



Effective Shoulder Design and Maintenance

tech transfer summary

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RESEARCH PROJECT TITLE

Effective Shoulder Design and Maintenance

SPONSORS

Iowa Highway Research Board (TR-531)
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MORE INFORMATION

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The Partnership for Geotechnical Advancement (PGA) is part of the Center for Transportation Research and Education (CTRE) at Iowa State University. The mission of the PGA is to increase highway performance in a cost-effective manner by developing and implementing methods, materials, and technologies to solve highway construction problems in a continuing and sustainable manner.

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Objectives

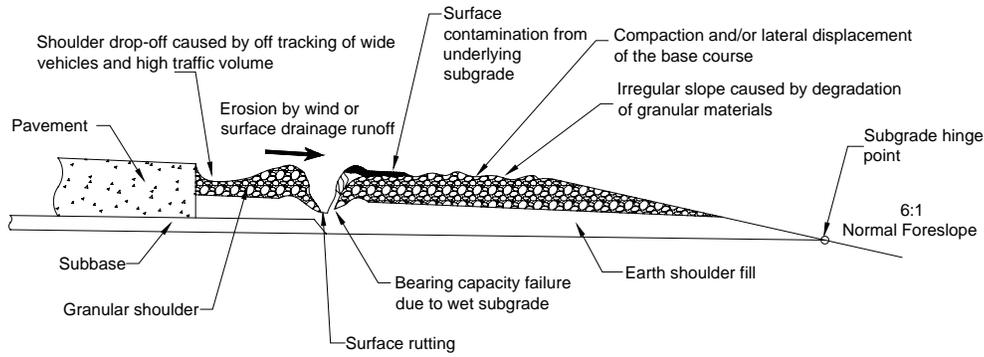
- Identify practices for design, construction, and maintenance of granular shoulders that result in reduced rutting and edge drop-off, improved safety, reduced maintenance costs, and extended performance life, with recommendations specific to Iowa materials and conditions.
- Document several granular shoulder sites where poor and good performance has been observed in order to better understand the factors contributing to shoulder problems.
- On a pilot study basis, evaluate and compare the performance of several test sections using chemical stabilization (e.g., fly ash and portland cement) and mechanical reinforcement (e.g., geogrid) techniques, including application of waste and recycled materials in construction (e.g., limestone screenings, recycled concrete, recycled asphalt).
- Perform a cost-benefit analysis to investigate the owner costs of alternative systems.

Problem Statement

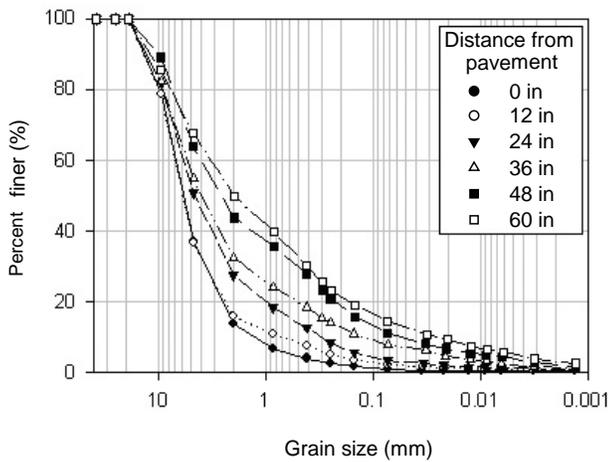
Shoulders are an important element of the highway system, providing space for emergency stops, a recovery zone for errant vehicles, structural support for the pavement, drainage, improved sight distance, passage for bicyclists, and increased roadway width to accommodate agricultural vehicles.

Granular shoulders are a commonly used shoulder option. Although the construction of granular shoulders is initially less expensive than that of paved shoulders (by up to 70%), granular shoulders often add expense later because they require more frequent maintenance and have performance problems. Common granular shoulder problems include edge drop-off, shoulder rutting, erosion by water or wind, irregular slope, and settlement of the subgrade soil.

