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Soil Stabilization

Prepared for
North Central Pavement Research Partnership

Prepared by
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Transportation Literature Searches are prepared for practitioners and investigators to identify completed research and other authoritative information in an area of interest. The citations below are representative, rather than exhaustive, of available English-language studies on the topic. Primary online resources for the literature searches are OCLC's WorldCat and TLCat, U.S. DOT's TRIS Online, the National Transportation Library (NTL), TRB's Research in Progress (RiP) database, and other academic, engineering and scientific databases as appropriate.

Keywords: Soil stabilization, base stabilization, bitumen stabilization, modified aggregates, cement stabilization, chemical stabilization, chemical stabilized layers, stabilized soils, lime-cement stabilized soils, fly ash stabilization, nontraditional stabilization, mechanistic stabilization, lime stabilization, kiln dust stabilization, stabilization engineering, nontraditional additives soil, sodium chloride stabilization, geosynthetic stabilization.

Summary

We found 51 citations dating back to 1996 addressing soil stabilization, 15 of these from the 2008 New Zealand Institute of Highway Technology Recycling & Stabilisation Conference. In the course of this literature search, we identified six subcategories representing different aspects of soil stabilization research:

- Bituminous Stabilization and Fly Ash (17 studies)
- Cement and Lime Stabilization (12 studies)
- Nontraditional and Chemical Additives (8 studies)
- Design and Performance (10 studies)
- Unpaved Roads (3 studies)
- Waste Minimization (1 study)

The citations below are arranged according to these subcategories. While most studies do not fit strictly under only one of these headings, we have grouped each study according to its primary focus area.

Citations

Links to online copies of cited literature are provided when available. To obtain hard copies, contact your local transportation library or the Wisconsin DOT Library at library@dot.state.wi.us.

Bituminous Stabilization and Fly Ash

Title: WHO and WHAT are Baulking at the Implementation of Cold-Recycling Techniques Using Bitumen Stabilisation? WHY?
Author(s): Kim Jenkins
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 15 pp.

Contents: The introduction of new technology in any field invariably results in resistance to change from certain quarters. Notwithstanding this, cold recycling technology for road pavements has experienced exponential growth in southern Africa and other global regions over the past decade. A measure of the numbers of milling/stabilisation and recycling machines purchased into the market verifies this, but the implementation of the technology has not been without opposition. The resistance to change can generally be grouped into five categories:

- *Inertia in the comfort zone:* remain with tried and tested techniques and find no merit in taking unnecessary risks.
- *Fear of the unknown:* Initial R&D into new technology is never sufficient to cover all scenarios or important aspects of performance. Are the risks too high?
- *Ignorance:* Cold recycling can easily be underestimated as a "simple, user friendly technology". It is not. Are practitioners prepared to make the effort to understand the complexities of this new technology?
- *Vested interests:* Without an incentive to innovate or produce the most cost effective solutions, second rate technologies will prevail.
- *Poor initial economic incentives.* Although cold recycling technology has significant potential economic benefits, experience has shown that these benefits are seldom passed onto the client i.e. road authorities, during early stages of implementation.

This paper explores some of the issues outlined above and attempts to answer some of the questions by providing details on the developments of improved mix design, structural pavement design procedures, improved material testing techniques and updated specifications for the construction of bitumen stabilised materials (cold recycled) with foamed bitumen and emulsion binders.

Title: Foamed Bitumen Stabilisation in New Zealand—A Performance Review and Lessons Learnt
Author(s): Allen Browne
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 12 pp.
Contents: Hiway Stabilizers (Hiways) has been stabilising pavements in New Zealand for over 20 years—but have been carrying out foamed bitumen stabilisation only since 2004, and since 2005 with purpose-built plant. While four years is a relatively small proportion of the (generally) 20 to 25 year nominal design life, the performance of these foam bitumen stabilised pavements has been exemplary. All quality assurance and post construction evaluation to date suggests, at the least, a continued achievement of design expectations.

