduli estimated from dynamic cone penetrometer VA-659, Virginia (data provided by Reza Ashtiani).

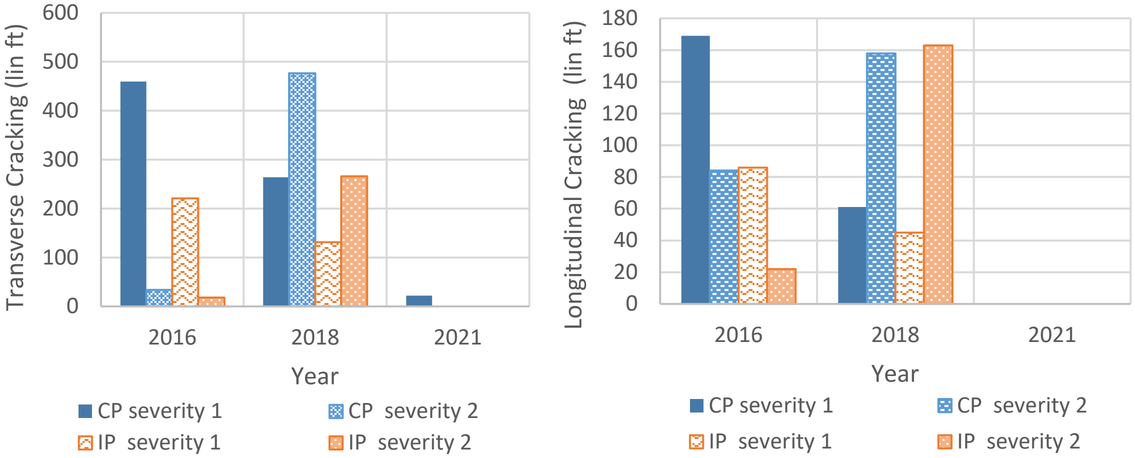
Limited pavement performance data were available. The VDOT pavement management system (PMS) segmented the road in sections that roughly, but not exactly, corresponded to the CP and IP test sections. The start and end of VDOT PMS segments are off by up to about 80 ft (24 m) from the start and end of the test sections. Figure 152 includes PMS data collected in 2017, 2018, and 2021 for the section that roughly corresponds to the CP and IP test sections, including IRI, rut depth, transverse cracking, longitudinal cracking, and alligator cracking.

The IRI data suggested that the CP test section presented an overall better performance in the fourth year of the pavement life, compared to the IP section. The IRI measured in 2018 was lower than the 2016 measurement, indicating that it was measured after the new AC surfacing layer was constructed. The IRI for the CP test section was significantly reduced in 2018 but increased at a higher rate than the IP section after that, surpassing the IRI for the IP section in 2021. When the new AC surfacing layer was constructed, sometime in 2018 or 2019, the CP section also received a new intersection, providing access to the quarry. The presence of the intersection within the CP test section is believed to have led to considerably more braking and accelerating trucks within this section, therefore accelerating rutting, as confirmed in figure 152.B.

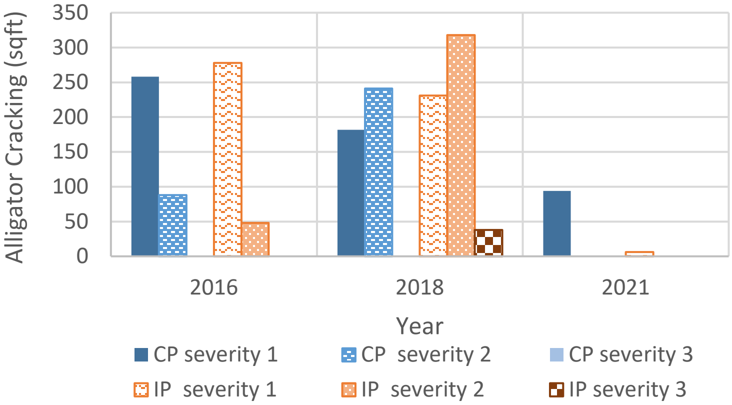
The cracking data for 2018 appears to correspond to data collected prior to the resurfacing of the test sections. Transverse cracking was more prominent in the CP test section than in the IP. This suggests that the unbound layer between the cemented layer and the AC layer in the IP section was effective in delaying the appearance of reflective cracking at the surface. Longitudinal cracking was more prominent in the CP section in 2016, though both sections presented relatively similar values in 2018. Alligator cracking in 2016 appeared to be of similar extension for both sections but slightly more severe in the CP section. In 2018, the IP presented significantly more alligator cracking.



A. Average international roughness index B. Average rut depth



C. transverse cracking. D. Longitudinal cracking.



E. Alligator cracking.

Figure 152. Graph. Pavement performance data; VA-659, Virginia (data provided by Virginia DOT).

Figure 153 and figure 154 show, respectively, photos of the IP and CP sections taken in 2017, the fifth year of pavement life. The photos indicate that both pavement sections presented extensive cracking, with very limited crack sealing applied. The crack sealing in the photos appeared to be old and worn off, no longer providing a functional seal to the pavement cracks.

Hairline cracking in NB direction

Instrumentation location

1/9/2017

Core holes

1/9/2017

Instrumentation location?

1/9/2017

Instrumentation location?

1/9/2017

Instrumentation location

1/9/2017

Cracking at north end of inverted section

1/9/2017

A. Northbound.

B. Southbound.

Figure 153. Photo. VA-659, Virginia (inverted pavement photos from 2017, provided by Virginia DOT).

A. Northbound.

B. Southbound.

Figure 154. Photo. VA-659, Virginia (conventional pavement photos from 2017, provided by Virginia DOT).

Cost Assessment

Weingart (2010) indicated potential savings of 22.14 percent on the initial construction of the IP with the CP cost at $206.40 per linear feet ($677.16 per linear meter) and the IP at $160.71 per linear feet ($527.26 per linear meter).

Discussing the benefits of this IP trial application, Weingart (2012) reported a potential for 22.3 percent cost savings compared to the construction of a conventional flexible pavement with equivalent structural and functional capacities. The estimated cost for construction of the conventional flexible pavement section was $213.11 per linear feet ($699.18 per linear meter), whereas for the IP section, the cost was $165.98 per linear feet ($544.57 per linear meter).

Summary and Remarks

The VA-659 IP section comprised of 5 inches (130 mm) of AC, 6 inches (150 mm) of UAB, and 10 inches (250 mm) of CTB over an untreated subgrade with a modulus of 10,000 psi (69 MPa). This section was compared to a CP test section comprised of 11 inches (280 mm) of AC over 3 inches (75 mm) of an open-graded drainage layer, and 8 inches (200 mm) of CTB over a subgrade with CBR 5 percent. Both sections were opened to traffic in 2012 and presented extensive cracking in 2017, being resurfaced sometime in 2018 or 2019, when a new intersection was built.

FWD measurements shortly after construction indicated that the subgrade, CTB, and AC layers in the IP and CP sections achieved similar compaction (the backcalculated moduli were relatively similar).

The limited pavement performance data available suggested that the development of cracking started first in the CP section, but it then accelerated at a faster rate in the IP section. IRI data indicated better overall performance of the CP in 2016, prior to the test sections being resurfaced.

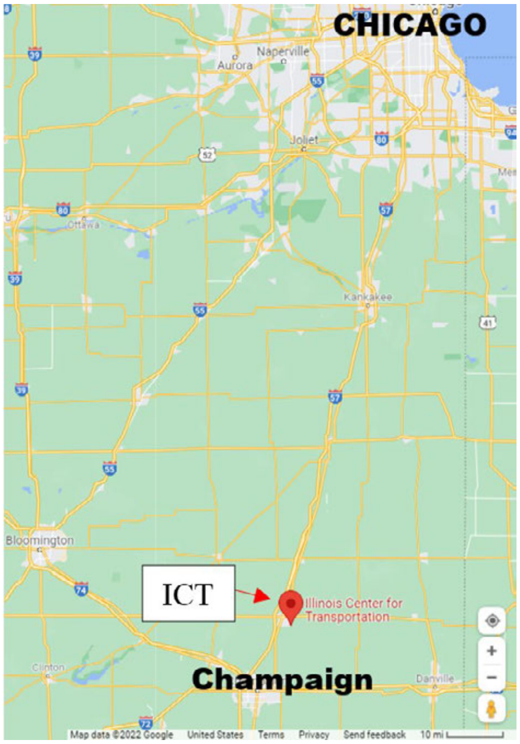
The unbound base layer in the IP section appears to have been to some degree effective in delaying the appearance of reflective cracks at the surface. Once the cracks started to appear, however, the IP section deteriorated faster than the CP section. A potential reason for this behavior is that the cracks, once developed, allowed ingress of water into the unbound aggregate layer, lowering its modulus and leading to higher traffic load–induced strains at the bottom of the AC layer.

The IP solution represented potential savings of 22.14 percent in construction costs. However, based on the limited pavement performance data from 2016, prior to the sections receiving a new AC surfacing around 2018, the IP had a higher IRI than the CP.

ILLINOIS CENTER FOR TRANSPORTATION, UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN, ILLINOIS

Location

The Illinois Center for Transportation (ICT) at the University of Illinois Urbana-Champaign conducted a research study funded by the Illinois Department of Transportation (IDOT) to investigate the potential use of quarry by-products in pavements (Qamhia, Tutumluer, and Ozer 2018). ICT is located 25 miles north of Champaign, in the Village of Rantoul, as indicated in figure 155.



Original Photo: © 2015 Google® (see Acknowledgements section).

Figure 155. Illustration. ICT location.

Full-scale pavement test sections were constructed at ICT using different quarry by-product materials and configurations. As part of this study, two sections were constructed with an IP configuration: Cell 3, Section 2 (C3S2); and Cell 3, Section 3 (C3S3). The location of the test sections within ICT is indicated in figure 156.

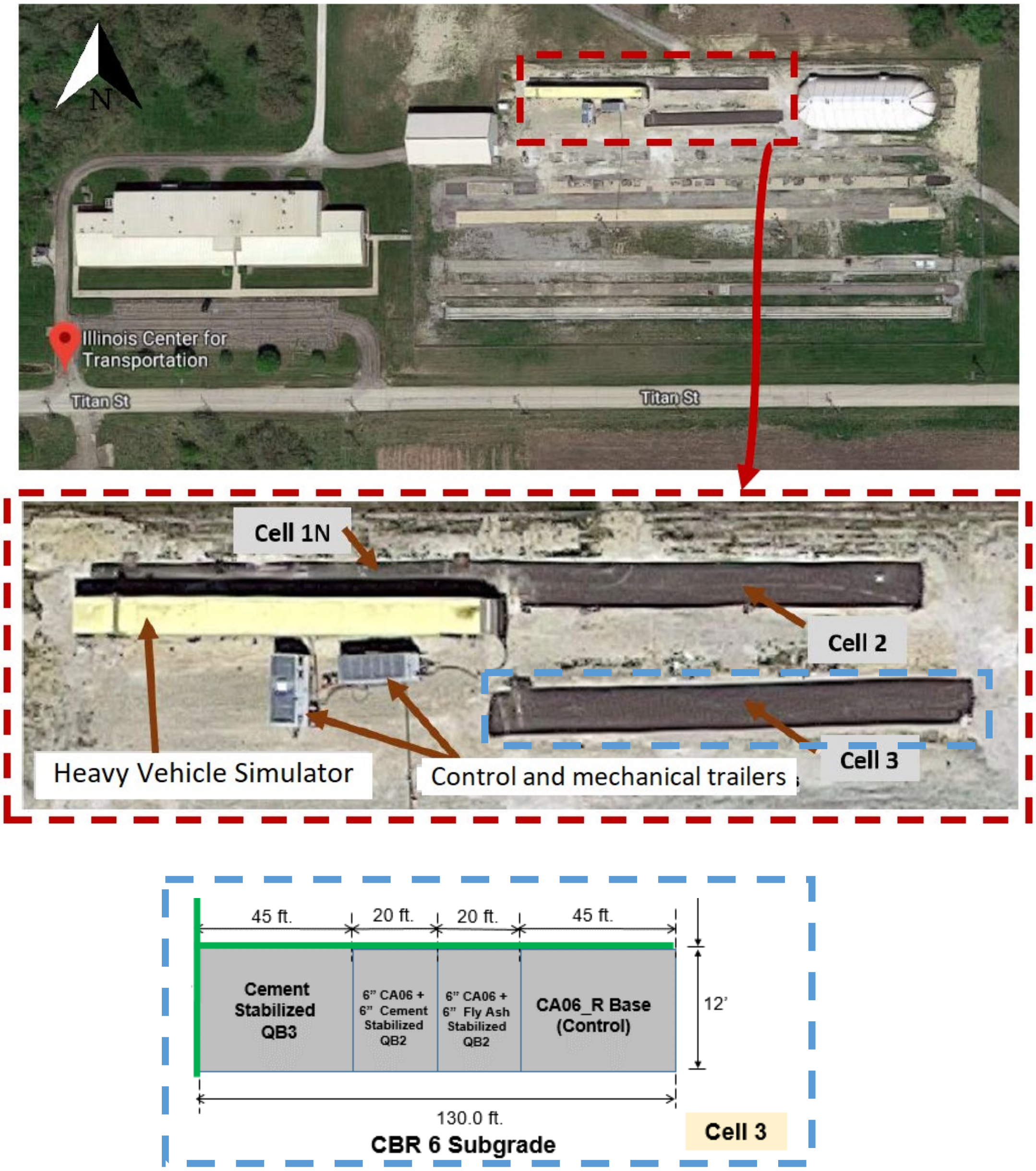


Figure 156. Illustration. Test section locations; ICT (Qamhia 2019).

Pavement Configuration

The pavement configuration of the IP test sections (C3S2 and C3S3) and adjacent test sections (C3S1 and C3S4) is summarized in table 43, where:

- QB2 is a quarry by-product from Thornton, Illinois (south of Chicago), with a high percentage of dolomitic fines; and
- QB3 is a quarry by-product from Dupo, Illinois (south of St Louis, Missouri), with a high percentage of limestone fines.

Table 43. ICT cell 3 pavement cross sections; ICT (Qamhia 2019).

Pavement layer	Thickness (and layer material details			
	C3S1	C3S2 (Inverted pavement)	C3S3 (Inverted pavement)	C3S4
AC	4 in (100 mm)	4 in (100 mm)	4 in (100 mm)	4 in (100 mm)
Base layer	12 in (300 mm) blend of QB3 and 3% Type I cement by weight	6 in (150 mm) dense-graded unbound dolomite aggregate (referred to as CA06_R)	6 in (150 mm) dense-graded unbound dolomite aggregate (referred to as CA06_R)	12 in (300 mm) dense-graded dolomite aggregate (referred to as CA06_R
Subbase layer	12 in (300 mm) blend of QB3 and 3% Type I cement by weight	6 in (150 mm) blend of QB2 and 3% Type I cement by weight	6 in (150 mm) blend of QB2 and 10% Class C fly ash by weight	12 in (300 mm) dense-graded dolomite aggregate (referred to as CA06_R)
Subgrade	Engineered CBR of 6%	Engineered CBR of 6%	Engineered CBR of 6%	Engineered CBR of 6%

It should be noted that even though section C3S3 is referred to here as an IP, the subbase in that section was not as strong as the CTB in traditional IP.

Figure 157 shows the dense-graded unbound dolomite aggregate used as base layer in the two IP sections (C3S2 and C3S3).

Figure 157. Photo. Dense-graded unbound dolomite aggregate layer construction in Cell 3 (Qamhia 2019).

QB2 and QB3 are well-graded quarry by-product sands, with QB2 having a slightly coarser gradation than QB3. The QB2 material had higher MgO content than QB3, while QB3 had higher SiO2 and Al2O3 content, which are associated with higher long term strength gain.

Construction

The South African slushing technique was not used in the construction of the unbound granular base layers.

Achieved densities and moisture content are summarized in table 44. The achieved subgrade compaction varied by up to about 8 percent and moisture content by up to 1.5 percent. The highest compaction for the subgrade was recorded in C3S3, which also recorded the lowest moisture content. The highest compaction for the unbound dolomite aggregate base layer was recorded in C3S3, followed by C3S4 and then C3S2. The driest unbound dolomite aggregate base layer was in C3S4, followed by C3S3 and then C3S2. C3S2 had the lowest compaction and highest moisture in the unbound dolomite aggregate base layer.

Table 44. Compacted density and moisture; ICT (based on Qamhia 2019).

Section	Material	Average field density (pcf)	MDD (pcf)	Relative compaction (%)	Achieved moisture content (%)	Optimum moisture content (%)	Achieved moisture content as percentage of OMC (%)
C3S1	QB3 + cement	128.0	129.9	98.4	5.3	8.4	63
	Subgrade	117.8		96.8	10.8		
C3S2	Unbound base	133.7	131.8	101.5	5.0	5.4	93
	QB2 + cement Subbase	127.3	137.5	92.5	8.7	9.1	96
	Subgrade	125.4		103.4	10.3		
C3S3	Unbound base	143.9	131.8	109.2	4.2	5.4	78
	QB2 + fly-ash subbase	131.1	135.6	96.6	6.5	8.0	81
	Subgrade	127.3		104.9	9.3		
C3S4	Unbound base	142.6	131.8	108.1	4.1	5.4	76
	Subgrade	122.9		100.8	10.4		

As-constructed thicknesses are illustrated in figure 158, where the black arrows on the left indicate target thicknesses. The AC thickness generally decreases from C3S1 to C3S4. Base (or base plus subbase) thickness presented some variation, with the thickness in C3S2 slightly higher than in the other sections.