Current maintenance procedures for granular shoulders in Iowa typically involve shoulder regrading, placing additional material, and recompaction. These maintenance and repair problems are costly and require investigation to illuminate the factors that contribute to these problems.



Common granular shoulder problems



Change in granular material graduation by wind erosion

Field Observations of Granular Shoulder Sites

In field investigations across Iowa, various granular shoulders were inspected. These inspections revealed the following:

- The two major problems observed were edge drop-off and soft subgrade layer.
- Approximately 60% of the inspected sites had an edge drop-off greater than 1.5 in., and 40% had a slope higher than the 4% slope grade specified by the Iowa DOT.
- About 50% of the shoulder sections had a soft subgrade layer (CBR values less than 10 at depths between 8 and 10 in.).
- Wind induced by high-profile vehicles removes the fines and changes the granular material gradation, contributing to edge drop-off formation.
- Granular shoulders are maintained by adding virgin or recycled material, such as hot mixed asphalt (HMA) or recycled concrete.



Edge drop-off along the outside shoulder caused by vehicle off-tracking



Severe shoulder rutting caused by bearing capacity failure of the soft underlying subgrade



Monitoring tire-aggregate interaction using stationary high-speed camera



Digital images captured by camera showing elevated aggregate particles

Observation of Vehicle Tire-Aggregate Interaction

Vehicle off-tracking is a prime contributor to the development of edge drop-off. An approach was therefore conceived to study vehicle tire-aggregate interaction for unpaved shoulders using high-speed cameras. To capture the vehicle tire-aggregate behavior, a pickup truck was driven on an unpaved shoulder at 40 mph while the high-speed camera captured the aggregate trajectories. The results show that aggregates are elevated upward and pushed in the opposite direction of vehicle travel.

Evaluation of Granular Shoulder Stabilization Techniques

To test different chemical and mechanical stabilization techniques, six problematic granular shoulder sections were selected. The test sections were either experiencing edge drop-off or severe rutting due to a soft subgrade layer.

Stabilization of Granular Layer

The granular layer at four of the six test sections was stabilized using either a polymer emulsion, foamed asphalt with fly ash, soybean oil, or portland cement.

Performance summary of chemically stabilized granular layer at four test sections

Test Section	Location	Stabilizer	Application	Observations
1	Highway 122, Clear Lake, IA	Soil Sement polymer emulsion	Topical	Edge drop-off started to redevelop after 30 days
2	I-35	Foamed asphalt	Full depth reclamation	Failed along the pavement edge due to water migration and off-tracking vehicles
3	Highway 18, Rudd, IA	Soybean oil	Reclamation to a depth of 6 inches (0.7gal/yd ²)	Separation of soy oil and emulsion obstructed the construction process
4	16th St., Ames, IA	Portland cement	Reclamation to a depth of 6 inches (10% cement)	Improved the strength of the section; however, signs of edge drop-off and washboarding was noted due to poor mixing and water control



Performance of the fly ash–stabilized shoulder section after seven months: stabilized section (top) and control section (bottom)



