U.S. Department of Transportation
Federal Highway Administration

SUSTAINABLE PAVEMENTS PROGRAM

LOUISIANA EXPERIENCE WITH INVERTED PAVEMENT SYSTEMS

FHWA-HIF-19-082

Inverted pavement systems are used to optimize material consumption and provide long-term performance benefits. The Louisiana Department of Transportation and Development has successfully adopted inverted pavement systems with demonstrated cost savings and environmental benefits.

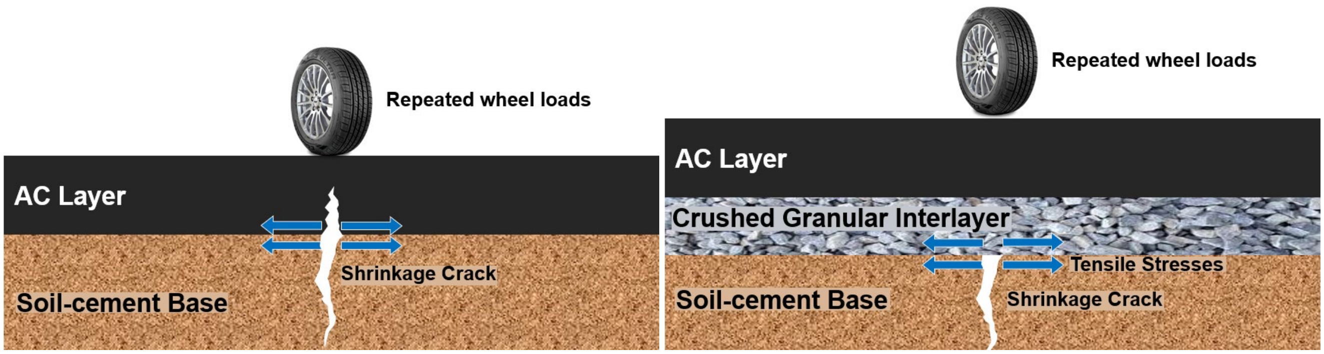
WHAT WAS THE MOTIVATION?

The Louisiana Department of Transportation and Development (LDOTD) has been using semi-rigid pavement structures—consisting of an asphalt concrete (AC) surface on a soil-cement (SC) or cement-stabilized base (CSB) and a lime-treated subgrade—to overcome soft soils and poor support conditions. Thousands of miles of highway pavements 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). 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 forming block cracking that detrimentally affects pavement performance (see figure 1). To meet this challenge and to improve pavement performance and overall environmental sustainability, LADOTD experimented with inverted pavement systems.

Figure 1. Reflective shrinkage cracks in the form of block cracking on LA 97.

WHAT WAS DONE?

To improve the long-term performance of semi-rigid pavements built with SC layers, one method used by LADOTD is the placement of a granular material between the SC base and the AC surface. In this design, the granular layer effectively behaves as a cushion between the two stiff layers and thereby minimizes the reflection of shrinkage cracks from the base into the pavement, as illustrated schematically in figure 2. The resultant design was coined a stone interlayer pavement in Louisiana, but it is also commonly referred to as inverted pavement (Tutumluer 2013). The approach allows for the optimization of granular materials and cement contents to achieve cost-effective designs. The Louisiana 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.



a. Conventional asphalt pavement design

b. Stone interlayer design

Figure 2. Stone interlayer design concept used in Louisiana to control reflection of shrinkage cracks.

The first installation of the inverted pavement system 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 study, additional inverted pavement sections were designed, constructed, and monitored after 2000 (Chen et al. 2014). To illustrate the cost, environmental, and performance benefits of inverted pavements in Louisiana, the following two pavement projects are examined.

LA 97

This was Louisiana's first inverted pavement project and consisted of two test sections constructed in 1991: one a semi-rigid structure with an in-place CSB and the second an inverted pavement design with crushed limestone placed between the CSB layer and the AC surface layer (see figures 3a and 3b). Both pavement designs were constructed on a 12-inch lime-treated subgrade soil. The cement content in the CSB layer was 10 percent. The 1990 ADT for the roadway is 2000 vehicle per day (vpd).