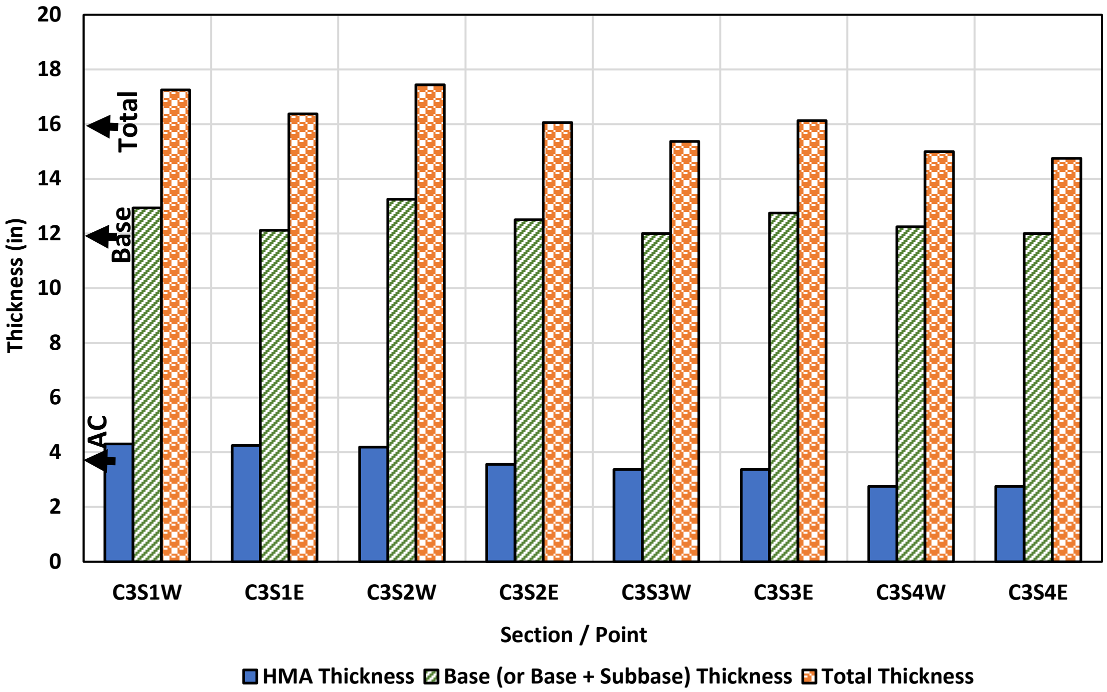


Figure 158. Graph. As-constructed thicknesses; ICT (reproduced from Qamhia 2019).

Figure 159 shows UCS values from laboratory-prepared cylinders and cubes retrieved from the test sections exposed to two harsh winters and many freeze-thaw cycles. The results indicated that the subbase in C3S2, comprised of a cement-stabilized QB2, had a significantly higher UCS than the subbase in C3S3, which consisted of a fly ash–stabilized QB2 material.

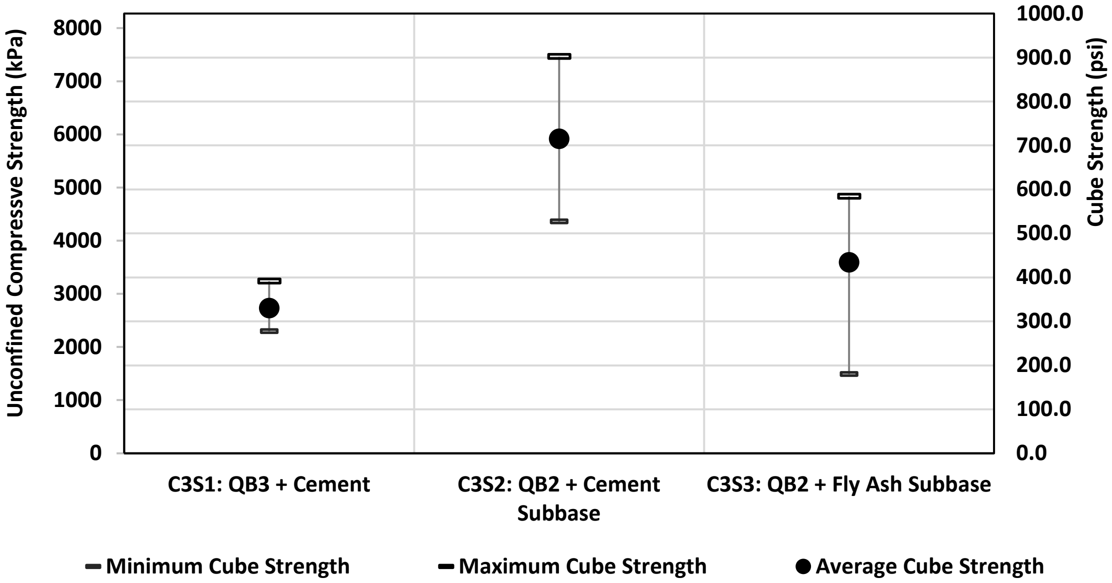


Figure 159. Graph. Unconfined compressive strength values of the cement- and fly ash–stabilized quarry by-products and aggregate material combinations; ICT (reproduced from Qamhia 2019).

The AC was constructed directly on top of the granular base course, with no prime coat or chip seal applied. The AC was compacted in two equal-thickness lifts (2 inches [50 mm]), using a PG 64-22 asphalt binder and maximum nominal aggregate size 0.375 inches (9.5 mm).

Traffic Loading

The ICT IP test section was subjected to an initial 100,000 passes of a 10-kip (44.5 kN) unidirectional load with a tire pressure of 110 psi (758 kPa) at constant speed, followed by 35,000 passes of an increased unidirectional load of 14 kip (62.3 kN) and increased tire pressure of 125 psi (862 kPa).

Environmental Conditions

After the first 85,000 passes, with the arrival of winter, it was decided to insulate the test section. Test sections were kept within a temperature-controlled environment using heaters and insulation panels to maintain the AC surface at 75 degrees Fahrenheit (24 degrees Celsius). Figure 160 shows the insulation assembly, including the heaters used inside the insulation panels.

Figure 160. Photo. Insulation panels and heaters; ICT (Qamhia 2019).

The depth of the water table level varied within the test sections, as shown in figure 161, which includes measurements observed one week after trenching. Section C3S4 had the highest water table level, approximately 43 inches (1,092 mm) below the top of the AC layer (27 inches [686 mm] below the top of the subgrade).

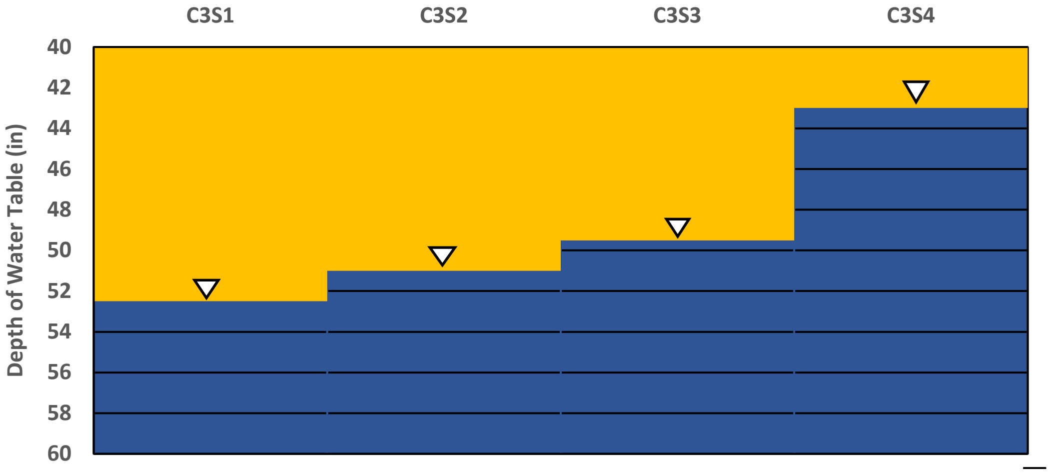


Figure 161. Graph. Depth of water table levels from the surface; ICT (reproduced from Qamhia 2019).

Performance

Figure 162 shows the development of rutting. The rut depth in C3S4, which did not have a stabilized subbase, developed faster than the other sections. It was reported that the C3S4 pavement had the thinnest as-constructed AC layer, the lowest achieved density, and the shallowest water table depth when compared to other sections. Among the two IP sections, C3S3, with fly ash–stabilized subbase, developed more rutting than C3S2, which had a cement-stabilized subbase. Section C3S1, which had a cement-stabilized base and subbase, presented the lowest rut depth.

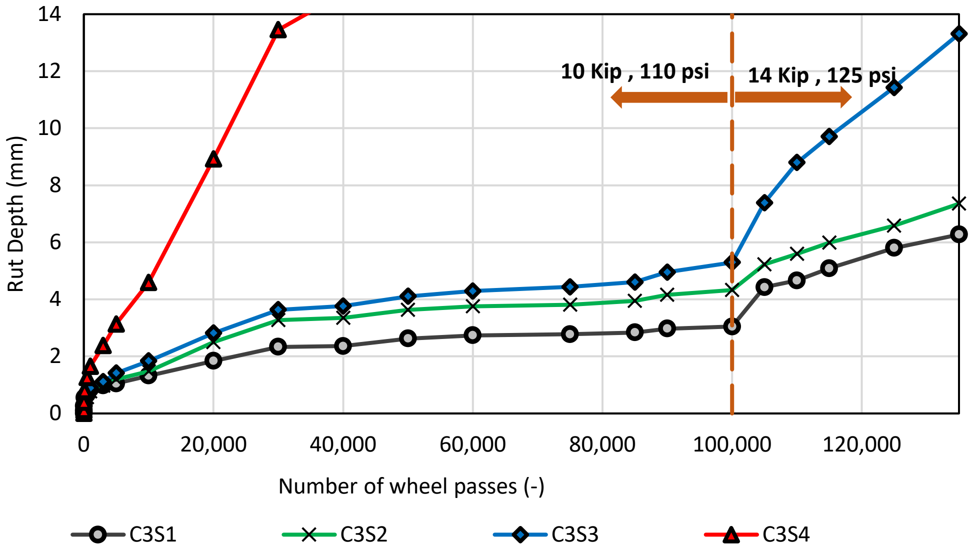


Figure 162. Graph. Surface rut depth vs. number of load repetitions; ICT (reproduced from Qamhia 2019).

Cracks were not observed in the sections with stabilized layers (C3S1, C3S2, and C3S3), but they appeared in the AC layer in C3S4 after 30,000 load passes.

Figure 163 shows the DCP penetration into the base, subbase, and subgrade layers for the various test sections. The sections with a higher number of DCP drops per inch of penetration and the lower water table levels presented less rut depth development.

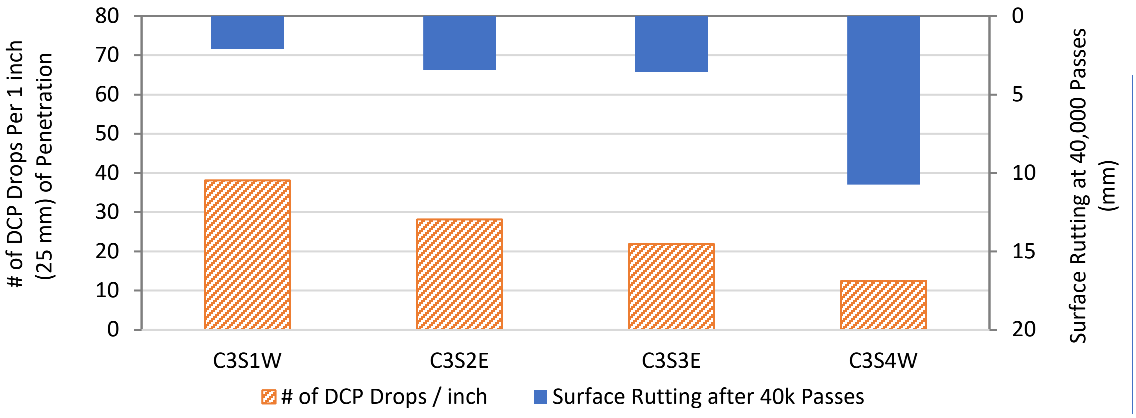


Figure 163. Graph. Dynamic cone penetrometer penetrations into base, subbase, and subgrade layers; ICT (Qamhia 2019).

Analysis of deflection bowl parameters using Horak's benchmarking methodology is shown in figure 164 through figure 167. Air temperature during testing was 75 degrees Fahrenheit (23.9 degrees Celsius) before APT and 76 degrees Fahrenheit (24.4 degrees Celsius) after APT. Surface temperature varied from 104.0 to 121.4 degrees Fahrenheit (40 to 49.7 degrees Celsius). No correction for temperature was applied.

Figure 164 shows maximum deflection. Maximum deflection for the IP section with a CSB (C3S2) was lower than the for the section with a fly ash–stabilized subbase (C3S3). The highest deflections were reported for the pavement section with unbound granular base and subbase layers (C3S4). The following observations were made:

- C3S4W fell within Horak's severe condition category, C3S3 was between warning and severe, C3S1E was within the warning category, and C3S1W and C3S2 were within the sound category.
- Higher deflections were observed at C3S1E compared to C3S1W. C3S1W had a thicker AC, base course, and subbase layers than C3S1E.
- Overall maximum deflections for C3S1 were higher than for C3S2.
- The data for C3S1 showed that the maximum deflection increased following trafficking, whereas the data for C3S2 showed a slightly reduction in maximum deflection following trafficking, and data for C3S4W showed a more significant reduction. The reduction in maximum deflection is believed to be due to further densification of unstabilized granular layers with traffic loading. The pavement at C3S4W included the thickest layer of non-stabilized granular material.

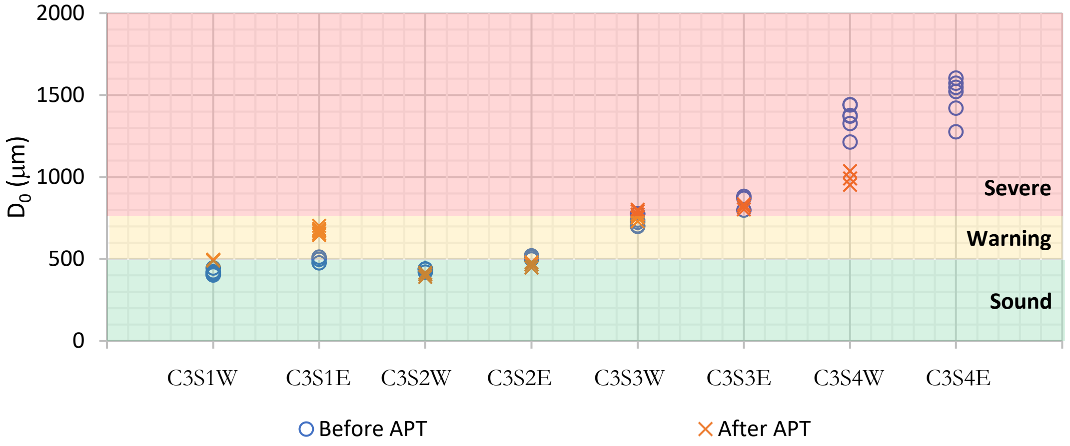


Figure 164. Graph. Maximum deflection; ICT (FWD data provided by Qamhia).

Figure 165 shows the BLI, which according to Horak (2008), correlates mostly with the condition of the surface and base layers. The following observations were made:

- C3S4 fell within the severe category, and C3S3 was between the warning and severe categories. C3S1E was within the warning category, C3S1W was within the sound category, and C3S2 was within both sound and warning.
- BLI decreased following trafficking in C3S1, C3S3E, and C3S4W, indicating further densification of the non-stabilized granular pavement layers.

The AC was the thinnest at C3S4, followed by C3S3, and C3S2, and the thickest AC was found in C3S1. The thickness of the AC could have affected D_0 and BLI.

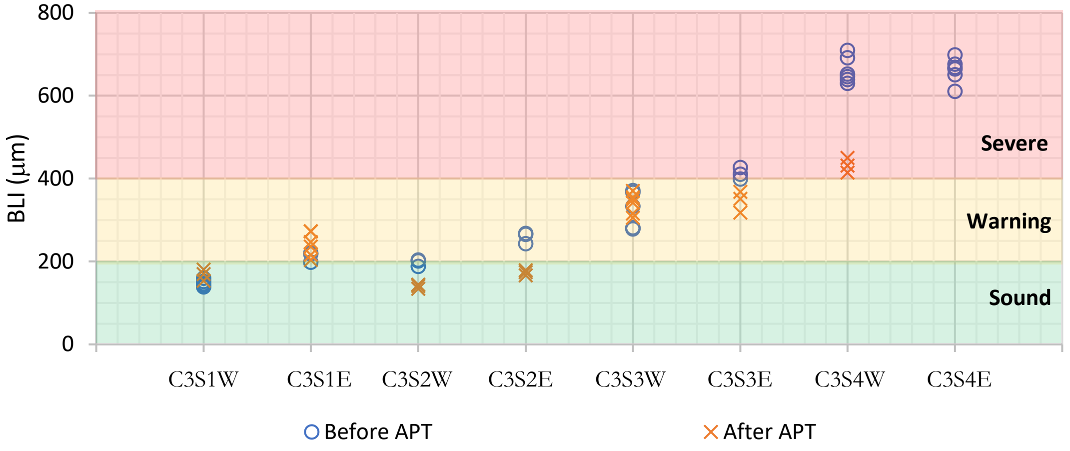


Figure 165. Graph. Base layer index; ICT (FWD data provided by Qamhia).

Figure 166 shows the MLI, which, according to Horak (2008), correlates mostly with the condition of the subbase. The following observations were made:

- C3S1 and C3S2 generally fell within the warning category, except for the measurements in C3S1E after APT, which was in the severe category. C3S3 and C3S4W were within the severe category.
- MLI slightly increased following trafficking at C3S1, C3S2, and C3S3, but it decreased at C3S4W. This is potentially due to the stabilized subbase in C3S1, C3S2, and C3S3 developing cracks or microcracks, whereas the subbase in C3S4 was non-stabilized and may have densified with traffic loading, providing a stiffer layer.

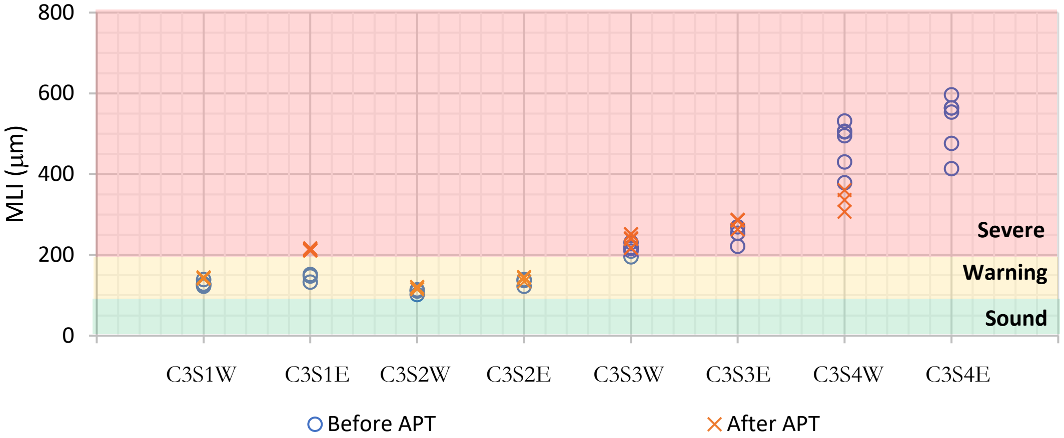


Figure 166. Graph. Middle layer index; ICT (FWD data provided by Qamhia).