Rolling the geogrid over the soft subgrade layer near Nashua, Iowa

Stabilization of Subgrade Layer

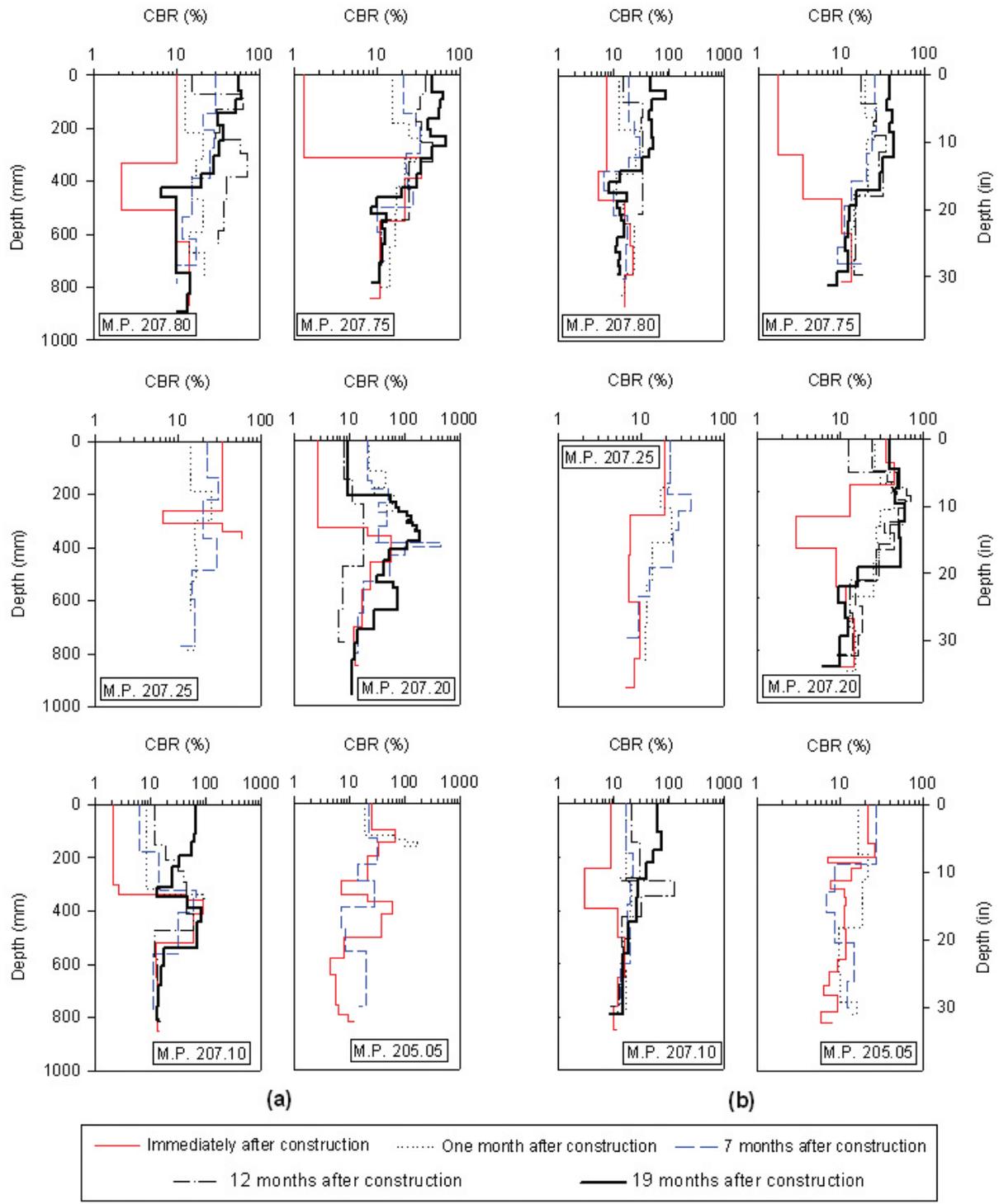
Two of the six test sections that had soft subgrade layers were stabilized using class C fly ash and different geosynthetic products.

For the fly ash stabilization techniques, shoulder sections located on Highway 34 near Batavia, Iowa, were undergoing severe rutting due to soft subgrade layers. The upper 12 in. of the subgrade were stabilized with 15% to 20% class C fly ash. The section was monitored for 19 months. Fly ash stabilization was successful in eliminating shoulder rutting and improving the overall long-term performance of the shoulder section.