The last two years has seen Hiways undertake a significant quantity of foamed bitumen stabilisation nationwide. During this time various research has been undertaken on refining mix designs, curing/hydration times, sensitivity to different types and/or proportions of reagents and laboratory failure mode(s). A wide variety of locations, materials and treatment constraints have also been encountered. As a result of this experience some valuable lessons have been learnt regarding materials requirements, surfacing preparation / design and the unique challenges regarding quality assurance testing.

With this relatively new technology (to New Zealand conditions), an effort has been made to gently 'push the envelope' and assess performance in a variety of materials and settings. This has lead to a significant improvement in understanding where the process is applicable in New Zealand conditions and what considerations can enhance the likelihood of project success. This paper will expand on Highway Stabilizers foamed bitumen performance to date and focus on a number of lessons learnt regarding identifying risk elements and ensuring the successful application of this innovative treatment option.

Title: Foamed Bitumen Stabilisation in New Zealand—Projects, Do's and Don'ts, Performance
Author(s): Thorsten Frobel and John Hallett
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 31 pp.
Contents: Fulton Hogan introduced the first purpose built stabilisation hoe to New Zealand for stabilising pavements with foamed bitumen in 2004. Many lessons have been learnt during the introduction of this "new" technology into New Zealand, including the pavement and laboratory investigation, procurement, operational and surfacing aspects of the work.

The first two foamed bitumen treated pavement projects carried out by Fulton Hogan involved rehabilitation of pavements on moderately and heavily trafficked State Highways. Four years later these are still performing as expected in terms of the design and performance. In this paper a closer analysis is carried out on these two projects in terms of the performance based on falling weight deflection measurements and high speed data.

In addition typical applications to date, aspects of procurement, and lessons learnt in terms of pavement investigation, laboratory performance testing, incorporation of the subgrade into the treated basecourse and sealing are discussed.

Title: Rheological Properties of Bitumen in RAP—How to Account for It in Recycled Asphalt Mixtures
Author(s): Hussain Bahia, Salvo Mangiafico, Emil Bautista
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 15 pp.
Contents: Recycling of bitumen reclaimed from damaged pavements is one of the unique opportunities for reducing cost of pavement construction. It is also an opportunity to conserve natural resources and reduce impact of bitumen and aggregate production on the environment. Re-use of bitumen, however, should be done properly by accounting for the characteristics of the aged bitumen. Aging of bitumen is known to cause significant changes in its properties as a result of oxidation and, in some case, volatile loss. For many years estimating or measuring the properties of aged bitumen has been a challenge. This paper is prepared to show the factors affecting changes in bitumen properties as a result of in-service aging and the typical changes in rheological properties with time. It includes a study of published data for bitumens recovered from various regions in the United States and a comparison with laboratory accelerated aging. The focus is on the critical changes that could affect performance of pavements constructed with aged bitumens and is also on presenting simple procedures to determine the requirements of new bitumens that are needed to balance aged properties and bring the recycled mixture to required properties.

The results show that properties of aged bitumen could vary significantly depending on the climatic conditions at which the bitumens were used, the pavement depth, the mineralogy, and the number of years of service. The results indicate the need for careful testing of aged bitumen and for optimizing the properties of the new added bitumen to.

Title: TG2: "The Design and Use of Foamed Bitumen Treated Materials." Shortcomings and Imminent Revisions
Author(s): Kim Jenkins, Dave Collings, Fritz Jooste
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 16 pp.
Contents: In 2002, the Interim Technical Guideline TG2 was released in South Africa as a best practice document. The main purpose of the document was, as a matter of urgency, to provide a standardised methodology for mix design, pavement design and construction of foamed bitumen treated materials. The primary objectives were to assist road authorities in the adjudication of alternate designs for rehabilitation projects that incorporated this technology and to assist practitioners in the correct design formulation and construction requirements. At the outset certain limitations were recognised due to the fact that TG2 was based on best available information at the time, without additional research input. It was emphasised that TG2 was published as an interim document and would require updating as more information became available. However, as the TG2 procedures became more widely implemented, additional limitations became apparent, some rather serious by nature.