Figure 167 shows the LLI, which according to Horak (2008), correlates mostly with the condition of the subgrade. The following observations were made.

The LLI followed a trend similar to the other parameters investigated, with the lowest values being recorded for C3S2, followed by C3S1, then C3S3 and lastly C3S4. This indicates that the subgrade also played a role in the overall pavement structural condition. Subgrade conditions were not the same throughout all test sections in Cell 3. The highest water table level (figure 161) was found at C3S4, followed by C3S3, which also corresponded to the highest and second highest recorded LLI. Backcalculated subgrade moduli (table 45) also indicated that the subgrade at C3S4 was the lowest among the test sections, followed by the subgrade at C3S3. The backcalculated moduli for C3S1 and C3S2 were significantly higher. LLI increased following trafficking in C3S1 and C3S2, and to a lesser degree in C3S3.

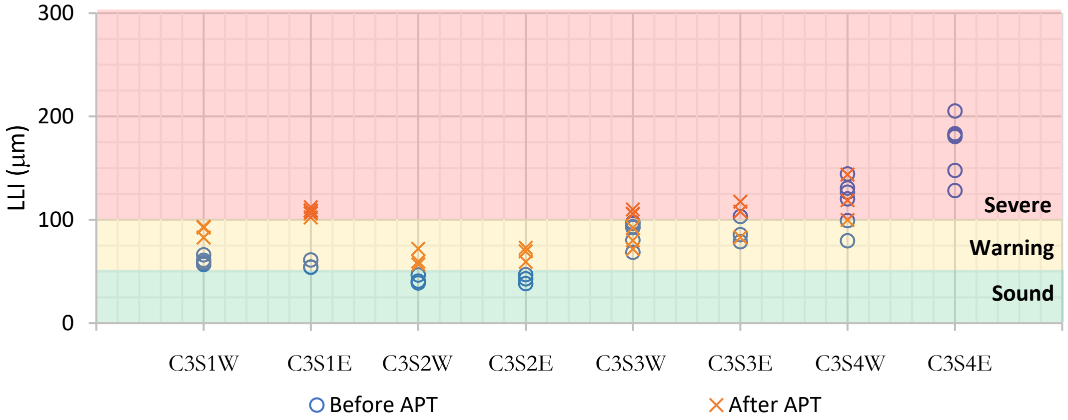


Figure 167. Graph. Lower layer index; ICT (FWD data provided by Qamhia).

FWD Backcalculated Moduli

Backcalculated layer moduli obtained by Qamhia (2019) are included in table 45. The moduli were calculated using a forward calculation analysis approach (i.e., manually fitting FWD deflection bowls). The modulus assignment for the stress-dependent granular layers was calculated using the K-θ model by Hicks and Monismith (1971) (figure 168). The analysis assumed a horizontal to vertical modulus ratio (M_{Rh}/M_{Rv}) of 0.15 and a shear to vertical modulus ratio (G/M_{Rv}) of 0.35, based on findings of Kazmee (2018). The Mishra and Tutumluer (2012) relationship between the regression parameters in the K-θ model (figure 169) was used in the analysis.

$$M_R = K\theta^n$$

Figure 168. Equation. Relationship between the regression parameters in the K-θ model.

$$K = 868.29n^{-3.78}$$

Figure 169. Equation. Relationship between the regression parameters in the K-θ model.

where:

M_R = resilient modulus.
K, n = regression coefficient.
θ = bulk stress (sum of principal stresses).

Table 45. FWD backcalculated layer moduli obtained by matching deflection basin; ICT (Qamhia 2019).

Section	AC	Base	Subbase	Subgrade
C3S1	300 ksi (2070 MPa)[+] 135 ksi (930 MPa)*	250,000 psi (1,720 MPa)	250,000 psi (1,720 MPa)	11.7 ksi (81 MPa)
C3S2	300 ksi (2070 MPa)	K = 7,800 psi (54 MPa) n = 0.5 $M_{Rh} = 0.15\ M_{Rv}$ $G = 0.35\ M_{Rv}$	280,000 psi (1,930MPa)	12.6 ksi (87 MPa)
C3S3	300 ksi (2070 MPa)[+] 225 ksi (1550 MPa)*	K = 1,750 psi (12.1 MPa) n = 0.55 $M_{Rh} = 0.15\ M_{Rv}$ $G = 0.35\ M_{Rv}$	45,000 psi (310 MPa)	6.5 ksi (45 MPa)
C3S4	350 ksi (2410 MPa)	K = 1,350 psi (9.3 MPa) n = 0.51 $M_{Rh} = 0.15\ M_{Rv}$ $G = 0.35\ M_{Rv}$	K = 1,350 psi (9.3 MPa) n = 0.51 $M_{Rh} = 0.15\ M_{Rv}$ $G = 0.35\ M_{Rv}$	4.6 ksi (32 MPa)

[+] AC modulus fixed to 300 psi (2,070 MPa).

* Backcalculated AC modulus that produces best fit predicted deflection basin.

The backcalculated modulus of the cement-stabilized subbase (in C3S2) was considerably higher than that of the fly ash–stabilized subbase (in C3S3).

Figure 170 shows the relationship between backcalculated vertical moduli and bulk stress for the stress-dependent layers detailed in table 45. Even though the material used was the same for all the layers shown in figure 170, and the layer above was the same (according to designed thicknesses), the higher the modulus of the underlying layer, the higher the backcalculated base course modulus. This shows that the modulus of the granular base course layer depended not only on their material and layers above but also on the stiffness characteristics of the layers underneath. The C3S2 base course backcalculated modulus was significantly higher than the backcalculated base course moduli of the C3S3 section, which in turn was higher than that calculated for C3S4, where no stabilized layer was present.

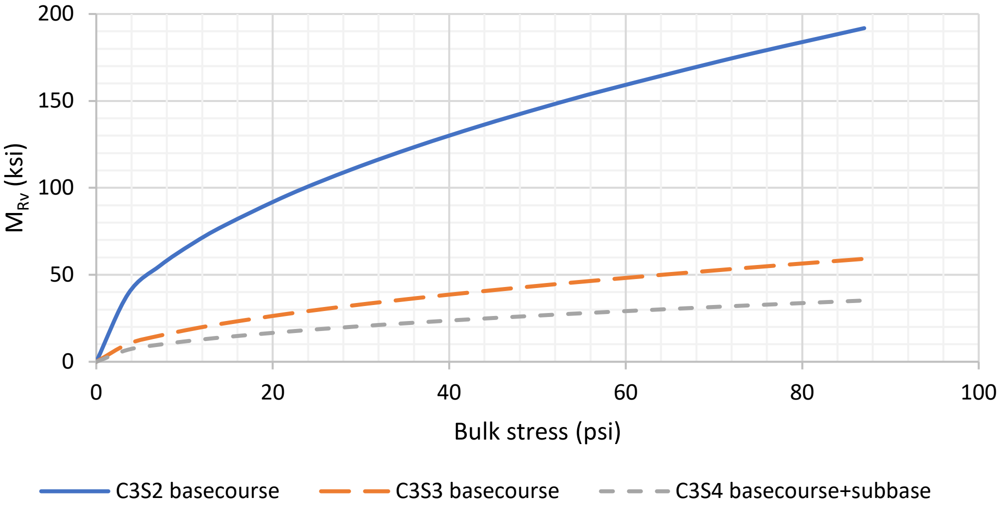


Figure 170. Graph. Backcalculated moduli vs. bulk stress; ICT (data from Qamhia 2019).

Durability

In addition to the APT, Qamhia et al. (2019) conducted durability tests on laboratory-prepared specimens and samples extracted from the test sections, in accordance with AASHTO T135 wet-dry and AASHTO T136 freeze-thaw durability test methods. Samples tested included QB3 with 3 percent cement from C3S1, QB2 with 3 percent cement and QB2 with 10 percent fly ash from C3S3. The authors reported the following: 1) The QB2 material, with high percentages of dolomitic fines, had better durability than the QB3 material, which had higher percentages of calcium limestone fines, 2) stabilization with 3 percent cement resulted in better wet-dry durability performance than stabilization with 10 percent Class C fly ash, and 3) samples with improved packing, compacted at or near maximum dry density, resulted in better durability.

Cost Assessment

A cost assessment prepared by Qamhia (2019) shows the as-designed total construction costs of each section, compared to as-constructed costs (i.e., based on constructed thicknesses) and the as-constructed costs normalized by the impact of 100,000 ESALs in terms of rutting (figure 171). On the basis of the normalized results, Qamhia (2019) concluded that the largest cost savings were expected from the sections incorporating a cement-stabilized layer (C3S1 and C3S2), followed by the section incorporating a fly ash–stabilized layer (C3S3). The IP sections (C3S2 and C3S3) showed a higher cost-benefit than the granular pavement with no stabilized layer (C3S4), but it was less than for the section with the entire granular layers stabilized with cement (C3S1).

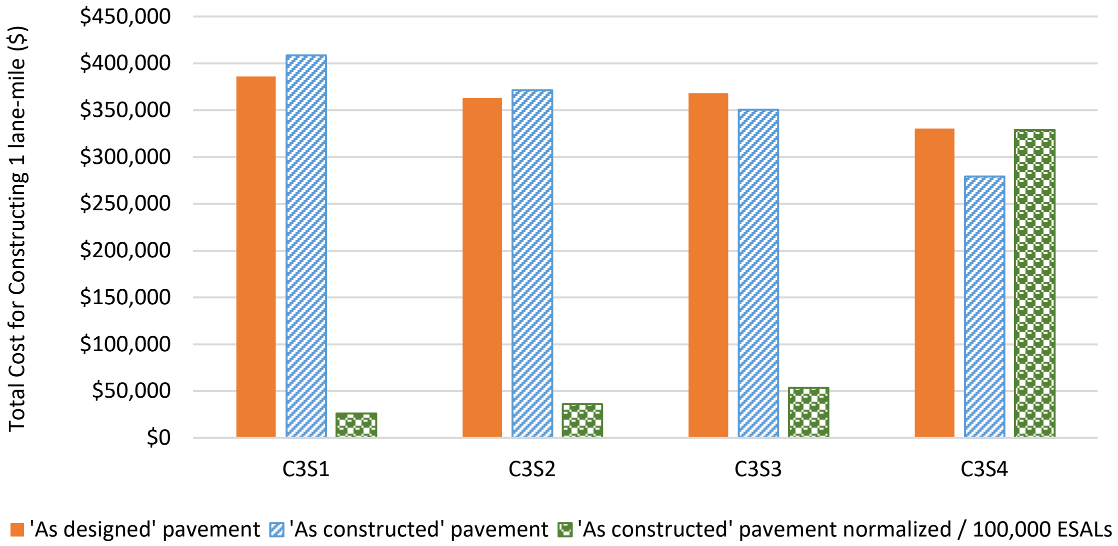


Figure 171. Graph. Total costs; ICT (data from Qamhia 2019).

Environmental Sustainability Assessment

Qamhia (2019) conducted an environmental assessment analysis considering the materials and construction phase for the as-constructed section, taking into consideration the actual constructed thicknesses as shown in figure 158. When specific project data were not available, the analysis was conducted using Ecoinvent library data. The results for the as-constructed sections were further normalized by the impacts—in terms of rut depth per 100,000 ESALs—to provide an indication about the effectiveness of each solution. The impacts were calculated for the construction of one 12-ft lane-mile.

For all categories considered, environmental impacts decreased from C3S1 to C3S4, as shown in table 46 and figure 172. The production of cement had significant impact on GWP, leading to the sections containing a cement-stabilized layer (C3S1 and C3S2) to have a higher overall impact in this category. Figure 173 through figure 176 show the contribution of each phase and each material to the total GWP and energy demand for each section.

Table 46. Environmental impacts per lane-mile; ICT as-constructed (data from Qamhia 2019).

Impact indicator	**C3S1 (per lane-mile)**	**C3S2 (per lane-mile)**	**C3S3 (per lane-mile)**	**C3S4 (per lane-mile)**
Total energy consumption (renewable + nonrenewable) (MJ)	2.6E+06	2.2E+06	1.7E+06	1.4E+06
Acidification (kg SO_2 eq)	1.8E+03	1.5E+03	1.2E+03	1.1E+03
Ecotoxicity (CTUe)	8.1E+05	7.4E+05	6.4E+05	5.3E+05
Eutrophication (kg N eq)	1.7E+02	1.5E+02	1.3E+02	1.1E+02
Fossil fuel depletion (MJ surplus)	8.3E+05	7.5E+05	6.6E+05	5.5E+05
GWP (kg CO_2 eq)	2.7E+05	2.1E+05	1.4E+05	1.2E+05
Human health, cancer (CTUh)	5.8E-03	5.1E-03	4.3E-03	3.6E-03
Human health, noncancer (CTUh)	4.7E-02	4.0E-02	3.3E-02	2.7E-02
Human health effects, particulates (kg $PM_{2.5}$ eq)	2.4E+02	2.3E+02	2.1E+02	1.9E+02
Ozone depletion (kg CFC-11 eq)	3.0E-02	2.7E-02	2.5E-02	2.1E-02
Smog formation (kg O_3 eq)	3.4E+04	3.1E+04	2.6E+04	2.3E+04

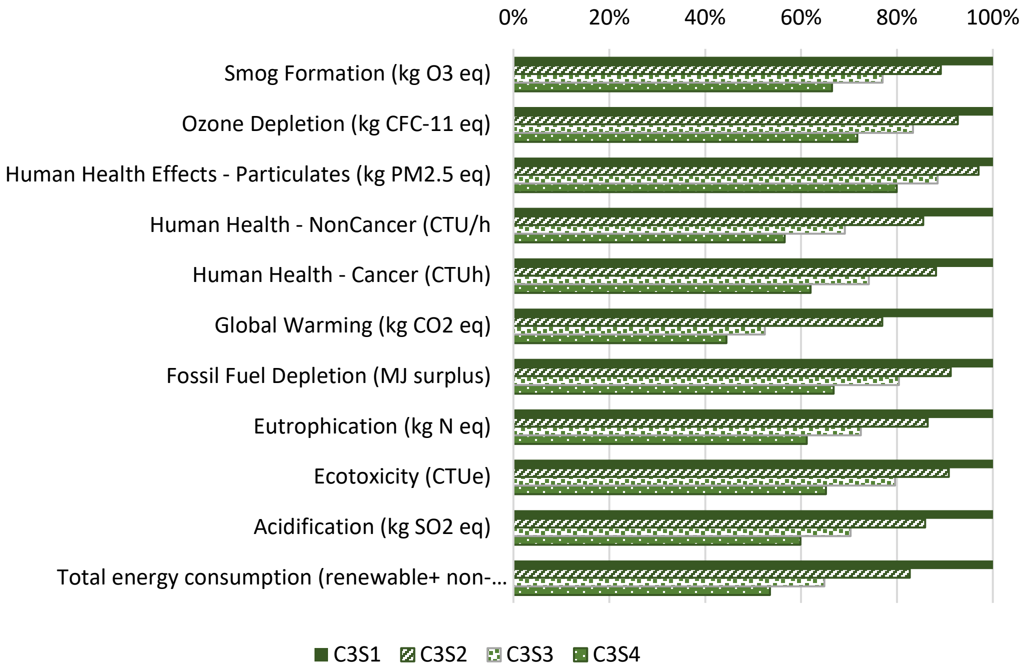
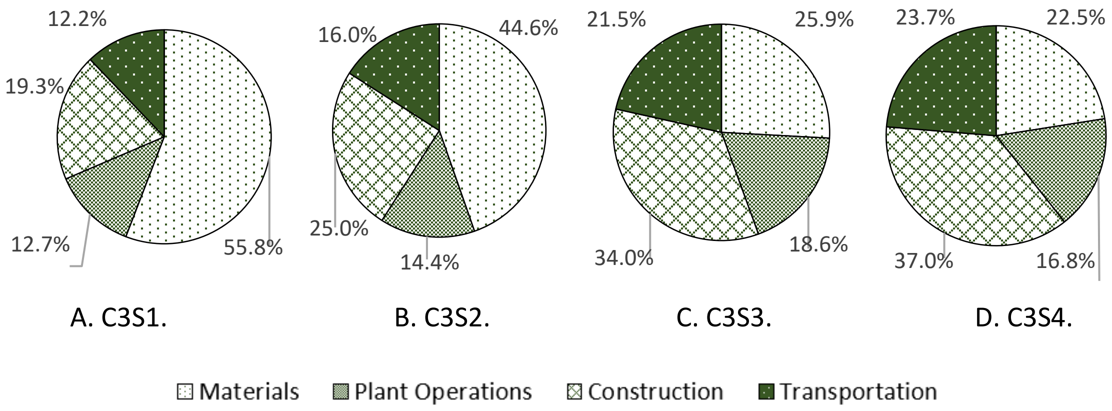


Figure 172. Graph. Comparison of normalized impact indicator values for each pavement section; ICT as-constructed (data from Qamhia 2019).



A. C3S1.

B. C3S2.

C. C3S3.

D. C3S4.

Figure 173. Graph. Contribution of each stage to GWP (kg CO_2 eq) for each pavement section; ICT as-constructed (data from Qamhia 2019).

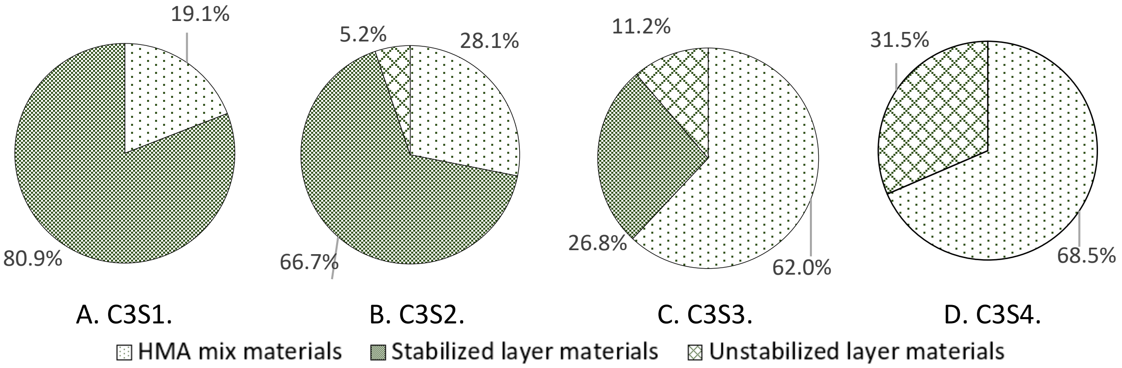


Figure 174. Graph. Contribution of each material to GWP (kg CO_2 eq) for each pavement section; ICT as-constructed (data from Qamhia 2019).