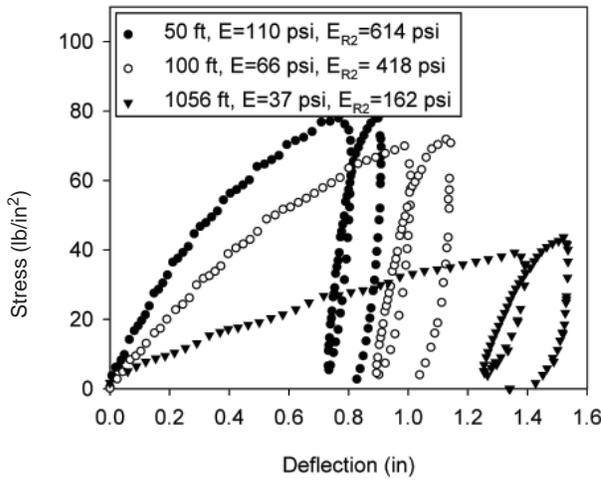
For the geogrid stabilization techniques, the inside granular shoulder on Highway 218 near Nashua, Iowa, was experiencing severe rutting due to soft subgrade conditions. The section was stabilized by placing various types of geogrid at the interface between the granular and subgrade layers, and the test section was monitored for 10 months. Four different geogrids were evaluated, and all considerably improved the performance of the shoulder test section and eliminated shoulder rutting.



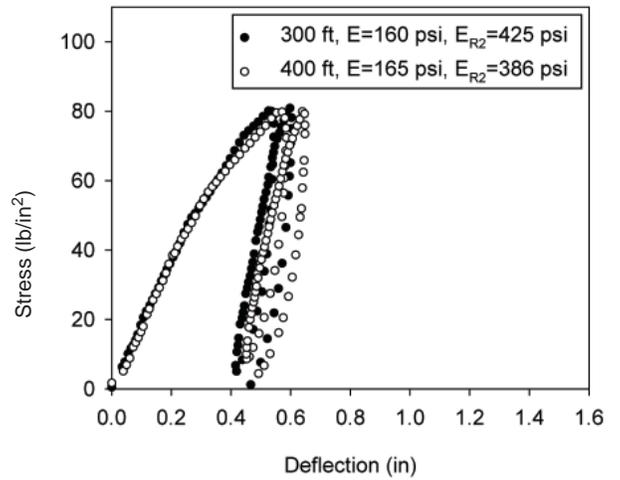
Inside shoulder near Nashua, Iowa: before stabilization (top) and two months after stabilization (bottom)



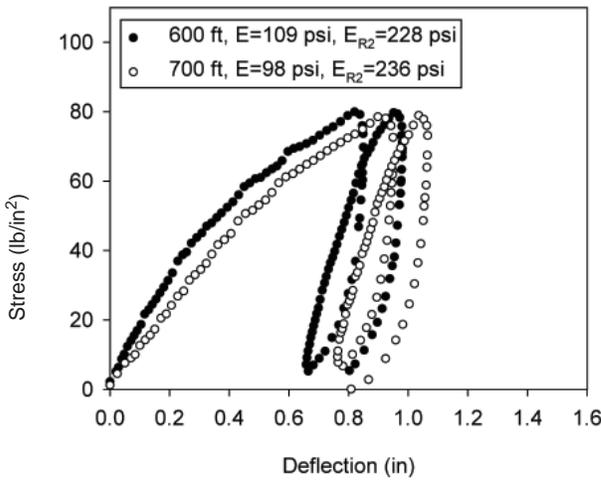
*Dynamic cone penetrometer test results with time for the fly ash–stabilized sections:
 (a) 3.0 ft and (b) 6.0 ft from the pavement edge*