The prevailing limiting factor at the outset was the lack of comprehensive research or data on the laboratory formulation and design of foamed Bitumen Stabilised Materials (BSMs). In particular, the mix design procedures were inadequate in a number of areas, including:

- The lack of a suitable laboratory curing method that is adequately linked to field curing.
- The variable and inappropriate nature of "simple" tests for engineering properties, such as UCS and ITS, for mix selection and classification.
- The need for laboratory tests to assess mix properties, which provide a closer link to field performance, taking account of flexibility, shear strength and durability.

The structural design of foamed BSMs proposed in TG2, was based on accelerated pavement testing (APT) research on one pavement structure, providing the following limitations:

- The mix formulation that was tested included more cement (2%) than foamed bitumen (1.8%) i.e. was unrepresentative.
- Accelerated testing, which is carried out in several months, does not account for the dominant influence of curing of the mix with time. The curing mechanism is known to affect an increased resilient modulus in foamed BSMs over several years of trafficking.

This paper discusses the shortcomings of TG2 in the context of the revisions that are currently being implemented in South Africa. It describes the immense challenges faced in developing a guideline that addresses both foamed bitumen and bitumen emulsion stabilising agents. It outlines new tests being proposed for mix designs that address flexibility, shear properties and durability. It also provides details of the database of long term pavement performance (LTPP) sections that include layers treated with either foamed bitumen or bitumen emulsion, seven years and older, and how this data has been used to develop heuristic (or knowledge) based pavement design procedures.

Title: Toxicity & Management of Coal Tar-Contaminated Roads in Christchurch Using Foamed-Bitumen Stabilisation
Author(s): Craig Depree, Thorsten Fröbel, Steve McNeill
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 31pp.
Contents: Coal tar-derived roading material contains over 1000-times more polycyclic aromatic hydrocarbons (PAHs) than equivalent bitumen pavements and is a major source of particulate PAH contaminants in Christchurch stream and river sediments, and although not used for ca. 30-40 years, considerable ‘reservoirs’ of coal tar contaminated material are still present in ca. 50% of Christchurch streets. The majority of the coal tar is sealed below successive bitumen chip seal layers; however, many of these old streets are approaching the end of their designed service life and will soon require reconstruction. The excavation and disposal of contaminated road construction layers could add millions of dollars annually to road reconstruction costs.

To assess the possible environmental risk of contaminated roading material, the toxicity of pavement aggregate and roadside soil was determined using the soil dwelling insect Folsomia candida (i.e. springtails). PAHs in roadside soils were found to have low bioavailability, exhibiting no toxic effects (i.e. No Observed Effects Concentration, or NOEC) for PAH concentrations up to 1113 µg/g. In contrast, the largely unweathered coal tar in footpath construction aggregate was acutely toxic to F. candida, with an EC50 (effects concentration required to kill 50 % of the test population) of ca. 300 µg/g of PAHs. In light of these toxicity results, a new collaborative Land Transport NZ-funded project investigated in-situ foamed bitumen (FB) stabilisation as a practical alternative to the removal and disposal of tarcontaminated road material. The in-situ method ‘grinds and binds’ the coal tar contaminants and uses the bound matrix as the foundation for the new seal layer. Leaching and algal toxicity tests were conducted on ‘unstabilised’, ‘cement only’ stabilised and ‘FB + cement’ stabilised samples. Compared to ‘cement only’, “FB + cement” stabilisation resulted in a 5-6-fold reduction in PAH leaching. Algal toxicity of the leachates ranged from ‘low’ to ‘moderate’ with the most toxic leachate ‘cement only’ having an EC50 concentration of 160 g/L. Low toxicity was consistent with the observation that the higher concentration of the major PAH (fluoranthene) was still 30-times lower than literature EC50 values. The low levels of leachate toxicity were correlated to the concentration of metals, with copper and chromium accounting for ca. 90% of leachate metals in cement containing samples. Although encapsulation or compaction (excluding water) were initially thought to be the main mechanisms for reducing PAH mobility in FB stabilisation, it was actually due to the increased bitumen content which has a high affinity for PAHs (i.e. large partitioning coefficient). Despite difficulties encountered with thin construction layers, the research showed that in-situ FB stabilisation is a practical and low cost method of reconstructing coal tar-contaminated roads.