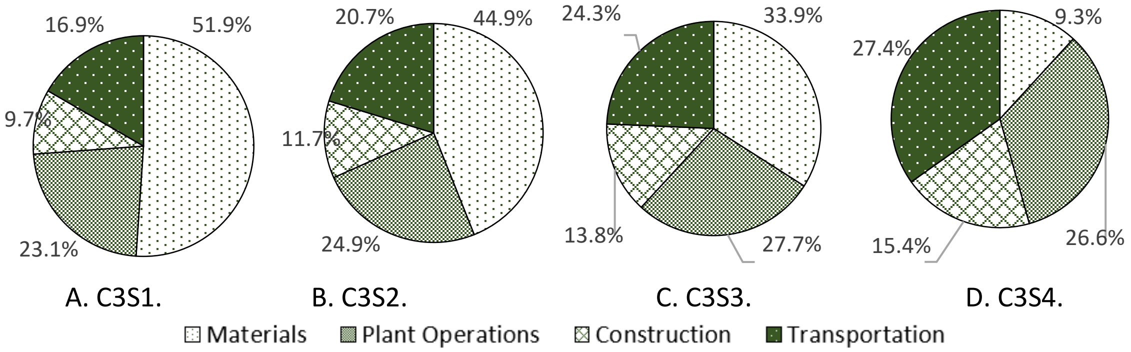


Figure 175. Graph. Contribution of each stage to total use of energy resources for each pavement section; ICT as-constructed (data from Qamhia 2019).

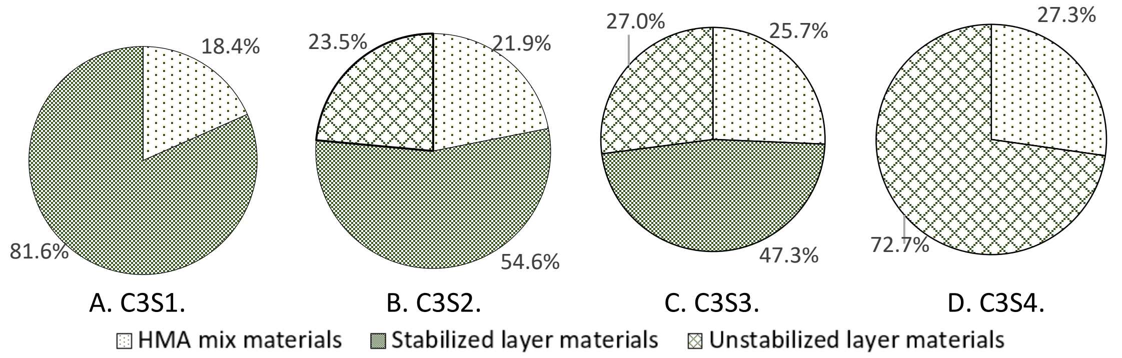


Figure 176. Graph. Contribution of each material to total use of primary energy resources for each pavement section; ICT as-constructed (data from Qamhia 2019).

When the results were normalized by the effects of 100,000 ESALs, the opposite trend was observed. C3S4 showed the highest impact, followed by C3S3, C3S2, and lastly C3S1, as shown in figure 177. The sections with cement represented less impact than the section with fly ash and the section with no stabilized layer.

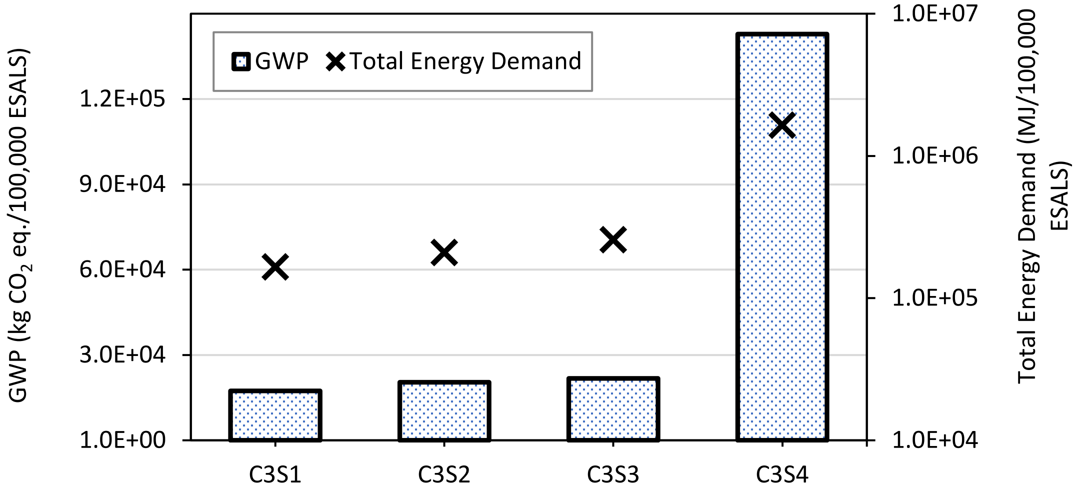


Figure 177. Graph. Normalized GWP and total energy demand for each 100,000 equivalent single axle loads trafficking for as-constructed sections; ICT (adapted from Qamhia 2019).

The results for analysis conducted for as-designed sections (without adjustment for actual constructed thicknesses) were generally similar to those of the as-constructed sections. Table 47 shows the effect of construction variability on the results. The values on the table represent the as-constructed impacts in relation to as-designed. Sections where the constructed thicknesses were lower than the designed thickness presented a variation of up to about –30 percent in the results, whereas sections where layer thicknesses were higher than designed presented a variation of up to about +7 percent in the results.

Table 47. Environmental impacts of as-constructed pavements in relation to as-designed pavements; ICT (data from Qamhia 2019).

Impact indicator	C3S1 (per lane-mile)	C3S2 (per lane-mile)	C3S3 (per lane-mile)	C3S4 (per lane-mile)
Total energy consumption (renewable + nonrenewable) (MJ)	105.7%	100.1%	91.2%	79.0%
Acidification (kg SO_2 eq)	105.5%	101.3%	93.5%	83.3%
Ecotoxicity (CTUe)	106.8%	97.6%	85.8%	70.8%
Eutrophication (kg N eq)	105.3%	102.0%	95.2%	85.9%
Fossil fuel depletion (MJ surplus)	106.5%	98.6%	87.7%	74.0%
GWP (kg CO_2 eq)	105.3%	100.8%	92.8%	82.1%
Human health, cancer (CTUh)	106.3%	99.0%	88.3%	75.0%
Human health, noncancer (CTU/h)	106.5%	97.6%	85.5%	70.5%
Human health effects, particulates (kg $PM_{2.5}$ eq)	105.3%	103.4%	96.7%	89.5%
Ozone depletion (kg CFC-11 eq)	105.6%	101.8%	94.2%	84.7%
Smog formation (kg O_3 eq)	105.2%	102.8%	96.7%	88.7%

Summary and Remarks

The IP sections in the ICT project were constructed and kept under controlled or closely monitored environments. Two IP sections were constructed, one with a subbase containing 3 percent cement and one with 10 percent fly ash. The section with 3 percent cement performed better in terms of overall rutting, although it was noted that most rutting was associated with the upper layers, especially the AC layer, rather than with the cemented subbase layer. Cracking was not observed.

Cost and environmental impacts (GWP and total energy demand) normalized by the effect of traffic in terms of rutting showed that the IP section with a cement-stabilized subbase (C3S2) was slightly less effective than the section with a base course plus subbase stabilized with cement (C2S1) and slightly more effective than the IP with a fly ash–stabilized subbase (C3S3), while being considerably more effective than the section with no stabilized layer (C3S4). It was noted, however, that C3S4 had the thinnest as-constructed asphalt layer, lowest achieved density, and the shallowest water table depth, which could all have negatively affected pavement performance.

Finally, it is emphasized that the APT was conducted in a controlled environment. Therefore, the influence of climate variations on pavement performance was not simulated. Field conditions, including the influence of climate on the appearance of microcracks and cracks in the CTB layer and AC oxidation, were not accurately represented. It is possible that these factors, leading to potentially higher cracking in the section where the cement-stabilized layer was placed directly below the AC (C3S1), could lead to reduced effectiveness of this solution compared to the IP pavement.

CHAPTER 4. SUMMARY

Inverted pavements are widely used in South Africa because they demonstrated well-performing pavements under high traffic. The IP solution emerged with the need to provide performing roads at relatively low upfront costs. The IP in South Africa has a low initial construction cost and a relatively low maintenance cost. The experience in South Africa showed that IP technology was effective for the South African arid climate (dry and warm) conditions and when effective crack-sealing programs are followed. Given that the mechanistic behavior of unbound granular layers is highly affected by moisture conditions, IP should be used with caution in cold and humid areas climates.

In general, case studies indicated that the unbound base layer placed between the AC and CTB layers in IP could be effective in delaying the reflection of cracking from the CTB layer to the pavement surface. However, when crack sealing was not timely applied, once cracks appeared, pavement deterioration accelerated due to water ingress. This would reduce the pavement support capacity (i.e., UAB layer modulus of elasticity). This then would lead to greater stresses and strains throughout the pavement, accelerating cracking and rutting.

In South Africa, the AC layer in IP is generally less than 2.3 inches (60 mm). However, in the United States, the IP AC layer thickness is 2.5 to 6.0 inches (60 to 150 mm). In addition, in South Africa and Australia, there are maximum moisture condition limits specified for the UAB prior to application of a prime coat and construction of the subsequent layers. In South Africa, the top half of the unbound aggregate layer is required to dry to 50 percent of OMC. In Australia, the specifications vary (e.g., in Western Australia, crushed rock bases should dry to a maximum of 60 percent of modified OMC).

Good bonding between the UAB and the top AC layer(s) should be achieved. Relatively high horizontal stresses and strains may develop at the bottom of the AC layer. This would lead to premature AC cracking. It was unclear that a prime coat was applied on the UAB prior to AC construction in the United States projects.

Some of the IP cases in the United States deviate from the South African design, construction, and maintenance practices. Pavement was constructed with significantly thicker AC layer, a threshold was not identified for drying UAB prior to the construction of subsequent layers, constructed in harsh cold climate, and/or a crack-sealing program was absent. Nevertheless, most of the IP case studies showed satisfactory performance.

The cement-stabilized subbase provides a strong and relatively moisture-resilient layer, while unstabilized crushed rock stiffness may experience drastic changes with variations in moisture. For locations that require a more moisture- and freeze-resilient solution, quarry by-products stabilized with 3 percent cement provided durable pavement foundation. In addition, consideration could be given to the use of a nontraditional IP by incorporating an asphalt emulsion or foamed asphalt-stabilized base course. The cement-treated subbase would continue to provide a strong and moisture-resilient layer foundation, and the asphalt-stabilized granular base course would still act as a retardant to the propagation of reflective cracking, delaying the appearance of cracks in the AC layer.

Limited information was available to perform LCCA and LCA considering the entire life-cycle of the pavement (from cradle to grave). Nevertheless, LCCA and LCA analysis performed on select case studies indicated that it is possible to achieve lower costs and environmental impacts with the use of IP, although this was not the case for all the sections analyzed. A summary of the findings presented below:

- In the New Mexico I-25 case study, LCCA and LCA analysis were conducted assuming a cycle of maintenance and rehabilitation activities that would be required to maintain the IP and CP in similar condition based on historical performance data. The analysis indicated higher life-cycle costs and environmental impacts for the IP. The rate of deterioration in the IP section was faster than that of the CP that resulted in higher life-cycle cost and environmental impact. Many different factors were believed to play a role in the higher deterioration rates in the IP including harsh winter climatic conditions, AC thickness, mixture selection, and maintenance practices.

- The LA-97 case study in Louisiana indicated higher construction costs, but generally lower environmental impacts from the IP compared to the CP. Both pavement sections presented a similar IRI after 28 years, with the IP section presenting generally more rutting and less cracking than the control section.

- The Quarry Access Roads in North Carolina case indicated lower construction costs and lower environmental impacts of the IP, with both pavements showing only limited cracking after six years.

- The Morgan County Quarry Access Road case study in Georgia indicated the IP had higher initial construction environmental impacts but better performance compared to the CP. The South African slushing technique was applied and proved to work better than Georgia's traditional base course compaction practice.

- In the LaGrange Bypass case study, the IP solution was compared to a conventional PCC pavement. Construction costs were lower for the IP, while the environmental impacts varied. Initial construction of the IP represented a lower GWP but a higher total use of energy.

- In Illinois, the ICT APT case study indicated that when normalized by the impact of 100,000 ESALs on rutting, the IP sections had total costs slightly higher than a CP with a cement-stabilized base and lower than a pavement with no stabilized layer. The opposite trend was observed when comparing normalized environmental impacts, with the IP representing more impacts than the pavement with no stabilized layer and less impact than the pavement with the entire base course stabilized with cement.

The literature review and information presented on the United States case studies showed that IP technology could be successfully used if appropriate design, construction, and maintenance practices are followed. It is suggested, however, that IP be avoided in locations with harsh climates or where extreme high moisture events are likely to occur (such as flooding and inundations). Available data and information on maintenance and rehabilitation activities were limited, thus not allowing for quantifying entire life-cycle costs and environmental impacts. Based on the extensive evaluation of eight projects in the United States and the review of best practice worldwide, the following is suggested for future projects:

- Apply IP sections in relatively drier and warmer environments first—conditions for which this type of pavement was proven effective in South Africa.
- Specifying a maximum moisture content in the UAB layer prior to the application of the prime and construction of the AC layer.
- Use the South African slushing technology to improve particle interlock.
- Application of a prime coat on top of the UAB using a proper material and at suitable application rate to enhance bonding and providing a waterproof membrane.
- Potentially including a chip seal following the prime coat on top of the UAB, especially in areas of high rainfall to enhance the waterproof layer.
- Use of thinner AC layers to enhance cost and environment effectiveness.
- Implementation of a highly responsive and effective annual crack-sealing program to minimize water ingression.
- Use adequate drainage features, especially in areas of high-water table level, high rainfall, and sections in cut; this includes consideration of features to avoid damaging effects of capillary rise of water into the upper subgrade layers and/or pavement layers.

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APPENDIX A: AC MIX DESIGNS

A.1 I-25, COLFAX COUNTY, NEW MEXICO

A.1.1 AC Mix

Table 48. SP-III Mix Design, Compaction Parameters; I-25, Colfax County, New Mexico.

Design ESALs (mi)	$N_{initial}$	N_{design}	$N_{maximum}$
8.8	8	100	160

Table 49. SP-III Mix Design, Materials; I-25, Colfax County, New Mexico.

Combination Used		Bulk Specific Gravities	T84/T85 Av. Abs. %
1"	24.0%	2.674	2.4
1/2"	25.0%	2.673	2.4
C/F	30.0%	2.719	2.5
Filler	5.0%	2.518	2
RAP	15.0%	2.724	
Antistripping Additive	1.0%	3.000	

Table 50. SP-III Mix Design, Aggregates; I-25, Colfax County, New Mexico.

Sieve Size	% Passing	Specification	Acceptance Tolerances
2" (50.8 mm)	100		
1.5" (38.1 mm)	100		
1" (25.4 mm)	100	100	100
3/4" (19.0 mm)	96	90-100	91-100
1/2" (12.7 mm)	81	Max. 90	100
3/8" (9.5 mm)	70		62-78
NO. 4 (4.7 mm)	43		36-50
NO. 8 (2.4 mm)	29	23-49	
NO. 16 (1.2 mm)	22		
NO. 30 (0.6 mm)	17		
NO. 50 (0.3 mm)	13		
NO. 100 (0.15 mm)	8.1		
NO. 200 (75 mm)	5	2.0-8.0	3.6-6.4

Table 51. SP-III Mix Design, Properties at Design Gyrations; I-25, Colfax County, New Mexico.

AC (%)	Gmm (T-209)	Gmb (T-166)	Unit Wt. (lb/ft^3)	Air Voids (%)	VMA (%)	VFA (%)	Dust to Binder Ratio
4.80	2.561	2.416	150.7	5.7	14.5	60.8	1.55
5.30	2.531	2.442	152.4	3.6	14	74.1	1.34
5.80	2.518	2.462	153.6	2.2	13.8	83.7	1.21
6.30	2.502	2.472	154.3	1.2	13.9	91.5	1.10

Table 52. SP-III Mix Design, Tensile Strength Ratio; I-25, Colfax County, New Mexico.

Parameter	Value
Average Dry Tensile Strength	161.9 psi
Average Wet Tensile Strength	154.3 psi
Tensile Strength Ratio	95
Specification	> or = 85

Table 53. SP-III Mix Design, Aggregates and RAP; I-25, Colfax County, New Mexico.

Property	Pit Material	RAP
Flat & Elongated Pieces @ 3:1 (ASTM D4791)	16%	13%
Fine Aggregate Angularity (T-304, Method A)	48.7%	
CA 1 Fractured Face (NMDOT)	100%	96%
CA 2 Fractured Faces (NMDOT)	100%	95%
Combined Sand Equivalent (T-176)	79%	
Soundness Loss (T-104)	1%	
LA Wear (T-96)	31%	35%
Aggregate Index Pit #1	15	

A.1.2 OGFC Mix Test Results

Table 54. OGFC Mix Sieve Analysis Average; I-25, Colfax County, New Mexico.

Sieve Size	% Retained	% Passed	Specs
1/2" (12.5 mm)	0.0	100	100
3/8" (9.5 mm)	0.9	97	90-100
NO. 4 (4.75 mm)	51.7	47	25-55
NO. 10 (2.0 mm)	99	1	0-12
NO. 40 (4.25 mm)	99.6	1	0-8
NO. 200 (75 mm)	99.8	0.5	0.0-4.0

Table 55. OGFC Mix Design Data; I-25, Colfax County, New Mexico.

Asphalt Binder Performance Grade	Asphalt Binder Content	Additive Content
PG 70-28+	6.5% by weight of total mix	1.0%

A.2 US-165, OUACHITA PARISH, LOUISIANA

Table 56. Summary of AC Mix Design, Cold Feed Material; US-165, Ouachita Parish, Louisiana.

Cold Feed Material	%
# 67 LS	30
# 11 SP LS	25
KY 11	30
C SAND	15

Table 57. Summary of AC Mix Design, RAP and Binder; US-165, Ouachita Parish, Louisiana.

Material	%
HWY I33 RAP	15
New PG 76-22	3.8
RAP AC Binder	0.8
TOTAL AC Binder	4.6

Table 58. Summary of AC Mix Design, TSR and Permeability; US-165, Ouachita Parish, Louisiana.