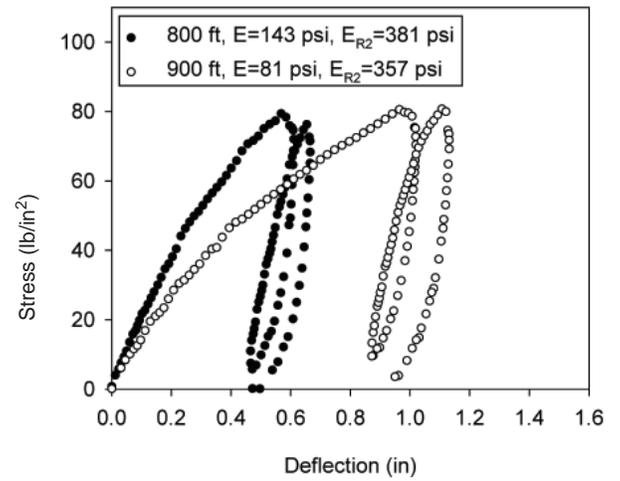
Control Section



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BX1100

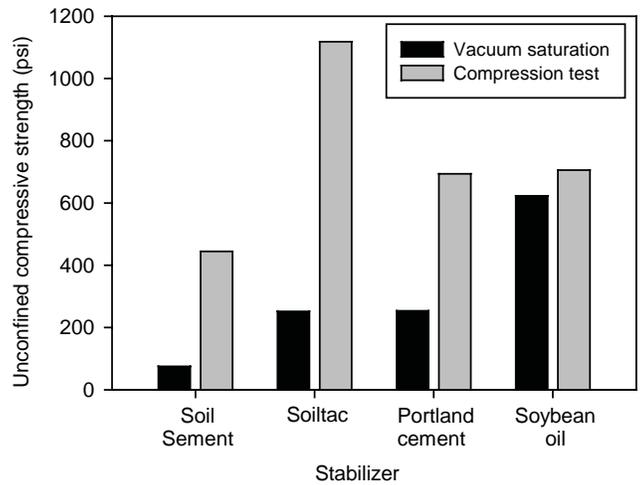


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Plate load test results 10 months after construction, geogrid-stabilized sections

Laboratory Evaluation of Stabilizers

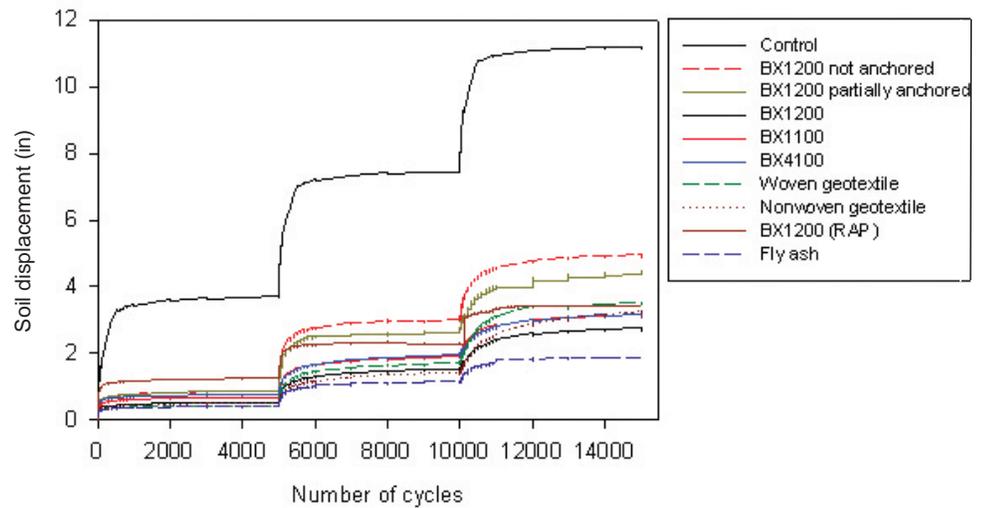
To develop the findings from the field study, different stabilizers were selected to conduct a laboratory study of stabilization methods for shoulder granular material. The stabilizers selected for this study were Soil Sement polymer emulsion, Soiltac polymer emulsion, portland cement, and Dustlock soybean soil. The results of the study show that soybean oil can be a good candidate in stabilizing the shoulder granular layer.