U.S. 165

This project was constructed on U.S. 165 in the Ouachita Parish area in 2006. It is exposed to a greater traffic volume (6500 vpd in 2006 and about 8800 vpd in 2016) than LA 97 and thus was constructed with a thicker AC surface layer (6-inch layer placed in two lifts), as shown in figure 3c. The CSB layer was stabilized with 8 percent cement. The project included only an inverted pavement design.

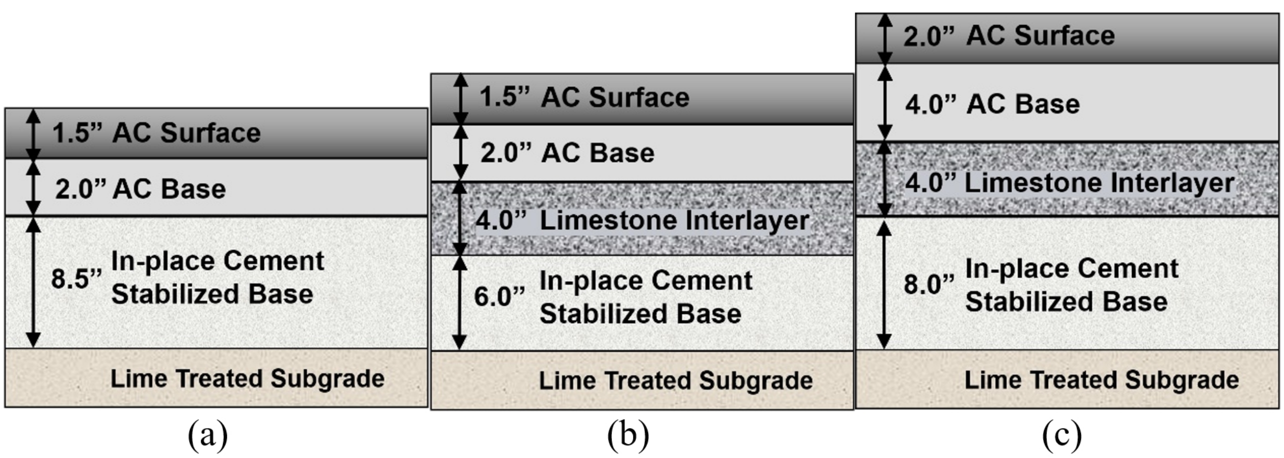


Figure 3. Pavement structures used on LA 97 and U.S. 165 highways:
(a) semi-rigid conventional design (LA 97), (b) inverted design (LA 97), and (c) inverted design (U.S. 165).

WHAT BENEFITS WERE ACHIEVED?

PERFORMANCE

The two inverted sections presented herein, as well as other similar projects monitored in Louisiana, have shown that the placement of a limestone interlayer can significantly reduce the propagation of shrinkage cracks from the CSB layer (Chen et al. 2014). This is a key benefit of the inverted pavement structure that has led to improved overall performance of pavements constructed on weak subgrades.

LA 97

After nearly 20 years in service, the conventional and inverted sections on LA 97 exhibited average International Roughness Index (IRI) values of 98 inches/mi and 106 inches/mi, respectively, with average rut depths of 0.17 inches and 0.26 inches, respectively. Cracking density and severity were lower in the inverted section compared to those in the conventional section (35 percent vs. 56 percent). The cracking density was calculated by summing the total length of longitudinal and transverse cracks per lane area. The overall composite pavement condition index (CPCI) for both sections is considered fair per the last measurements taken in 2017. Figure 4 shows the condition of the inverted pavement in 2017.

Figure 4. Overall condition of inverted section on LA 97 in 2017.

U.S. 165

The condition data provided for the U.S. 165 project from 2017 indicate that the pavement is performing well. After 11 years of service, the inverted section had an IRI of 58 inches/mi, an average rut depth of 0.31 inches, and a cracking density of 4.5 percent. The overall CPCI is considered good. Figure 5 shows the condition of the inverted section on U.S. 165 in 2017.

Figure 5. Overall condition of inverted section on U.S. 165 in 2017.