Parameter	Value
Tensile Strength Ratio (TSR)	90.8
Permeability	0.2

Table 59. Summary of AC Mix Design, Volumetrics; US-165, Ouachita Parish, Louisiana.

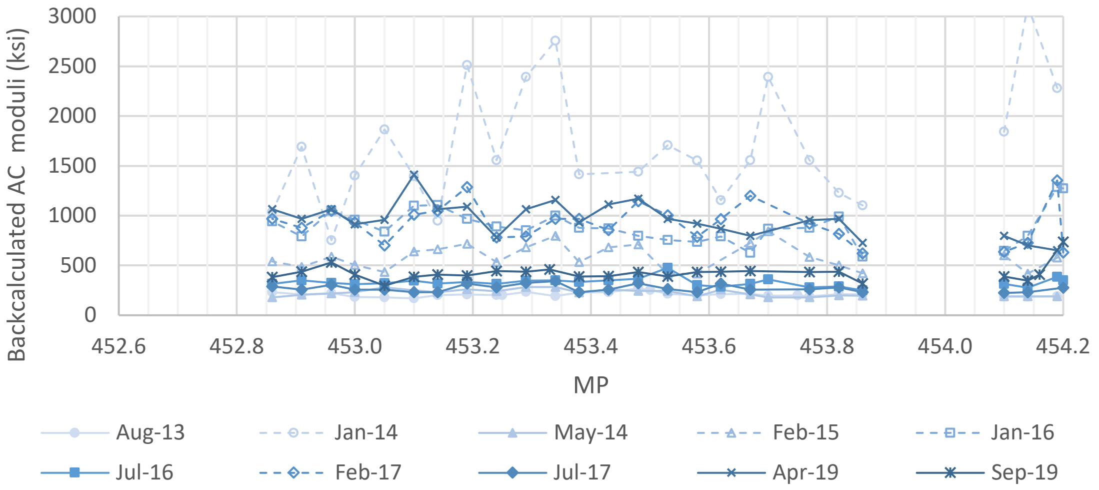
Parameter	Value
Optimum AC Content	4.6
Gmm (Maximum Gravity)	2.469
%Gmm @ N initial	87.8
%Gmm @ N Design	96.1
%Gmm @ N Final	97.3
Air Voids	3.9
Voids in Mineral Aggregates	14.2
Voids Filled with Asphalt	73%
Slope of Compaction Curve	8.03
Dust/Effective AC Ratio	0.9

Table 60. Summary of AC Mix Design, Aggregates; US-165, Ouachita Parish, Louisiana.

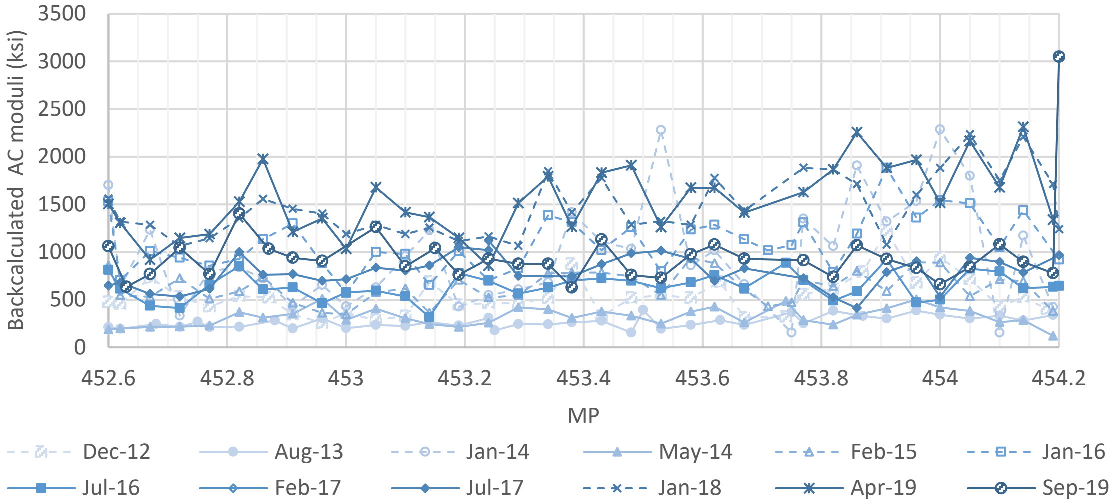
Parameter	Value
Combined Bulk Specific Gravity (Gsb)	2.640
Combined Effective Specific Gravity (Gse)	2.646
Water Absorption	0.66
Coarse Aggregate Angularity (% Crushed)	100
Fine Aggregate Angularity (Uncompacted Voids)	46
Sand Equivalent	84
Flat and Elongated	0.9
% Natural Sand	15
% RAP	15
Friction Aggs	3

APPENDIX B: FWD BACKCALCULATION

B.1 I-25, NEW MEXICO

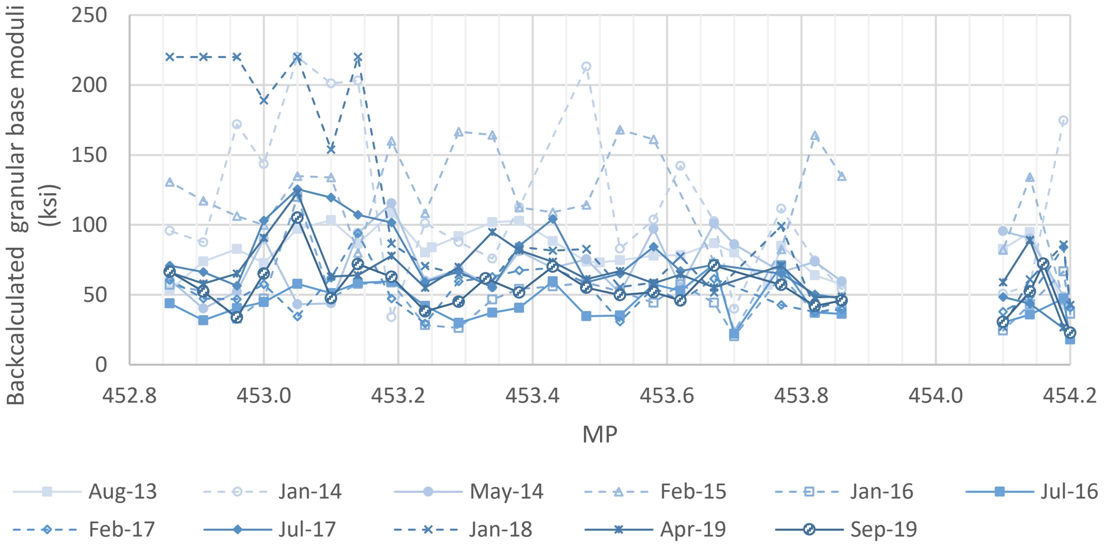


A. Southbound; conventional pavement excluding pavement at bridge overpasses.

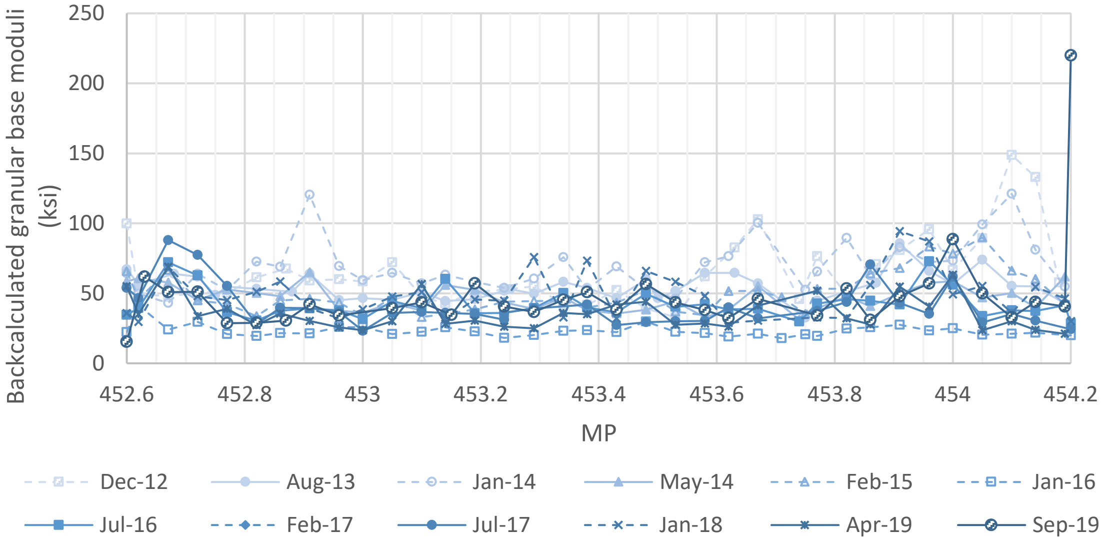


B. Northbound; inverted pavement.

Figure 178. Graph. AC backcalculated moduli; I-25, Colfax County, New Mexico.

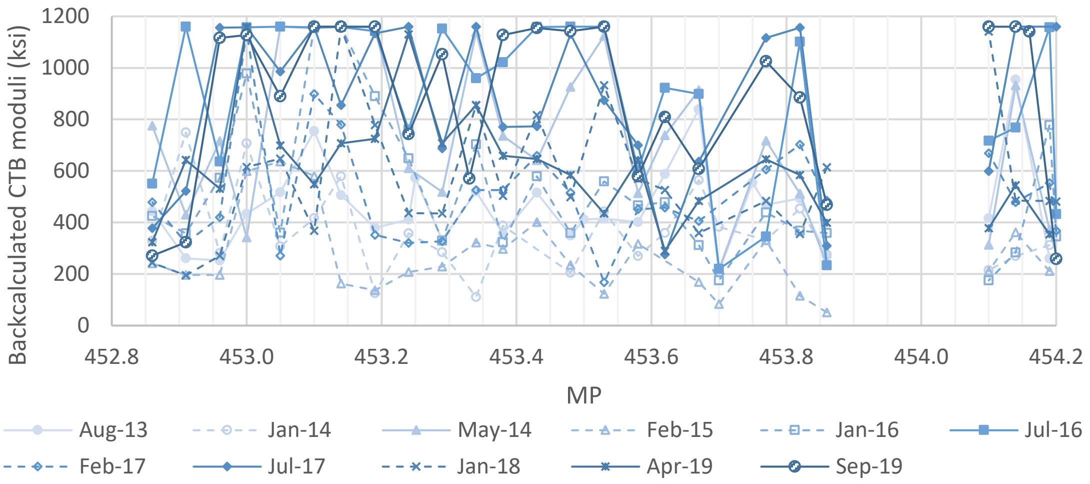


A. Southbound; conventional pavement excluding pavement at bridge overpasses.

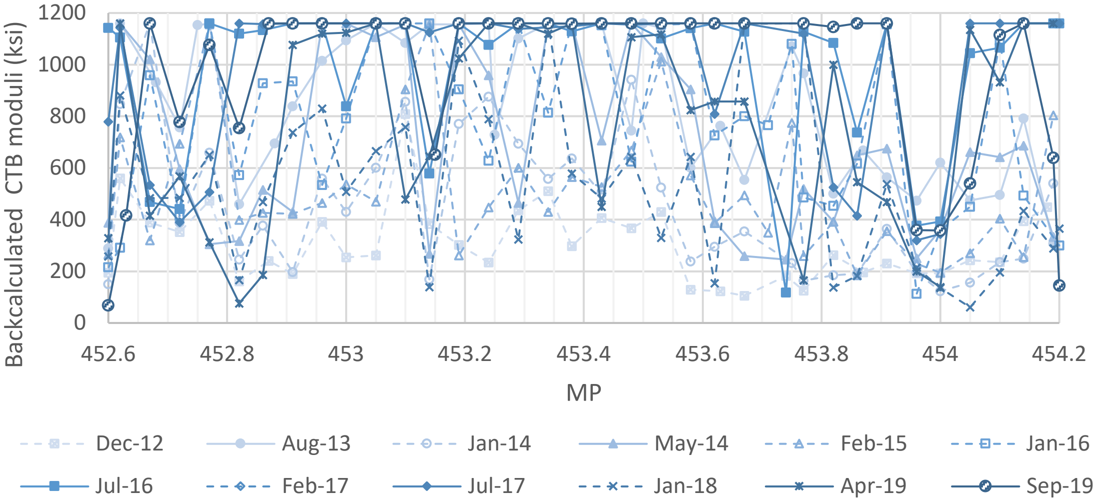


B. Northbound; inverted pavement.

Figure 179. Graph. Unbound granular layer backcalculated moduli; I-25, Colfax County, New Mexico.



A. Southbound; conventional pavement excluding pavement at bridge overpasses.



B. Northbound; inverted pavement.

Figure 180. Graph. Cement-treated base backcalculated moduli; I-25, Colfax County, New Mexico.

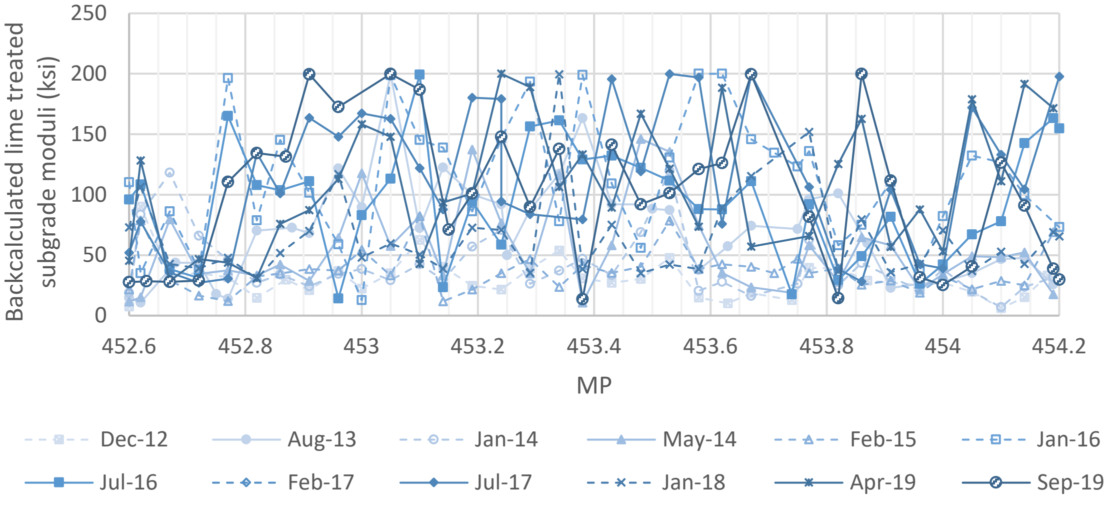
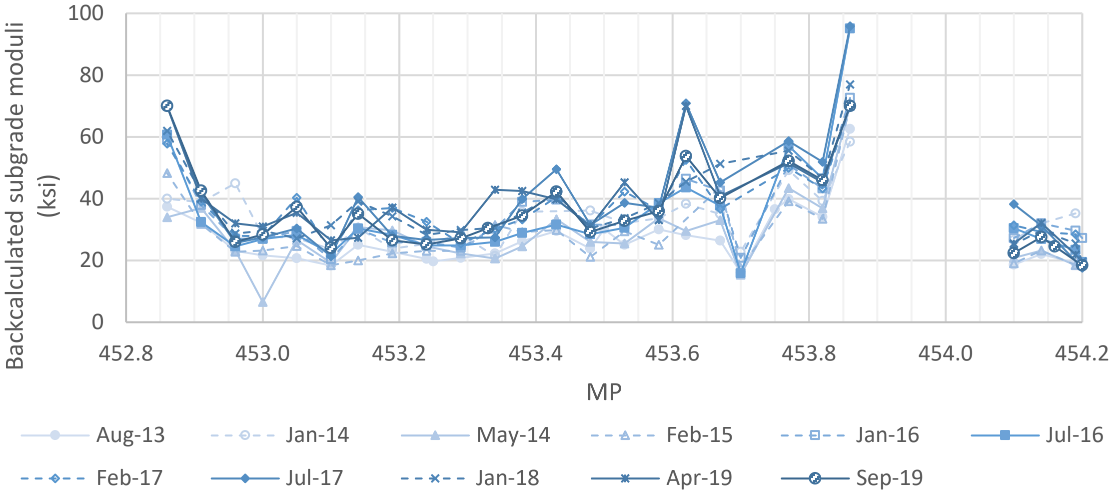
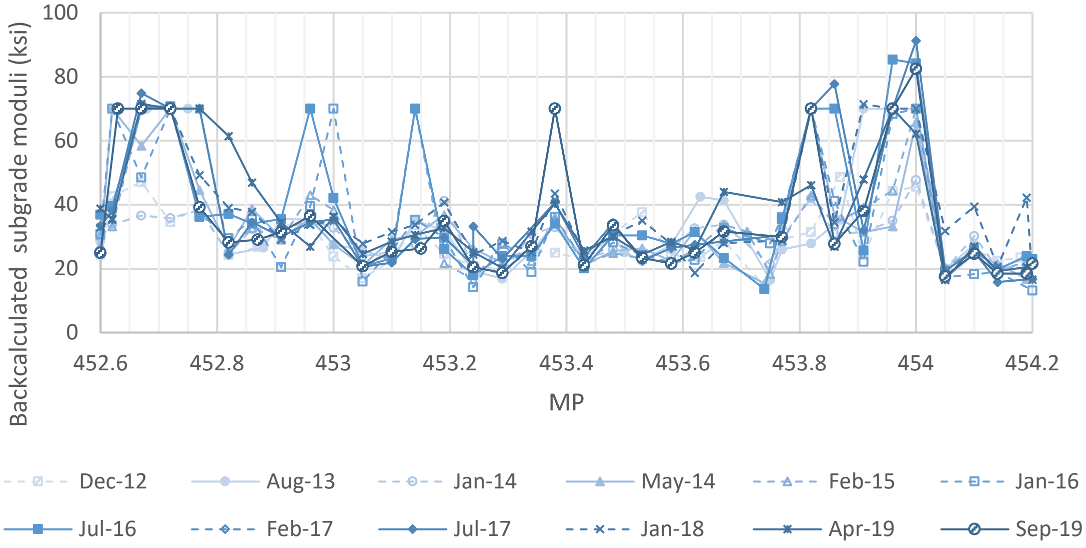


Figure 181. Graph. Lime-treated subgrade backcalculated moduli, northbound inverted pavement; I-25, Colfax County, New Mexico.