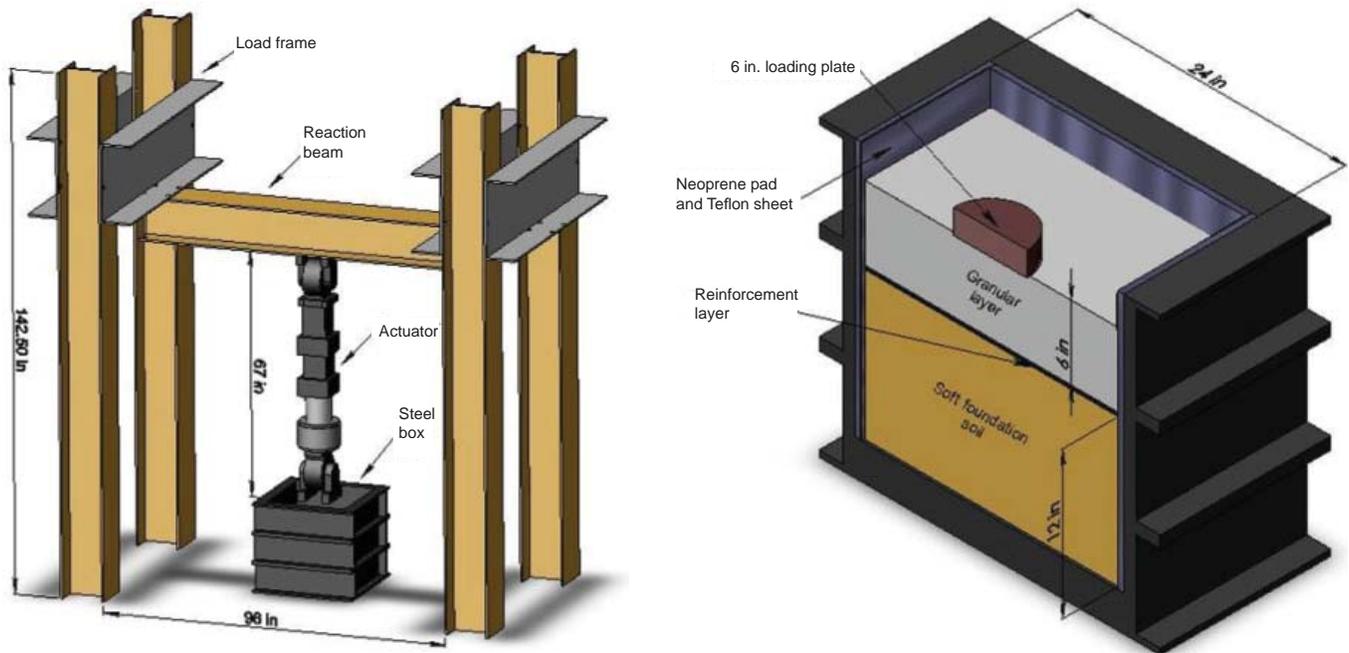
Summary of compressive strength results for the different stabilizers tested

Laboratory Box Study

To simulate a shoulder section overlying a soft subgrade, a laboratory study was conducted. Cyclic loading with three loading stages was used to study the performance of the laboratory model under different mechanical and chemical stabilization techniques. At each stage, a pressure was applied and sustained for 5,000 cycles at a frequency of 1 Hz. These pressures were 40, 80, and 120 psi. The soil properties before and after each test and the cumulative soil displacement over an increasing number of cycles were recorded.



