Iowa State University
Institute for Transportation

Feasibility of Granular Road and Shoulder Recycling

tech transfer summary

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RESEARCH PROJECT TITLE
Feasibility of Granular Road and Shoulder Recycling

SPONSORS
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The mission of the Institute for Transportation (InTrans) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.

Methods were developed to cost-effectively recycle degraded granular-surfaced roadway materials while improving them to optimum gradations and plasticity for improved performance and durability.

Goal

The goal of this study was to develop an approach to cost-effectively recycle existing degraded granular surface materials by mixing them with fresh aggregates in optimized proportions to achieve a target gradation and plasticity that will maximize performance and durability.

Background

Granular-surfaced roads and shoulders frequently experience extensive surface damage caused by heavy agricultural traffic loads, freeze-thaw cycles, and wet-dry cycles. Such damage increases maintenance requirements and reduces safety.

Current practice to address surface damage typically involves covering the entire road surface with fresh aggregate followed by blading with little or no compaction. Meanwhile, most state department of transportation (DOT) specifications for the gradation and plasticity of granular surface materials are neither performance based nor strictly followed.

Consequently, sub-optimal gradations can be placed. This may lead to the rapid degradation of the freshly placed aggregate material to smaller particles and the generation of fugitive dust, which further contributes to a costly cycle of recurring maintenance.

Granular-surfaced roads typically require a smaller top size for better stability and ride quality and a small amount of plastic fines to bind the aggregate and reduce aggregate loss.

Problem Statement

The importance of index properties such as maximum aggregate size, gradation, plasticity, and abrasion characteristics has long been recognized. However, very few studies to date have focused on quantifying the effects of gradation and plasticity on the performance and durability of granular surface materials.

Mixing the optimized surface course materials using a reclaimer

Research Methods

The research involved a literature review, web survey of county engineers, and evaluation of current specifications; laboratory and field studies; a statistical evaluation of laboratory testing methods; and technology transfer activities to translate the research into practice.

Laboratory Study

A laboratory study was conducted to quantify the effects of altering the gradation and plasticity of granular surface materials to restore or improve their mechanical performance levels. Because granular-surfaced roads are most prone to damage during spring thaws and rainy seasons, the evaluation was focused on the post-saturation performance of surface materials.

Tests included soil index property tests, California Bearing Ratio (CBR) tests, and unconfined compressive strength and slaking tests.

Two types of granular surface materials collected from an existing granular-surfaced road and a quarry in Pottawattamie County, Iowa, were evaluated, and bentonite clay from Wyoming was used to adjust the plasticity of the testing specimens.

Field Performance

To validate the optimal gradations and bentonite contents determined in the laboratory study, granular road and shoulder test sections were designed and constructed in Pottawattamie County and Boone County, Iowa, in summer 2016.

Compacting the new granular-surfaced road layer with a vibratory smooth drum roller (left), and bentonite-treated surface material after compaction (right)

To help local roads agencies implement the proposed design methods and recycle existing degraded surface materials, a Microsoft Excel-based program was developed to optimize the proportions of existing surface materials and two or three available quarry materials.

Performance-based field tests and visual surveys were conducted following construction and again after the 2016-2017 freeze-thaw season to compare the as-constructed performance and freeze-thaw durability of the test sections.

Statistical Evaluation of Laboratory Methods

The commonly used ASTM-standardized (Casagrande cup) Atterberg limits tests, fall cone device, and bar linear shrinkage tests were evaluated in terms of their repeatability, reproducibility, and sources of error. An innovative two-way ANOVA-based analysis method was developed to determine the tests' repeatability and reproducibility (R&R) and capacity.

To address deficiencies in the Los Angeles (LA) abrasion and Micro-Deval tests, a new laboratory testing method, Gyratory Abrasion and Image Analysis (GAIA), was developed and tested. The method employs a gyratory compaction device and two-dimensional (2D) image analyses to evaluate the mechanical degradation and changes in morphology and shear strength of granular materials under simulated field compaction and traffic loads.