A. Southbound; conventional pavement excluding pavement at bridge overpasses.



B. Northbound; inverted pavement.

Figure 182. Graph. Subgrade backcalculated moduli; I-25, Colfax County, New Mexico.

B.2 VULCAN MATERIALS QUARRY ACCESS ROAD, NORTH CAROLINA

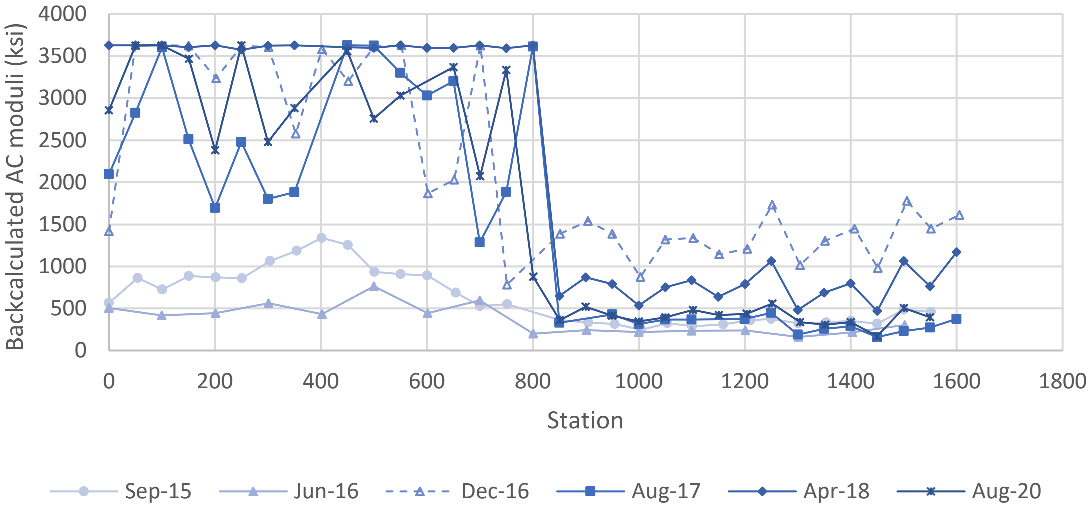


Figure 183. Graph. AC backcalculated moduli; Vulcan Materials Quarry Access Road, North Carolina.

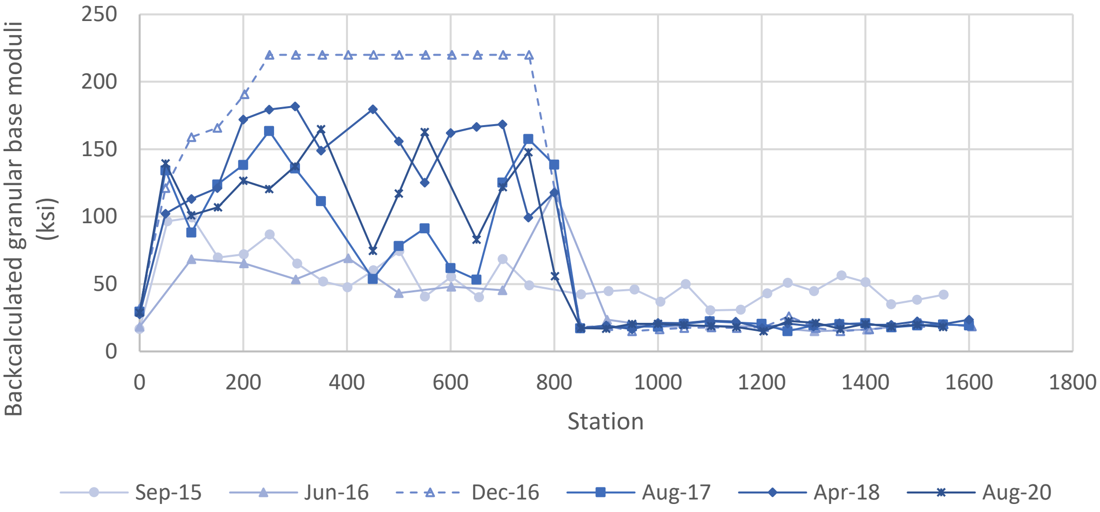


Figure 184. Graph. Unbound granular layer backcalculated moduli; Vulcan Materials Quarry Access Road, North Carolina.

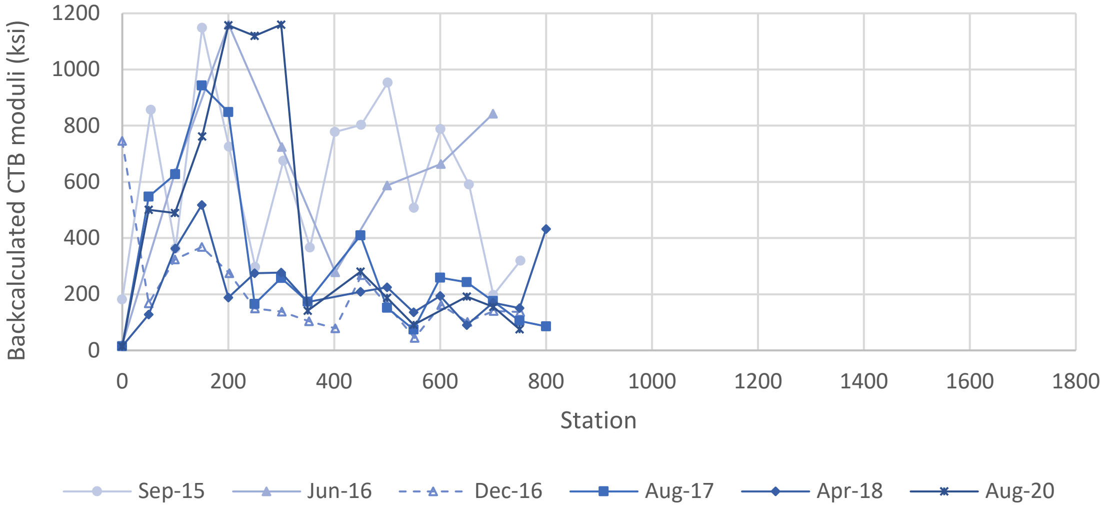


Figure 185. Graph. Cement-treated base backcalculated moduli; Vulcan Materials Quarry Access Road, North Carolina.

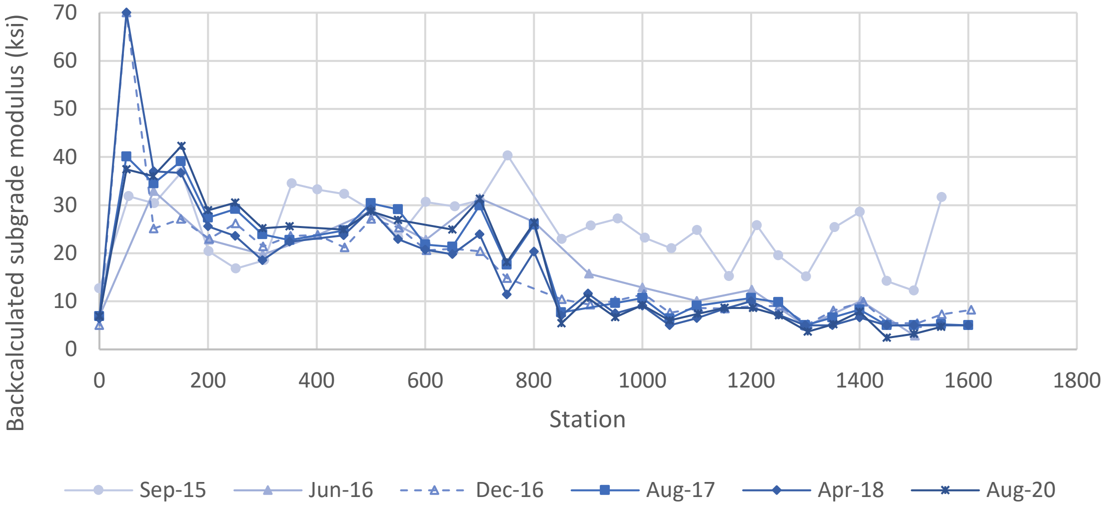


Figure 186. Graph. Subgrade backcalculated moduli; Vulcan Materials Quarry Access Road, North Carolina.

APPENDIX C: LCA ANALYSIS ASSUMPTIONS

C.1 I-25, NEW MEXICO

Table 61. LCA input parameters SB CP (per lane-mile); I-25, Colfax County, New Mexico.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	-	-	-	-	-	-	Alternative	Description: None; Analysis Period: 20 yrs	-	-
Alternative: SB CP	Pavement: CP	-	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	-	-	Mix Design	Mix Design Type: Built from Library Items	212 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	104 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 104 short-tons; 22 mi	2,288 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	92.3 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 92.3 short-tons; 22 mi	2,031 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	13.78 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 13.78 short-tons; 193 mi	2,660 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Lime, Hydrated	-	Material	Material Type: Other	2.1 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 2.1 short-tons; 446 mi	935 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	212 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Transport: Transport: OGFC (To Construction Site)	-	Transport	Transported Item: OGFC; 212 short-tons; 20 mi	4,240 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	6 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	6 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: OGFC	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	6 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	-	-	Mix Design	Mix Design Type: Built from Library Items	2819 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	1,323 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 1,323 short-tons; 22 mi	29,106 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	945 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 945 short-tons; 22 mi	20,790 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	118 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 118 short-tons; 193 mi	22,774 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	-	Material	Material Type: Recycled, Co-Product, or Waste Material	405 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	Transport: Transport: Reclaimed Asphalt Pavement (RAP) (To Production Site)	Transport	Transported Item: Reclaimed Asphalt Pavement (RAP); 405 short-tons; 13 mi	5,265 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Lime, Hydrated	-	Material	Material Type: Other	28.0 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 28.0 short-tons; 446 mi	12,488 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	2,819 short-tons	User-Defined

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Mix Design: HMA SP-III	Transport: Transport: HMA SP-III (To Construction Site)	-	Transport	Transported Item: HMA SP-III; 2,819 short-tons; 20 mi	56,380 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	12 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	12 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: HMA SB CP	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	12 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: Prime Coat	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: Prime Coat	Mix Design: Prime	-	-	Mix Design	Mix Design Type: Built from Library Items	13.2 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: Prime Coat	Mix Design: Prime	Material: Liquid Asphalt Binder, in refinery	-	Material	Material Type: Asphalt Binder	13.2 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: Prime Coat	Mix Design: Prime	Transport: Transport: Tack coat (To Construction Site)	-	Transport	Transported Item: Tack coat; 13.2 short-tons; 193 mi	2,548 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: Prime Coat	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	4 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: SB Granular Basecourse	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: SB Granular Basecourse	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	2,048 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: SB Granular Basecourse	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 2,048 short-tons; 101 mi	206,848 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: SB Granular Basecourse	Material: Water	-	-	Material	Material Type: Other	186 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: SB Granular Basecourse	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	16 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CTB SB CP	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CTB SB CP	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	2,692 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CTB SB CP	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 2,692 short-tons; 22 mi	59,224 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CTB SB CP	Material: Cement (Blended with SCMs)	-	-	Material	Material Type: Cementitous	137 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CTB SB CP	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Construction Site)	-	Transport	Transported Item: Cement (Blended with SCMs); 137 short-tons; 227 mi	31,099 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CTB SB CP	Material: Water	-	-	Material	Material Type: Other	153 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CTB SB CP	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	22 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	-	-	-	-	Project	Project Type: Maintenance and Preservation	-	-
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	-	-	-	Activity	Activity Type: Activity #3	1 mile	-

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	-	-	Mix Design	Mix Design Type: Built from Library Items	201 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	98.99 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 98.99 short-tons; 22 mi	2,178 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	87.6 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 87.6 short-tons; 22 mi	1,927 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	13.1 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 13.1 short-tons; 193 mi	2,528 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Lime, Hydrated	-	Material	Material Type: Other	2.0 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 2.0 short-tons; 446 mi	892 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	201 short-tons	User-Defined

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Transport: Transport: Blading AC Mix (To Construction Site)	-	Transport	Transported Item: Blading AC Mix; 201 short-tons; 20 mi	4,020 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Tack coat	-	-	Mix Design	Mix Design Type: Built from Library Items	2.3 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Tack coat	Material: Liquid Asphalt Binder, in refinery	-	Material	Material Type: Asphalt Binder	0.575 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Tack coat	Material: Water	-	Material	Material Type: Other	1.73 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Mix Design: Tack coat	Transport: Transport: Tack coat (To Construction Site)	-	Transport	Transported Item: Tack coat; 2.3 short-tons; 193 mi	444 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Equipment: Paving Equipment, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Tacker/ Emulsion Distributor Trucks/ Spray Trucks	4 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Equipment: Sweepers/Scrubbers, Nonroad Diesel Fuel, 100 < hp <= 175	-	-	Equipment	Equipment Type: Scrubbers	1 hour	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Maintenance and Preservation (Year 9)	Activity: Maintenance blading	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	8 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	-	-	-	-	Project	Project Type: Rehabilitation	-	-
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	-	-	-	Activity	Activity Type: HMA Mill and Inlay	1 mile	-
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	-	-	Mix Design	Mix Design Type: Built from Library Items	212 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	104 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 104 short-tons; 22 mi	2,285 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	92.17 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 92.17 short-tons; 22 mi	2,028 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	13.78 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 13.78 short-tons; 193 mi	2,660 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Material: Lime, Hydrated	-	Material	Material Type: Other	2.1 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 2.1 short-tons; 446 mi	935 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	212 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: OGFC	Transport: Transport: OGFC (To Construction Site)	-	Transport	Transported Item: OGFC; 212 short-tons; 20 mi	4,240 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: Tack coat	-	-	Mix Design	Mix Design Type: Built from Library Items	2.3 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: Tack coat	Material: Liquid Asphalt Binder, in refinery	-	Material	Material Type: Asphalt Binder	0.575 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: Tack coat	Material: Water	-	Material	Material Type: Other	1.73 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: Tack coat	Transport: Transport: Tack coat (To Construction Site)	-	Transport	Transported Item: Tack coat; 2.3 short-tons; 193 mi	444 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	-	-	Mix Design	Mix Design Type: Built from Library Items	1208 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	567 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 567 short-tons; 22 mi	12,473 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	405 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 405 short-tons; 22 mi	8,909 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	50.57 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 50.57 short-tons; 193 mi	9,759 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	-	Material	Material Type: Recycled, Co-Product, or Waste Material	174 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	Transport: Transport: Reclaimed Asphalt Pavement (RAP) (To Production Site)	Transport	Transported Item: Reclaimed Asphalt Pavement (RAP); 174 short-tons; 13 mi	2,256 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Lime, Hydrated	-	Material	Material Type: Other	12.0 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 12.0 short-tons; 446 mi	5,351 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,208 short-tons	User-Defined
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Mix Design: HMA SP-III	Transport: Transport: HMA SP-III (To Construction Site)	-	Transport	Transported Item: HMA SP-III; 1,208 short-tons; 20 mi	24,160 short-ton-miles	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Equipment: Milling Machine, Nonroad Diesel Fuel, 50 < hp <= 75	-	-	Equipment	Equipment Type: Milling Machines	4 hours	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Equipment: Sweepers/Scrubbers, Nonroad Diesel Fuel, 50 < hp <= 75	-	-	Equipment	Equipment Type: Scrubbers	1 hour	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	12 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	12 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	12 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Equipment: Paving Equipment, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Tacker/ Emulsion Distributor Trucks/ Spray Trucks	4 hours	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Waste: Waste: Asphalt	-	-	Waste	Waste Method: Landfill	1,420 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Rehabilitation (Year 12)	Activity: Rehabilitation	Waste: Waste: Asphalt	Transport: Transport: Landfill-Asphalt (From Construction Site)	-	Transport	Transported Item: Landfill-Asphalt; 1,420 short-tons; 20 mi	28,400 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: SB CP	Pavement: CP	Project: Removal (Year 20)	-	-	-	-	Project	Project Type: Removal	-	-
Alternative: SB CP	Pavement: CP	Project: Removal (Year 20)	Activity: AC Landfill	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: SB CP	Pavement: CP	Project: Removal (Year 20)	Activity: AC Landfill	Waste: Waste: Asphalt	-	-	Waste	Waste Method: Recycled Offsite	3,031 short-tons	Default Database
Alternative: SB CP	Pavement: CP	Project: Removal (Year 20)	Activity: AC Landfill	Waste: Waste: Asphalt	Transport: Transport: Recycled Offsite-Asphalt (From Construction Site)	-	Transport	Transported Item: Recycled Offsite-Asphalt; 3,031 short-tons; 20 mi	60,620 short-ton-miles	Default Database

Table 62. LCA input parameters NB IP (per lane-mile); I-25, Colfax County, New Mexico.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	-	-	-	-	-	-	Alternative	Description: None; Analysis Period: 20 yrs	-	-
Alternative: NB IP	Pavement: IP	-	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	-	-	Mix Design	Mix Design Type: Built from Library Items	212 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	104 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 104 short-tons; 22 mi	2,288 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	92.3 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 92.3 short-tons; 22 mi	2,031 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	13.78 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 13.78 short-tons; 193 mi	2,660 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Lime, Hydrated	-	Material	Material Type: Other	2.1 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 2.1 short-tons; 446 mi	935 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	212 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Mix Design: OGFC	Transport: Transport: OGFC (To Construction Site)	-	Transport	Transported Item: OGFC; 212 short-tons; 20 mi	4,240 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	6 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	6 hours	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: OGFC	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	6 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	-	-	Mix Design	Mix Design Type: Built from Library Items	1208 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	567 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 567 short-tons; 22 mi	12,473 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	405 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 405 short-tons; 22 mi	8,909 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	50.57 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 50.57 short-tons; 193 mi	9,759 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	-	Material	Material Type: Recycled, Co-Product, or Waste Material	174 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	Transport: Transport: Reclaimed Asphalt Pavement (RAP) (To Production Site)	Transport	Transported Item: Reclaimed Asphalt Pavement (RAP); 174 short-tons; 13 mi	2,256 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Lime, Hydrated	-	Material	Material Type: Other	12.0 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 12.0 short-tons; 446 mi	5,351 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,208 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Mix Design: HMA SP-III	Transport: Transport: HMA SP-III (To Construction Site)	-	Transport	Transported Item: HMA SP-III; 1,208 short-tons; 20 mi	24,160 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	6 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	6 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: HMA NB IP	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	6 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Prime Coat	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Prime Coat	Mix Design: Prime	-	-	Mix Design	Mix Design Type: Built from Library Items	13.2 short-tons	User-Defined