Title: Accelerated Full-Scale Experiment on Foamed Bitumen Pavements at CAPTIF
Author(s): David Alabaster, Alvaro Gonzalez
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 16 pp.

Contents: Pavement designers trying to use alternative materials in new construction and to recycle existing materials in rehabilitation are severely constrained by a lack of data on the performance of a range of stabilised materials. This paper presents the general results from an accelerated pavement-test and laboratory studies funded by Land Transport New Zealand and Industry to fill the gaps in this knowledge. The first phase consisted in the accelerated testing of 6 pavement sections at different foamed bitumen and cement contents to determine the benefits of increasing the binder content in foamed bitumen pavements.

Title: Granular Base Stabilization with Emulsion in Las Vegas, Nevada
Author(s): Chris Finberg, Dan Quire, Todd Thomas
Date: 2008
Source/URL: TRB 87th Annual Meeting Compendium of Papers DVD, Paper #08-2343.
Description: 12 pp.
Contents: Washington Avenue in the City of Las Vegas was distressed such that reconstruction was needed. However, reconstruction is a timely and costly process, especially on a busy city street. An alternate method, base stabilization with asphalt emulsion, was evaluated and chosen for its structural capacity and its ability to save time and money. The pavement was evaluated using ground penetrating radar (GPR) and falling weight deflectometer (FWD). Trenches were cut for obtaining samples for mix design. The mix design evaluated an asphalt emulsion designed specifically for granular base stabilization (GBS). The pavement design and FWD testing determined that the stabilization process with an overlay met the load requirements of the project. The project proceeded by milling off the existing four or six inches (100-mm or 150-mm) of asphalt pavement, lowering utilities, grading the remaining aggregate base, blending water to the recommended moisture content from the mix design with a reclaimer, and injecting asphalt emulsion with the same reclaimer. After compaction and fine grading, the stabilized base was allowed to cure for four to eleven days, and a 5-inch (125-mm) hot mix asphalt (HMA) overlay was placed in two lifts. The city saved an estimated $322,661 by using GBS, approximately 30 percent savings, which allowed additional network rehabilitation to be constructed. Furthermore, construction time was shortened from 120 days to 40 days, 3000 fewer loads were trucked on and off the project, and 23,432 square yards (19,592 square meters) of waste were not generated. The impact on nearby businesses was reduced.

Title: Evaluation of Laboratory Mix Design and Field Performance of Asphalt Emulsion and Cement Stabilized Full-Depth Reclamation Project in Texas
Author(s): Stacy L. Hilbrich, Tom Scullion
Date: 2008
Source/URL: TRB 87th Annual Meeting Compendium of Papers DVD, Paper #08-2439.
Description: 11 pp.
Contents: Full depth recycling (FDR) techniques have been used by the Texas Department of Transportation (TxDOT) for roadway rehabilitation since the early 1990s (1). The concept of using a dual-base stabilization process in full depth reclamation has been used in Texas based on the observed problems with single treatments of calcium-based stabilizers, such as cement. It is well known that cement treatment provides a durable base material but is prone to environmental cracking. Emulsions by themselves have advantages, like improved moisture resistance. However, their limitations are that the early strengths are low and that traffic has to be kept off the section for an extended period, which is unacceptable in many reclamation projects. By combining treatments it was hoped that a flexible, strong, waterproof, and durable base could be created with good early strength gain. In late 2005, TxDOT drafted a special specification on emulsion treatment. According to this specification the amount of calcium-based additive and optimum amount of emulsion must meet, among other requirements, a minimum indirect tensile strength (ITS), unconfined compressive strength (UCS), and retained UCS after 10 days of capillary rise. Farm to Market (FM) 429 in Kaufman County, Texas was among the first FDR projects constructed, using a combination of 4 percent emulsion and 1 percent cement, under this specification. The Texas Transportation Institute (TTI) conducted a full-scale laboratory and field investigation of FM 429 to evaluate the TxDOT mix design specification. The details of which are presented in this paper.