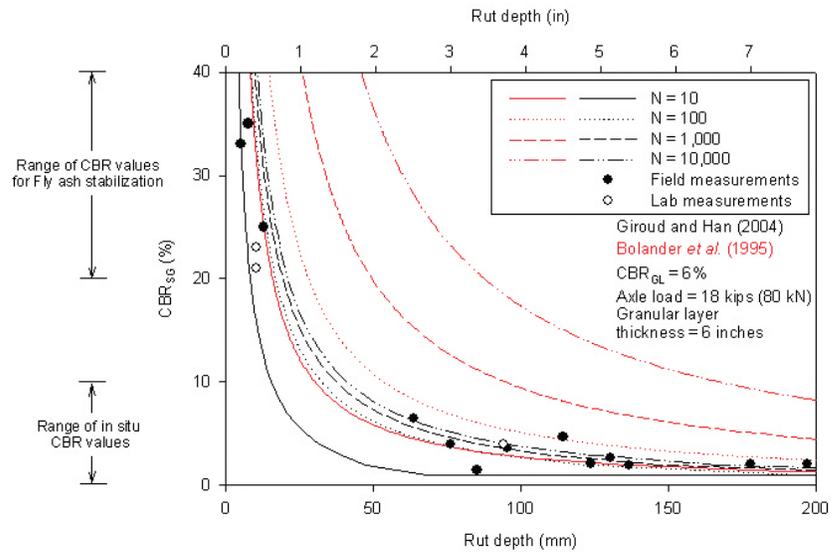
Summary of cumulative measured soil displacement for all laboratory box tests



Schematic of the laboratory apparatus setup: Steel frame and hydraulic actuator for loading the stabilized soil (left) and steel box used to contain the soil (right)

Shoulder Design Charts

Using the results of these field and laboratory data, shoulder design charts were developed to help mitigate shoulder rutting caused by the bearing capacity failure of the subgrade layer. The design charts, validated by the field and laboratory data, were based on the semi-empirical method proposed by Giroud and Han (2004) and an equation developed by the U.S. Army Corps of Engineers in 1989 for predicting surface rutting for low-volume roads (Bolander et al. 1995). The charts can be a rapid tool for designing new granular shoulders and predicting the behavior of existing ones.



Shoulder design chart showing the relationship between subgrade CBR and expected granular shoulder rut depth for different load cycles

Economic Analysis of Shoulder Construction, Maintenance, and Repair

To compare the cost-benefit scenarios for possible shoulder improvements and repairs, a cost estimate analysis was conducted. The analysis demonstrated that the monetary benefits of the reduced granular shoulder maintenance costs are small in comparison to the required investment (construction costs), though granular shoulders do result in a small reduction in the present value of the necessary cash outflow. However, it should be noted that the investment in shoulder improvements is often made to garner an improved level of service, greater safety, and other benefits that are difficult to quantify.

Calculations for present worth of granular shoulder expenditures

Category	Activity	Benefit	Costs	Net Value
Maintenance	Granular Shoulders	\$0.00	-\$9,510.00	-\$9,510.00
Improvement	Partial Paved			
	2 foot \$	3,314.00	-\$29,508.00	-\$26,194.00
	4 foot \$	3,314.00	-\$42,944.00	-\$39,630.00
	Foamed AC \$	6,206.00	-\$66,922.00	-\$60,716.00
	Full-width Paving			
	HMA	\$6,206.00	-\$128,567.00	-\$122,361.00
	PCCP \$	6,206.00	-\$185,469.00	-\$179,263.00
Repair	Polymer Grid \$	8,073.00	-\$41,382.00	-\$33,309.00
	Fly Ash \$	8,073.00	-\$54,817.00	-\$46,744.00

Recommendations

Shoulder Construction

- To avoid shoulder rutting, it is recommended that the weighted average CBR value of the earth shoulder fill and the subgrade layers up to a depth of 20 in. should be greater than or equal to 12.
- The weighted average CBR value for the granular layer should not be less than 10.
- Dynamic cone penetrometer and Clegg impact tests can be used rapidly to assess the in situ CBR values during shoulder construction.
- The provided design charts can be used as a guide for constructing new shoulders. The allowable rut depth can be controlled by selecting an appropriate CBR value for each layer and accounting for the expected traffic level and loads. The design charts can also be used to predict the behavior of existing shoulder sections.

Subgrade Repair

- In the case of severe rutting due to the bearing capacity failure of the subgrade, it is proposed that fly ash or geogrid stabilization be used.

Edge Drop-Off

- Edge rut repair options should include the incorporation of stabilizers such as portland cement, polymer emulsions, and soybean oil. However, improved mixing/compaction methods and equipment are needed for greater effectiveness and efficiency.