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Prime Coat	Mix Design: Prime	Material: Liquid Asphalt Binder, in refinery	-	Material	Material Type: Asphalt Binder	13.2 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Prime Coat	Mix Design: Prime	Transport: Transport: Tack coat (To Construction Site)	-	Transport	Transported Item: Tack coat; 13.2 short-tons; 193 mi	2,548 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Prime Coat	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	4 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: NB Granular Basecourse	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: NB Granular Basecourse	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	3,086 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: NB Granular Basecourse	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 3,086 short-tons; 22 mi	67,892 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: NB Granular Basecourse	Material: Water	-	-	Material	Material Type: Other	280 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: NB Granular Basecourse	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	16 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: NB Granular Basecourse	Equipment: Rollers, Nonroad Diesel Fuel, 100 < hp <= 175	-	-	Equipment	Equipment Type: Pneumatic Rollers	2 hours	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: CTB NB IP	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: CTB NB IP	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	3,365 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: CTB NB IP	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 3,365 short-tons; 22 mi	74,030 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: CTB NB IP	Material: Cement (Blended with SCMs)	-	-	Material	Material Type: Cementitious	171 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: CTB NB IP	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Construction Site)	-	Transport	Transported Item: Cement (Blended with SCMs); 171 short-tons; 227 mi	38,817 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: CTB NB IP	Material: Water	-	-	Material	Material Type: Other	191 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: CTB NB IP	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	25 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Lime treated subgrade	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Lime treated subgrade	Material: Lime, Hydrated	-	-	Material	Material Type: Other	117 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Lime treated subgrade	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Construction Site)	-	Transport	Transported Item: Lime, Hydrated; 117 short-tons; 654 mi	76,518 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Lime treated subgrade	Material: Water	-	-	Material	Material Type: Other	569 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: Lime treated subgrade	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	28 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	-	-	-	-	Project	Project Type: Maintenance and Preservation	-	-
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	-	-	-	Activity	Activity Type: Activity #3	1 mile	-
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	-	-	Mix Design	Mix Design Type: Built from Library Items	201 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	98.99 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 98.99 short-tons; 22 mi	2,178 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	87.6 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 87.6 short-tons; 22 mi	1,927 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	13.1 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 13.1 short-tons; 193 mi	2,528 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Lime, Hydrated	-	Material	Material Type: Other	2.0 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 2.0 short-tons; 446 mi	892 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	201 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Transport: Transport: Blading AC Mix (To Construction Site)	-	Transport	Transported Item: Blading AC Mix; 201 short-tons; 20 mi	4,020 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Tack coat	-	-	Mix Design	Mix Design Type: Built from Library Items	2.3 short-tons	User-Defined

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Tack coat	Material: Liquid Asphalt Binder, in refinery	-	Material	Material Type: Asphalt Binder	0.575 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Tack coat	Material: Water	-	Material	Material Type: Other	1.73 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Mix Design: Tack coat	Transport: Transport: Tack coat (To Construction Site)	-	Transport	Transported Item: Tack coat; 2.3 short-tons; 193 mi	444 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Equipment: Paving Equipment, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Tacker/ Emulsion Distributor Trucks/ Spray Trucks	4 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Equipment: Sweepers/Scrubbers, Nonroad Diesel Fuel, 100 < hp <= 175	-	-	Equipment	Equipment Type: Scrubbers	1 hour	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 5)	Activity: Maintenance blading	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	8 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	-	-	-	-	Project	Project Type: Rehabilitation	-	-
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	-	-	-	Activity	Activity Type: HMA Mill and Inlay	1 mile	-

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	-	-	Mix Design	Mix Design Type: Built from Library Items	212 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	104 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 104 short-tons; 22 mi	2,285 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	92.17 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 92.17 short-tons; 22 mi	2,028 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	13.78 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 13.78 short-tons; 193 mi	2,660 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Material: Lime, Hydrated	-	Material	Material Type: Other	2.1 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 2.1 short-tons; 446 mi	935 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	212 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: OGFC	Transport: Transport: OGFC (To Construction Site)	-	Transport	Transported Item: OGFC; 212 short-tons; 20 mi	4,240 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: Tack coat	-	-	Mix Design	Mix Design Type: Built from Library Items	2.3 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: Tack coat	Material: Liquid Asphalt Binder, in refinery	-	Material	Material Type: Asphalt Binder	0.575 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: Tack coat	Material: Water	-	Material	Material Type: Other	1.73 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: Tack coat	Transport: Transport: Tack coat (To Construction Site)	-	Transport	Transported Item: Tack coat; 2.3 short-tons; 193 mi	444 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	-	-	Mix Design	Mix Design Type: Built from Library Items	1208 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	567 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 567 short-tons; 22 mi	12,473 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	405 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 405 short-tons; 22 mi	8,909 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	50.57 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 50.57 short-tons; 193 mi	9,759 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	-	Material	Material Type: Recycled, Co-Product, or Waste Material	174 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	Transport: Transport: Reclaimed Asphalt Pavement (RAP) (To Production Site)	Transport	Transported Item: Reclaimed Asphalt Pavement (RAP); 174 short-tons; 13 mi	2,256 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Lime, Hydrated	-	Material	Material Type: Other	12.0 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 12.0 short-tons; 446 mi	5,351 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,208 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Mix Design: HMA SP-III	Transport: Transport: HMA SP-III (To Construction Site)	-	Transport	Transported Item: HMA SP-III; 1,208 short-tons; 20 mi	24,160 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Equipment: Milling Machine, Nonroad Diesel Fuel, 50 < hp <= 75	-	-	Equipment	Equipment Type: Milling Machines	4 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Equipment: Sweepers/Scrubbers, Nonroad Diesel Fuel, 50 < hp <= 75	-	-	Equipment	Equipment Type: Scrubbers	1 hour	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	12 hours	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	12 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	12 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Equipment: Paving Equipment, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Tacker/ Emulsion Distributor Trucks/ Spray Trucks	4 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Waste: Waste: Asphalt	-	-	Waste	Waste Method: Landfill	1,420 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 8)	Activity: Rehabilitation	Waste: Waste: Asphalt	Transport: Transport: Landfill-Asphalt (From Construction Site)	-	Transport	Transported Item: Landfill-Asphalt; 1,420 short-tons; 20 mi	28,400 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	-	-	-	-	Project	Project Type: Maintenance and Preservation	-	-
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	-	-	-	Activity	Activity Type: Activity #3	1 mile	-
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	-	-	Mix Design	Mix Design Type: Built from Library Items	201 short-tons	User-Defined

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	98.99 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 98.99 short-tons; 22 mi	2,178 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	87.6 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 87.6 short-tons; 22 mi	1,927 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	13.1 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 13.1 short-tons; 193 mi	2,528 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Lime, Hydrated	-	Material	Material Type: Other	2.0 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 2.0 short-tons; 446 mi	892 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	201 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Blading AC Mix	Transport: Transport: Blading AC Mix (To Construction Site)	-	Transport	Transported Item: Blading AC Mix; 201 short-tons; 20 mi	4,020 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Tack coat	-	-	Mix Design	Mix Design Type: Built from Library Items	2.3 short-tons	User-Defined

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Tack coat	Material: Liquid Asphalt Binder, in refinery	-	Material	Material Type: Asphalt Binder	0.575 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Tack coat	Material: Water	-	Material	Material Type: Other	1.73 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Mix Design: Tack coat	Transport: Transport: Tack coat (To Construction Site)	-	Transport	Transported Item: Tack coat; 2.3 short-tons; 193 mi	444 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Equipment: Paving Equipment, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Tacker/ Emulsion Distributor Trucks/ Spray Trucks	4 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Equipment: Sweepers/Scrubbers, Nonroad Diesel Fuel, 100 < hp <= 175	-	-	Equipment	Equipment Type: Scrubbers	1 hour	Default Database
Alternative: NB IP	Pavement: IP	Project: Maintenance and Preservation (Year 13)	Activity: Maintenance blading	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	8 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	-	-	-	-	Project	Project Type: Rehabilitation	-	-
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	-	-	-	Activity	Activity Type: HMA Mill and Inlay	1 mile	-

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	-	-	Mix Design	Mix Design Type: Built from Library Items	212 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	104 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 104 short-tons; 22 mi	2,285 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	92.17 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 92.17 short-tons; 22 mi	2,028 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	13.78 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 13.78 short-tons; 193 mi	2,660 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Material: Lime, Hydrated	-	Material	Material Type: Other	2.1 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 2.1 short-tons; 446 mi	935 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	212 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: OGFC	Transport: Transport: OGFC (To Construction Site)	-	Transport	Transported Item: OGFC; 212 short-tons; 20 mi	4,240 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: Tack coat	-	-	Mix Design	Mix Design Type: Built from Library Items	2.3 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: Tack coat	Material: Liquid Asphalt Binder, in refinery	-	Material	Material Type: Asphalt Binder	0.575 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: Tack coat	Material: Water	-	Material	Material Type: Other	1.73 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: Tack coat	Transport: Transport: Tack coat (To Construction Site)	-	Transport	Transported Item: Tack coat; 2.3 short-tons; 193 mi	444 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	-	-	Mix Design	Mix Design Type: Built from Library Items	1208 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	567 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 567 short-tons; 22 mi	12,473 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	405 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 405 short-tons; 22 mi	8,909 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	50.57 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 50.57 short-tons; 193 mi	9,759 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	-	Material	Material Type: Recycled, Co-Product, or Waste Material	174 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Reclaimed Asphalt Pavement (RAP)	Transport: Transport: Reclaimed Asphalt Pavement (RAP) (To Production Site)	Transport	Transported Item: Reclaimed Asphalt Pavement (RAP); 174 short-tons; 13 mi	2,256 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Lime, Hydrated	-	Material	Material Type: Other	12.0 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 12.0 short-tons; 446 mi	5,351 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Equipment: Asphalt Mixing in NM	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,208 short-tons	User-Defined
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Mix Design: HMA SP-III	Transport: Transport: HMA SP-III (To Construction Site)	-	Transport	Transported Item: HMA SP-III; 1,208 short-tons; 20 mi	24,160 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Equipment: Milling Machine, Nonroad Diesel Fuel, 50 < hp <= 75	-	-	Equipment	Equipment Type: Milling Machines	4 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Equipment: Sweepers/Scrubbers, Nonroad Diesel Fuel, 50 < hp <= 75	-	-	Equipment	Equipment Type: Scrubbers	1 hour	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	12 hours	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	12 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	12 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Equipment: Paving Equipment, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Tacker/ Emulsion Distributor Trucks/ Spray Trucks	4 hours	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Waste: Waste: Asphalt	-	-	Waste	Waste Method: Landfill	1,420 short-tons	Default Database
Alternative: NB IP	Pavement: IP	Project: Rehabilitation (Year 16)	Activity: Rehabilitation	Waste: Waste: Asphalt	Transport: Transport: Landfill-Asphalt (From Construction Site)	-	Transport	Transported Item: Landfill-Asphalt; 1,420 short-tons; 20 mi	28,400 short-ton-miles	Default Database
Alternative: NB IP	Pavement: IP	Project: Removal (Year 20)	-	-	-	-	Project	Project Type: Removal	-	-
Alternative: NB IP	Pavement: IP	Project: Removal (Year 20)	Activity: New Activity	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: NB IP	Pavement: IP	Project: Removal (Year 20)	Activity: New Activity	Waste: Waste: Asphalt	-	-	Waste	Waste Method: Recycled Offsite	1,421 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: NB IP	Pavement: IP	Project: Removal (Year 20)	Activity: New Activity	Waste: Waste: Asphalt	Transport: Transport: Recycled Offsite-Asphalt (From Construction Site)	-	Transport	Transported Item: Recycled Offsite-Asphalt; 1,421 short-tons; 20 mi	28,420 short-ton-miles	Default Database

C.2 US-165 AND LA-97, LOUISIANA

Table 63. LCA input parameters US-165 IP (per lane-mile), Louisiana.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: US-165 IP	-	-	-	-	-	-	Alternative	Description: US-165 IP; Analysis Period: 1 yrs	-	-
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	-	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	1,452 short-tons	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 1,452 short-tons; 50 mi	72,600 short-ton-miles	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Lime, Hydrated	-	-	Material	Material Type: Other	21.14 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Construction Site)	-	Transport	Transported Item: Lime, Hydrated; 21.14 short-tons; 50 mi	1,057 short-ton-miles	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Cement (Blended with SCMs)	-	-	Material	Material Type: Cementitous	168 short-tons	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Construction Site)	-	Transport	Transported Item: Cement (Blended with SCMs); 168 short-tons; 50 mi	8,400 short-ton-miles	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Water	-	-	Material	Material Type: Other	821 short-tons	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	-	-	Mix Design	Mix Design Type: Built from Library Items	2310 short-tons	User-Defined
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	1,017 short-tons	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 1,017 short-tons; 453 mi	460,701 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	810 short-tons	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 810 short-tons; 12 mi	9,720 short-ton-miles	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	79.6 short-tons	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 79.6 short-tons; 196 mi	15,602 short-ton-miles	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Reclaimed Asphalt Pavement (RAP)	-	Material	Material Type: Recycled, Co-Product, or Waste Material	389 short-tons	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Reclaimed Asphalt Pavement (RAP)	Transport: Transport: Reclaimed Asphalt Pavement (RAP) (To Production Site)	Transport	Transported Item: Reclaimed Asphalt Pavement (RAP); 389 short-tons; 50 mi	19,450 short-ton-miles	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Lime, Hydrated	-	Material	Material Type: Other	13.88 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 13.88 short-tons; 835 mi	11,593 short-ton-miles	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Equipment: AC Mixing in LA (A3 for US-165)	-	Equipment	Equipment Type: Mixing Operations - Asphalt	2,310 short-tons	User-Defined
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: US-165 AC layers	Transport: Transport: US-165 AC layers (To Construction Site)	-	Transport	Transported Item: US-165 AC layers; 2,310 short-tons; 19 mi	43,890 short-ton-miles	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	77 hours	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Equipment: Rollers, Nonroad Diesel Fuel, 100 < hp <= 175	-	-	Equipment	Equipment Type: Pneumatic Rollers	2 hours	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	12 hours	Default Database
Alternative: US-165 IP	Pavement: US-165 Inverted Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	12 hours	Default Database

Table 64. LCA input parameters LA-97 IP (per lane-mile), Louisiana.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Object Type	Object Properties	Quantity	Item Type
Alternative: LA-97 IP	-	-	-	-	-	Alternative	Description: LA-97 IP; Analysis Period: 1 yrs	-	-
Alternative: LA-97 IP	Pavement: New Pavement	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Material: Base and Subbase Material	-	Material	Material Type: Aggregate	1,452 short-tons	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	Transport	Transported Item: Base and Subbase Material; 1,452 short-tons; 50 mi	72,615 short-ton-miles	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Material: Lime, Hydrated	-	Material	Material Type: Other	22.25 short-tons	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Construction Site)	Transport	Transported Item: Lime, Hydrated; 22.25 short-tons; 50 mi	1,113 short-ton-miles	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Material: Cement (Blended with SCMs)	-	Material	Material Type: Cementitous	155 short-tons	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Construction Site)	Transport	Transported Item: Cement (Blended with SCMs); 155 short-tons; 50 mi	7,750 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Object Type	Object Properties	Quantity	Item Type
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Material: Water	-	Material	Material Type: Other	810 short-tons	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Mix Design: LA-97 AC layers	-	Mix Design	Mix Design Type: Built from Library Items	1345 short-tons	User-Defined
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Mix Design: LA-97 AC layers	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Material	Material Type: Aggregate	642 short-tons	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Mix Design: LA-97 AC layers	Material: Fine Aggregate (for asphalt)	Material	Material Type: Aggregate	428 short-tons	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Mix Design: LA-97 AC layers	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Material	Material Type: Asphalt Binder	47 short-tons	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Mix Design: LA-97 AC layers	Material: Reclaimed Asphalt Pavement (RAP)	Material	Material Type: Recycled, Co-Product, or Waste Material	220 short-tons	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Mix Design: LA-97 AC layers	Material: Lime, Hydrated	Material	Material Type: Other	8.05 short-tons	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Mix Design: LA-97 AC layers	Equipment: A3 for LA-97	Equipment	Equipment Type: Mixing Operations - Asphalt	1,345 short-tons	User-Defined
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Mix Design: LA-97 AC layers	Transport: Transport: LA-97 AC layers (To Production Site)	Transport	Transported Item: LA-97 AC layers; 1,345 short-tons; 1 mi	1,345 short-ton-miles	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Mix Design: LA-97 AC layers	Transport: Transport: LA-97 AC layers (To Construction Site)	Transport	Transported Item: LA-97 AC layers; 1,345 short-tons; 20 mi	26,900 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Object Type	Object Properties	Quantity	Item Type
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Equipment: equipment operation, > 75 hp and < 750 hp	-	Equipment	Equipment Type: Generic Construction Equipment	69 hours	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Equipment: Rollers, Nonroad Diesel Fuel, 100 < hp <= 175	-	Equipment	Equipment Type: Pneumatic Rollers	2 hours	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	6 hours	Default Database
Alternative: LA-97 IP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: LA-97 IP	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	Equipment	Equipment Type: Material Transfer Vehicle	6 hours	Default Database

Table 65. LCA input parameters LA-97 CP (per lane-mile), Louisiana.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Object Type	Object Properties	Quantity	Item Type
Alternative: LA-97 CP	-	-	-	-	-	Alternative	Description: LA-97 CP; Analysis Period: 1 yrs	-	-
Alternative: LA-97 CP	Pavement: New Pavement	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	-	-	Activity	Activity Type: Pavement Layers	1 cubic yard	-
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Cement (Blended with SCMs)	-	Material	Material Type: Cementitous	219 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Object Type	Object Properties	Quantity	Item Type
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Construction Site)	Transport	Transported Item: Cement (Blended with SCMs); 219 short-tons; 50 mi	10,950 short-ton-miles	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Lime, Hydrated	-	Material	Material Type: Other	22.25 short-tons	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Construction Site)	Transport	Transported Item: Lime, Hydrated; 22.25 short-tons; 50 mi	1,113 short-ton-miles	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Material: Water	-	Material	Material Type: Other	745 short-tons	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: LA-97 AC layers	-	Mix Design	Mix Design Type: Built from Library Items	1345 short-tons	User-Defined
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: LA-97 AC layers	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Material	Material Type: Aggregate	642 short-tons	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: LA-97 AC layers	Material: Fine Aggregate (for asphalt)	Material	Material Type: Aggregate	428 short-tons	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: LA-97 AC layers	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Material	Material Type: Asphalt Binder	47 short-tons	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: LA-97 AC layers	Material: Reclaimed Asphalt Pavement (RAP)	Material	Material Type: Recycled, Co-Product, or Waste Material	220 short-tons	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: LA-97 AC layers	Material: Lime, Hydrated	Material	Material Type: Other	8.05 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Object Type	Object Properties	Quantity	Item Type
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: LA-97 AC layers	Equipment: A3 for LA-97	Equipment	Equipment Type: Mixing Operations - Asphalt	1,345 short-tons	User-Defined
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: LA-97 AC layers	Transport: Transport: LA-97 AC layers (To Production Site)	Transport	Transported Item: LA-97 AC layers; 1,345 short-tons; 1 mi	1,345 short-ton-miles	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Mix Design: LA-97 AC layers	Transport: Transport: LA-97 AC layers (To Construction Site)	Transport	Transported Item: LA-97 AC layers; 1,345 short-tons; 20 mi	26,900 short-ton-miles	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Equipment: equipment operation, > 75 hp and < 750 hp	-	Equipment	Equipment Type: Generic Construction Equipment	57 hours	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	6 hours	Default Database
Alternative: LA-97 CP	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: New Activity	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	Equipment	Equipment Type: Material Transfer Vehicle	6 hours	Default Database