ENVIRONMENTAL AND ECONOMIC PERFORMANCE

To assess the broader environmental performance of the different designs included in the two projects, researchers contracted by FHWA performed a limited life-cycle assessment (LCA) in 2019. The analysis included the materials and initial construction stages to quantify energy, smog, and eutrophication potential impacts, the first being a commonly used environmental indicator and the latter two being important to the State of Louisiana in its programs to protect air and water quality (LDEQ 2019). The LCA results in table 1 indicate that the energy demand for inverted pavements is essentially equivalent to that for conventional pavements, primarily because of the increased energy demand related to the hauling of crushed limestone to this particular job site. When abundant sources of crushed aggregates are available and in local proximity, there could be a 3 to 5 percent reduction in energy demand for the inverted pavement.

Table 1. Environmental and economic sustainability analysis of inverted pavement sections (environmental results generated using environmental inventory data from Al-Qadi et al. 2015).

Section	Energy Demand, MJ per lane-mile	Smog, kg O_3 per lane-mile	Eutrophication, kg N per lane-mile	Initial Cost, $ per lane-mile[1]
LA 97 (control)	2.61E+06	1.73E+04	1.08E+02	–
LA 97 (inverted)	2.63E+06	1.63E+04	1.03E+02	–
U.S. 165 (control)[2]	3.63E+06	2.28E+04	1.43E+02	204,599
U.S. 165 (inverted)	3.54E+06	2.06E+04	1.32E+02	204,208
Average Sustainability Savings	Negligible	8.4%	7.0%	Negligible

1 Cost is calculated using average bid prices for construction of CSB, crushed granular base, and AC layers obtained for specific pay items used on the U.S. 165 project.
2 Control for U.S. 165 project is hypothetical and included for comparative purposes.

However, the LCA results presented in table 1 do indicate that inverted pavements have the potential to reduce smog and eutrophication when compared to conventional pavements; smog was reduced by an average of 8.4 percent and eutrophication by an average of 7 percent.

The initial costs were computed for the control and inverted sections on U.S. 165, as shown in table 1 (cost data for the LA 97 project were not available). These values are essentially equivalent, with the initial cost of the inverted section on the U.S. 165 project slightly higher because of the high cost of crushed aggregates in Louisiana. Where crushed aggregate is readily available, savings in initial construction costs of the inverted design would be expected.

WHAT WERE THE KEY OUTCOMES AND LESSONS LEARNED?

In this case study, two inverted pavement projects in Louisiana were reviewed to evaluate their performance (including the economic and environmental performance). Based on the review of the two projects, the following key outcomes were identified:

> *"LADOTD has fully endorsed the concept and have been designing most of the new projects 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 problem in Louisiana pavements and has proved to provide long-term pavement performance. We plan to continue to design pavements using this concept to serve the infrastructure needs of Louisiana."*
>
> – Mark Ordogne, Louisiana Dept. of Transportation

- The overall performance of the inverted sections on LA-97 and on U.S. 165 is satisfactory. The granular interlayer placed between the CSB and the AC surface layer reduces the propagation of reflective shrinkage cracking from the CSB resulting in performance benefits:
  - The U.S. 165 project exhibited good rideability after more than 11 years of service.

  - The LA 97 sections, which include a control section, have been in service since 1991 and are still in a fair to good condition. The control section had slightly better performance than the inverted section in terms of roughness and rutting, but it exhibited more cracking.
- An environmental performance analysis of the inverted and control section was performed considering energy demand, smog, and eutrophication. The results indicate a negligible benefit in terms of energy demand (only because significant aggregate hauling was involved for this particular project) but average potential reductions of 8.4 and 7 percent, respectively, were realized for smog and eutrophication, two environmental performance indicators important to Louisiana.
- Initial construction costs for an inverted and control section on U.S. 165 were very similar. Crushed aggregates in Louisiana is limited, which would increase the cost of inverted pavements. However, where crushed aggregate is available, savings in initial construction costs of inverted design are expected.

Currently, the AASHTO 1993 method is used for the design of inverted pavements in LADOTD. As the mechanics of inverted pavements is quite different than that of conventional flexible and semi-rigid pavements, mechanistic-empirical (M-E) methods are more appropriate to calculate critical responses in future. In addition to considering proper AC properties in the design, rutting in granular interlayer and fatigue in stabilized layers are critical responses that could be considered in the design. In this way, the use of M-E design methods could be used to help optimize the structural design and lead to greater cost and environmental savings.

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KEY WORDS

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