Key Findings

Laboratory Study

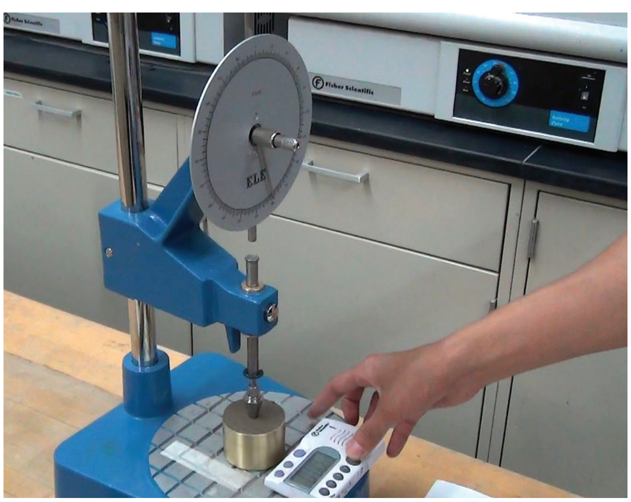
- The soaked strength of a granular material depends more strongly on the shape of its gradation curve and the associated particle packing than whether the particles fall within a specific gradation specification band.
- A theoretical optimal gradation in terms of maximizing the predicted soaked CBR for crushed limestone surface materials with known top size can be determined using the statistical model and spreadsheet developed in this study.
- The proposed method is more strongly performance related than the DOT gradation band specifications, and it can be used to develop specifications with more precise targets.
- Laboratory test results showed that adding plastic fines can reduce shear strength under wet conditions but greatly improve slaking performance. Based on the results of this study, the recommended plasticity index range for granular surface course materials is 7 to 15.
- Based on these key findings, a complete set of testing, design, and construction procedures for building or reconstructing granular-surfaced roads was developed.

Field Performance Study

- The field test results further validated the performance of the proposed methods.
- The road section with the "optimal" gradation without bentonite exhibited better performance than the control section and yielded the smallest reduction in stiffness and strength among all the test sections after the freeze-thaw season.
- The test section with the "optimal" gradation and plasticity (by incorporating bentonite) yielded the best as-constructed performance and lowest dust emissions. However, periodic visual observations and laboratory tests revealed that the bentonite content decreased significantly after the freeze-thaw season.

Statistical Evaluation of Laboratory Testing Methods

- Liquid limit determined using the fall cone test correlates very well with that determined using the Casagrande cup test.
- The fall cone test exhibits much smaller overall variations than the Casagrande cup test, which is more strongly affected by inter-operator errors. Therefore, the fall cone test is recommended for local roads agencies to more easily and reliably determine liquid limit than the Casagrande cup test.
- For the plastic limit test, the ASTM-recommended roller performs satisfactorily in terms of repeatability and reproducibility and eliminates one source of error in the test (i.e., variation and non-uniformity in thread diameter between different operators).
- Comparisons between the GAIA test and the commonly used LA abrasion test demonstrate that the GAIA test can address the shortcomings of the LA abrasion test and quantify the behavior of granular materials during compaction.



Fall cone test device used in this study

Recommended Testing, Design, and Construction Procedures

The following set of testing, design, and construction procedures is recommended:

- Determine the road geometries and the thickness, gradation, and plasticity of the existing surface aggregate layer.
- Design the thickness of the aggregate surface layer based on the in situ dynamic cone penetrometer CBR (DCP-CBR) values and traffic information. The thickness of the surface layer can be designed following the AASHTO, Giroud and Han, or other methods.
- Determine the optimal shape factor based on the top size of the material. Note that the statistical model used in this study was developed for crushed limestone materials and needs further validation for materials with significantly different particle shapes and origins.
- Calculate the design proportions for mixing the existing materials and two or three available virgin quarry materials using the optimization spreadsheet. Most quarries do not produce custom gradations or charge extra for them, so blending two or three available quarry materials with the existing surface material is recommended. Note that the quarry gradations used for the optimization should be representative and may therefore need to be verified.
- For construction, the aggregate materials can be mixed in a quarry or onsite using motor graders. Conventional equipment is sufficient to implement the proposed method, although compaction at optimum moisture content by a smooth drum vibratory roller is highly recommended. Quality control tests may be required to check the gradations of the quarry materials and blended mixtures.
- If bentonite or a local clay is incorporated to increase the plasticity of the surface material, Atterberg limits tests should be performed to determine the plasticity index of the treated mixture. It is recommended that plastic fines be mixed only into the top 50 to 75 mm of the roadway because they can greatly reduce the shear strength of granular materials under prolonged wet conditions. Mixing the fines into the top portion of the surface course can bind the larger aggregates to reduce material loss while preserving the shear strength of the deeper aggregates in the lower part of the surface course.

Implementation Benefits and Readiness

The set of recommended testing, design, and construction procedures developed in this research can provide state secondary roads departments with more cost-effective solutions for building or reconstructing granular road systems with improved performance and durability, with the option of recycling existing surface course and subgrade materials.

The gradation optimization spreadsheet developed in the field performance study was distributed to Iowa county engineers on the Iowa County Engineers Service Bureau website. Several counties have begun using it and providing feedback. The spreadsheet is available for download here.