C.3 VULCAN MATERIALS QUARRY VULCAN MATERIALS QUARRY ACCESS ROAD, NORTH CAROLINA

Table 66. LCA input parameters IP (per lane-mile), Quarry Access Road, North Carolina.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: IP	-	-	-	-	-	-	Alternative	Description: None; Analysis Period: 1 yrs	-	-
Alternative: IP	Pavement: IP	-	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	-	-	Mix Design	Mix Design Type: Built from Library Items	412 short-tons	User-Defined
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	24.31 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 24.31 short-tons; 50 mi	1,215 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Material: Lime, Hydrated	-	Material	Material Type: Other	4.12 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 4.12 short-tons; 50 mi	206 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	96.0 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 96.0 short-tons; 50 mi	4,800 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	288 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 288 short-tons; 50 mi	14,379 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Equipment: AC Mixing in North Carolina	-	Equipment	Equipment Type: Mixing Operations - Asphalt	412 short-tons	User-Defined
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5A	Transport: Transport: SF9.5A (To Construction Site)	-	Transport	Transported Item: SF9.5A; 412 short-tons; 20 mi	8,240 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	-	-	Mix Design	Mix Design Type: Built from Library Items	618 short-tons	User-Defined
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	36.46 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 36.46 short-tons; 50 mi	1,823 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Material: Lime, Hydrated	-	Material	Material Type: Other	6.18 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 6.18 short-tons; 50 mi	309 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	144 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 144 short-tons; 50 mi	7,200 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	431 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 431 short-tons; 50 mi	21,568 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Equipment: AC Mixing in North Carolina	-	Equipment	Equipment Type: Mixing Operations - Asphalt	618 short-tons	User-Defined
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Mix Design: SF9.5B	Transport: Transport: SF9.5B (To Construction Site)	-	Transport	Transported Item: SF9.5B; 618 short-tons; 20 mi	12,360 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	12 hours	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	12 hours	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP AC layers	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	12 hours	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP UAB	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP UAB	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	2,217 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP UAB	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 2,217 short-tons; 50 mi	110,870 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP UAB	Material: Water	-	-	Material	Material Type: Other	133 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP UAB	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	14 hours	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP UAB	Equipment: Rollers, Nonroad Diesel Fuel, 100 < hp <= 175	-	-	Equipment	Equipment Type: Pneumatic Rollers	2 hours	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP CTB	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	2,957 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 2,957 short-tons; 50 mi	147,830 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Cement (Blended with SCMs)	-	-	Material	Material Type: Cementitous	59 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Construction Site)	-	Transport	Transported Item: Cement (Blended with SCMs); 59 short-tons; 50 mi	2,950 short-ton-miles	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Water	-	-	Material	Material Type: Other	237 short-tons	Default Database
Alternative: IP	Pavement: IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	22 hours	Default Database

Table 67. LCA input parameters CP (per lane-mile), Quarry Access Road, North Carolina.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: CP	-	-	-	-	-	-	Alternative	Description: None; Analysis Period: 1 yrs	-	-
Alternative: CP	Pavement: CP	-	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	-	-	Mix Design	Mix Design Type: Built from Library Items	1030 short-tons	User-Defined

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	60.77 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 60.77 short-tons; 50 mi	3,039 short-ton-miles	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Material: Lime, Hydrated	-	Material	Material Type: Other	10.3 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 10.3 short-tons; 50 mi	515 short-ton-miles	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	240 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 240 short-tons; 50 mi	12,000 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	719 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 719 short-tons; 50 mi	35,947 short-ton-miles	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Equipment: AC Mixing in North Carolina	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,030 short-tons	User-Defined
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: SF9.5B	Transport: Transport: SF9.5B (To Construction Site)	-	Transport	Transported Item: SF9.5B; 1,030 short-tons; 20 mi	20,600 short-ton-miles	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	-	-	Mix Design	Mix Design Type: Built from Library Items	1461 short-tons	User-Defined
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	70.13 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 70.13 short-tons; 50 mi	3,506 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Material: Lime, Hydrated	-	Material	Material Type: Other	14.61 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 14.61 short-tons; 50 mi	731 short-ton-miles	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	688 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 688 short-tons; 50 mi	34,407 short-ton-miles	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	688 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 688 short-tons; 50 mi	34,407 short-ton-miles	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Equipment: AC Mixing in North Carolina	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,461 short-tons	User-Defined

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Mix Design: I19.0B	Transport: Transport: I19.0B (To Construction Site)	-	Transport	Transported Item: I19.0B; 1,461 short-tons; 20 mi	29,220 short-ton-miles	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	12 hours	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	12 hours	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP AC layers	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	12 hours	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP UAB	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP UAB	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	3,696 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP UAB	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 3,696 short-tons; 50 mi	184,800 short-ton-miles	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP UAB	Material: Water	-	-	Material	Material Type: Other	222 short-tons	Default Database
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP UAB	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	14 hours	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: CP	Pavement: CP	Project: Initial Construction (Year 0)	Activity: CP UAB	Equipment: Rollers, Nonroad Diesel Fuel, 100 < hp <= 175	-	-	Equipment	Equipment Type: Pneumatic Rollers	2 hours	Default Database

C.4 MORGAN COUNTY, GEORGIA

Table 68. LCA input parameters CP (per lane-mile); Morgan County, Georgia.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Conventional	-	-	-	-	-	-	Alternative	Description: GA Martin-Marietta; Analysis Period: 1 yrs	-	-
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	-	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	-	-	Mix Design	Mix Design Type: Built from Library Items	1236 short-tons	User-Defined
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	640 short-tons	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 640 short-tons; 50 mi	32,005 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	524 short-tons	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 524 short-tons; 50 mi	26,185 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	59.33 short-tons	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 59.33 short-tons; 50 mi	2,966 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Lime, Hydrated	-	Material	Material Type: Other	12.36 short-tons	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 12.36 short-tons; 50 mi	618 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Equipment: AC mixing GA	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,236 short-tons	User-Defined
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Transport: Transport: AC Morgan County Quarry Access Rd (To Construction Site)	-	Transport	Transported Item: AC Morgan County Quarry Access Rd; 1,236 short-tons; 20 mi	24,720 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	6 hours	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	6 hours	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: AC	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	6 hours	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: UAB CP	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: UAB CP	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	3,067 short-tons	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: UAB CP	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 3,067 short-tons; 50 mi	153,350 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: UAB CP	Material: Water	-	-	Material	Material Type: Other	206 short-tons	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: UAB CP	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	9 hours	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: Crushed stone CP	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: Crushed stone CP	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	1,584 short-tons	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: Crushed stone CP	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 1,584 short-tons; 50 mi	79,200 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: Crushed stone CP	Material: Water	-	-	Material	Material Type: Other	46 short-tons	Default Database
Alternative: GA Martin-Marietta Conventional	Pavement: GA Martin-Marietta	Project: Initial Construction (Year 0)	Activity: Crushed stone CP	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	9 hours	Default Database

Table 69. LCA input parameters South African IP (per lane-mile); Morgan County Georgia.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted SA	-	-	-	-	-	-	Alternative	Description: GA Martin-Marietta Inverted SA; Analysis Period: 1 yrs	-	-
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	-	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	-	-	Mix Design	Mix Design Type: Built from Library Items	1236 short-tons	User-Defined
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	640 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 640 short-tons; 50 mi	32,005 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	524 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 524 short-tons; 50 mi	26,185 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	59.33 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 59.33 short-tons; 50 mi	2,966 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Lime, Hydrated	-	Material	Material Type: Other	12.36 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 12.36 short-tons; 50 mi	618 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Equipment: AC mixing GA	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,236 short-tons	User-Defined
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Transport: Transport: AC Morgan County Quarry Access Rd (To Construction Site)	-	Transport	Transported Item: AC Morgan County Quarry Access Rd; 1,236 short-tons; 20 mi	24,720 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	6 hours	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	6 hours	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: AC	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	6 hours	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: IP UAB SA	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: IP UAB SA	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	2,300 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: IP UAB SA	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 2,300 short-tons; 50 mi	115,000 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: IP UAB SA	Material: Water	-	-	Material	Material Type: Other	167 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: IP UAB SA	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	16 hours	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: IP UAB SA	Equipment: Rollers, Nonroad Diesel Fuel, 100 < hp <= 175	-	-	Equipment	Equipment Type: Pneumatic Rollers	2 hours	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: CTB IP	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	3,067 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 3,067 short-tons; 50 mi	153,350 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Cement (Blended with SCMs)	-	-	Material	Material Type: Cementitous	148 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Construction Site)	-	Transport	Transported Item: Cement (Blended with SCMs); 148 short-tons; 50 mi	7,400 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Water	-	-	Material	Material Type: Other	245 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted SA	Pavement: Inverted SA	Project: Initial Construction (Year 0)	Activity: CTB IP	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	22 hours	Default Database

Table 70. LCA input parameters Georgia IP (per lane-mile); Morgan County, Georgia.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted GA	-	-	-	-	-	-	Alternative	Description: GA Martin-Marietta Inverted GA; Analysis Period: 1 yrs	-	-
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	-	-	-	-	-	Pavement	Facility: Mainline; Description: GA Martin-Marietta Inverted GA; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	-	-	Mix Design	Mix Design Type: Built from Library Items	1236 short-tons	User-Defined

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	640 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 640 short-tons; 50 mi	32,005 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	524 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 524 short-tons; 50 mi	26,185 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	59.33 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 59.33 short-tons; 50 mi	2,966 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Lime, Hydrated	-	Material	Material Type: Other	12.36 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 12.36 short-tons; 50 mi	618 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Equipment: AC mixing GA	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,236 short-tons	User-Defined
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC Morgan County Quarry Access Rd	Transport: Transport: AC Morgan County Quarry Access Rd (To Construction Site)	-	Transport	Transported Item: AC Morgan County Quarry Access Rd; 1,236 short-tons; 20 mi	24,720 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	6 hours	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	6 hours	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: AC	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	6 hours	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: IP UAB GA	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: IP UAB GA	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	2,300 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: IP UAB GA	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 2,300 short-tons; 50 mi	115,000 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: IP UAB GA	Material: Water	-	-	Material	Material Type: Other	154 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: IP UAB GA	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	9 hours	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: CTB IP	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	3,067 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 3,067 short-tons; 50 mi	153,350 short-ton-miles	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Cement (Blended with SCMs)	-	-	Material	Material Type: Cementitous	148 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Construction Site)	-	Transport	Transported Item: Cement (Blended with SCMs); 148 short-tons; 50 mi	7,400 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: CTB IP	Material: Water	-	-	Material	Material Type: Other	245 short-tons	Default Database
Alternative: GA Martin-Marietta Inverted GA	Pavement: New Pavement	Project: Initial Construction (Year 0)	Activity: CTB IP	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	22 hours	Default Database

C.5 LAGRANGE BYPASS ROAD, GEORGIA

Table 71. LCA input parameters IP (per lane-mile); LaGrange Bypass Road, Georgia.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: LaGrange ByPass IP	-	-	-	-	-	-	Alternative	Description: LaGrange ByPass IP; Analysis Period: 1 yrs	-	-
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	-	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	-	-	Mix Design	Mix Design Type: Built from Library Items	1441 short-tons	User-Defined
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	-	Material	Material Type: Aggregate	747 short-tons	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Material: Crushed Stone, granite (Coarse Aggregate for Asphalt)	Transport: Transport: Crushed Stone, granite (Coarse Aggregate for Asphalt) (To Production Site)	Transport	Transported Item: Crushed Stone, granite (Coarse Aggregate for Asphalt); 747 short-tons; 50 mi	37,336 short-ton-miles	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Material: Fine Aggregate (for asphalt)	-	Material	Material Type: Aggregate	611 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Material: Fine Aggregate (for asphalt)	Transport: Transport: Fine Aggregate (for asphalt) (To Production Site)	Transport	Transported Item: Fine Aggregate (for asphalt); 611 short-tons; 50 mi	30,549 short-ton-miles	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	-	Material	Material Type: Asphalt Binder	69.17 short-tons	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Material: Asphalt binder, no additives, consumption mix, at terminal, from crude oil	Transport: Transport: Asphalt binder, no additives, consumption mix, at terminal, from crude oil (To Production Site)	Transport	Transported Item: Asphalt binder, no additives, consumption mix, at terminal, from crude oil; 69.17 short-tons; 50 mi	3,458 short-ton-miles	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Material: Lime, Hydrated	-	Material	Material Type: Other	14.41 short-tons	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Material: Lime, Hydrated	Transport: Transport: Lime, Hydrated (To Production Site)	Transport	Transported Item: Lime, Hydrated; 14.41 short-tons; 50 mi	721 short-ton-miles	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Equipment: AC mixing GA	-	Equipment	Equipment Type: Mixing Operations - Asphalt	1,441 short-tons	User-Defined
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Mix Design: AC LaGrange Bypass	Transport: Transport: AC LaGrange Bypass (To Production Site)	-	Transport	Transported Item: AC LaGrange Bypass; 1,441 short-tons; 20 mi	28,820 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	12 hours	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Equipment: MTV, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Material Transfer Vehicle	12 hours	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: AC	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	12 hours	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP UAB	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP UAB	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	2,270 short-tons	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP UAB	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 2,270 short-tons; 50 mi	113,500 short-ton-miles	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP UAB	Material: Water	-	-	Material	Material Type: Other	152 short-tons	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP UAB	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	9 hours	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP CTB	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	4,044 short-tons	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 4,044 short-tons; 50 mi	202,200 short-ton-miles	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Cement (Blended with SCMs)	-	-	Material	Material Type: Cementitous	162 short-tons	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Construction Site)	-	Transport	Transported Item: Cement (Blended with SCMs); 162 short-tons; 50 mi	8,100 short-ton-miles	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Material: Water	-	-	Material	Material Type: Other	283 short-tons	Default Database
Alternative: LaGrange ByPass IP	Pavement: LaGrange ByPass IP	Project: Initial Construction (Year 0)	Activity: IP CTB	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	25 hours	Default Database

Table 72. LCA input parameters JPCP (per lane-mile); LaGrange Bypass Road, Georgia.

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: LaGrange ByPass CP	-	-	-	-	-	-	Alternative	Description: LaGrange ByPass CP; Analysis Period: 1 yrs	-	-
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	-	-	-	-	-	Pavement	Facility: Mainline; Description: n/a; Number of Lanes: 1; Length: 5280.0 ft; Width: 12.0 ft	63,360 square feet	-
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	-	-	-	-	Project	Project Type: Initial Construction	-	-
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	-	-	Mix Design	Mix Design Type: Built from Library Items	50160 cubic feet	User-Defined
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	Material: Crushed Stone (Coarse Aggregate for Concrete)	-	Material	Material Type: Aggregate	1,758 short-tons	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	Material: Crushed Stone (Coarse Aggregate for Concrete)	Transport: Transport: Crushed Stone (Coarse Aggregate for Concrete) (To Production Site)	Transport	Transported Item: Crushed Stone (Coarse Aggregate for Concrete); 1,758 short-tons; 50 mi	87,900 short-ton-miles	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	Material: Fine Aggregate (for concrete)	-	Material	Material Type: Aggregate	1,119 short-tons	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	Material: Fine Aggregate (for concrete)	Transport: Transport: Fine Aggregate (for concrete) (To Production Site)	Transport	Transported Item: Fine Aggregate (for concrete); 1,119 short-tons; 50 mi	55,950 short-ton-miles	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	Material: Cement (Blended with SCMs)	-	Material	Material Type: Cementitious	525 short-tons	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	Material: Cement (Blended with SCMs)	Transport: Transport: Cement (Blended with SCMs) (To Production Site)	Transport	Transported Item: Cement (Blended with SCMs); 525 short-tons; 50 mi	26,250 short-ton-miles	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	Material: Water	-	Material	Material Type: Other	8,972 short-tons	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	Equipment: Production fo Concrete Mixture at Plant only (19% Fly Ash and/or Slag) (Alternative 2)	-	Equipment	Equipment Type: Mixing Operations - Concrete	1,858 cubic yards	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Mix Design: PCP	Transport: Transport: PCP (To Construction Site)	-	Transport	Transported Item: PCP; 50,160 cubic feet; 50 mi	46.4 short-ton-miles	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Equipment: Pavers, Nonroad Diesel Fuel, 175 < hp <= 300	-	-	Equipment	Equipment Type: Pavers (Asphalt and Concrete)	6 hours	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: PCC	Equipment: equipment operation, < 25 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	600 hours	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: CP UAB	-	-	-	Activity	Activity Type: Pavement Layers	1 mile	-
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: CP UAB	Material: Base and Subbase Material	-	-	Material	Material Type: Aggregate	3,783 short-tons	Default Database

Tree Level 1	Tree Level 2	Tree Level 3	Tree Level 4	Tree Level 5	Tree Level 6	Tree Level 7	Object Type	Object Properties	Quantity	Item Type
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: CP UAB	Material: Base and Subbase Material	Transport: Transport: Base and Subbase Material (To Construction Site)	-	Transport	Transported Item: Base and Subbase Material; 3,783 short-tons; 50 mi	189,150 short-ton-miles	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: CP UAB	Material: Water	-	-	Material	Material Type: Other	253 short-tons	Default Database
Alternative: LaGrange ByPass CP	Pavement: LaGrange ByPass CP	Project: Initial Construction (Year 0)	Activity: CP UAB	Equipment: equipment operation, > 75 hp and < 750 hp	-	-	Equipment	Equipment Type: Generic Construction Equipment	9 hours	Default Database