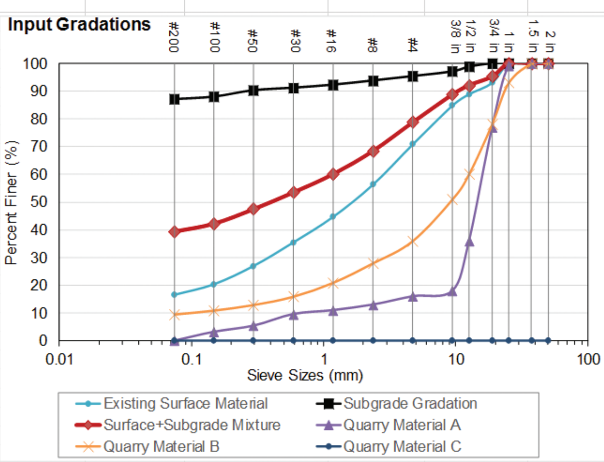
Gradation Optimization for Granular Surface Materials

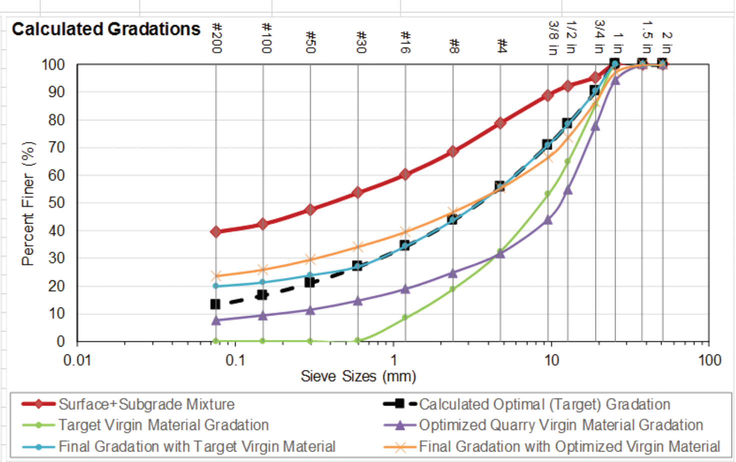
Developed in Iowa Highway Research Board Project TR-685

District		**Project**	Granular Surfaced Road	**Date**	
County		**Note**	This is a trial version of the program	**Designer**	

Road Geometry			**Properties of Existing Materials**		
Road Length	5280	ft	Thickness of Existing Suface Material	1.50	in.
Average Road Width	26	ft	Dry Unit Weight of the Virgin Material	125	pcf
			Thickness of Subgrade to be Incorporated into the Surface	1.00	in.
Final Design Parameter			Dry Unit Weight of the Subgrade	90	pcf
Target Final Thickness	5.00	in.	Total Thickness of the Existing Surface and Subgrade	2.50	in.
Target Maximum Aggregate Size (D_{max})	1.00	in.			
Target Gradation Shape Factor (*n*)	0.35	0.35 to 0.40 is recommeded. The coarseness increases as the *n* value increases.			

Sieve No.	Optimal Gradation (%)	Existing Surface Material Gradation (%)	Subgrade Gradation (%)	Quarry Material A (%)	Quarry Material B (%)	Quarry Material C (%)	Optimized Quarry Virgin Gradation (%)	Target Virgin Material Gradation (%)	Final Gradation with Target Virgin Material (%)	Final Gradation with Optimized Virgin Material (%)
2	100.0	100.0	100.0	100.0	100.0	0.0	100.0	100.0	100.0	100.0
1.5	100.0	100.0	100.0	100.0	100.0	0.0	100.0	100.0	100.0	100.0
1	100.0	100.0	100.0	99.0	93.0	0.0	94.3	100.0	100.0	97.1
3/4	90.3	93.0	100.0	77.0	78.0	0.0	77.8	85.4	90.3	86.5
1/2	78.5	88.9	98.8	36.0	60.0	0.0	55.0	64.8	78.5	73.5
3/8	70.9	84.8	97.1	18.0	51.0	0.0	44.1	53.0	70.9	66.4
#4	55.7	70.8	95.4	16.0	36.0	0.0	31.8	32.5	55.7	55.3
#8	43.7	56.3	93.8	13.0	28.0	0.0	24.8	18.9	43.7	46.7
#16	34.3	44.7	92.3	11.0	21.0	0.0	18.9	8.4	34.3	39.5
#30	26.9	35.5	91.2	9.6	16.0	0.0	14.7	0.2	26.9	34.1
#50	21.1	27.0	90.3	5.4	13.0	0.0	11.4	0.0	23.8	29.5
#100	16.6	20.4	88.0	3.2	11.0	0.0	9.4	0.0	21.2	25.8
#200	13.0	16.6	87.1	0.0	9.6	0.0	7.6	0.0	19.7	23.5
				Proportion (%)	21	79	0		100	100
				Quantity (tons)	375.9	1411.6	0.0		1787.5	1787.5





Screenshot of gradation optimization spreadsheet