Title: Laboratory and Field Evaluation of Fluid Bed Combustion Fly Ash as Granular Road Stabilizer
Author(s): Guillermo Thenoux, Felipe Halles, Angeles Vargas, Juan Pablo Bellolio, Hector Carrillo
Date: 2007
Source/URL: *Transportation Research Record* 1989, 2007: 36-41.
Description: 6 pp.
Contents: This paper presents the result of laboratory and field research on soil stabilization using fluid bed combustion fly ash. This type of ash is the result of the combustion of petroleum coke and limestone in an electric power generation plant (Petropower, located in the south of Chile), which makes it different from other types of ash used regularly in soil stabilization. The ash differs from the traditional ash used in soil stabilization, particularly

because of (a) a high concentration of lime that may produce cementing compounds and (b) the presence of sulfates that may produce a secondary reaction such as the formation of gypsum and ettringite, resulting in a different level of expansion in some types of soils. The main objectives of the research were to characterize fluid bed combustion fly ash from the Petropower plant and to evaluate the technical feasibility of using this ash as a soil stabilizer. The laboratory and field research showed that this type of ash improves the mechanical properties and water susceptibility of most types of soils. Although laboratory experimentation proves that the secondary reaction produces soil expansion in clayey soils, field experimentation indicates that the secondary reaction that produces soil expansion may be controlled by an adequate laboratory design and an appropriate dose of fly ash.

Title: Modern Soil Stabilization Techniques
Author(s): D.W. Starry Jr., T.E. Kowalski
Date: 2007
Source/URL: *Transportation Association of Canada*, 2007, http://www.tac-atc.ca/english/pdf/conf2007/s8/starry.pdf
Description: 16 pp.
Contents: Soil stabilization techniques are necessary to assure adequate subgrade stability, especially for weaker or wetter soils. It is widely recognized that the selection between the cementitious stabilizing agents cement and lime is based on the Plasticity Index (PI) of the primary soil type being improved. A PI of 10 is considered by many as the threshold that justifies the cost for use of Portland cement compared with lime. The use of bituminous stabilizing agents is somewhat less common, but worthy of consideration. Foamed bitumen is a developing technology that shows excellent performance. In the comparison of cement versus bitumen for stabilization, similar advantages and disadvantages as Portland Cement Concrete (PCC) versus Hot Mix Asphalt (HMA) pavements are recognized. Cement stabilization offers worldwide availability and ease of application. Bituminous stabilization provides material flexibility and resistance to cracking. Depending on regional availability, cost for construction is variable.

Title: Mechanistic Comparison of Cement- and Bituminous-Stabilized Granular Base Systems
Author(s): Curtis F. Berthelot, Brent Marjerison, Gary Houston, Jody D. McCaig, Stu Warrener, Rock Gorlick
Date: 2007
Source/URL: *Transportation Research Record* 2026, 2007: 70-80.
Description: 11 pp.
Contents: The Saskatchewan, Canada, Department of Highways and Transportation is investigating alternative recycling and strengthening systems for in-service thin granular pavements. This research is being performed to improve the granular pavement structural integrity and to reduce the dependence on new source aggregates. A pilot project investigated the mechanistic climatic laboratory characterization of materials used to construct test sections on Control Section Highway 15-11 (C.S. 15-11). This research demonstrated the use of ground-penetrating radar and falling weight deflection measurements to select uniform field test section locations. In situ recycled granular base was sampled and found to be a typical thin granular pavement requiring strengthening because it is relatively high in fine sand fraction and has a high portion of intermediate plastic clay fines. These two properties are known to cause marginal performance of granular bases in the field. This research showed that cement and bituminous stabilization significantly improved the mechanistic primary response and climatic durability properties of marginal granular base materials. However, it was found that the asphalt emulsion with cement stabilization showed the highest performance improvement. It also was found that the addition of cement to emulsified and foamed asphalt stabilization systems significantly improved the mechanistic climatic durability of the marginal granular base aggregate. This study demonstrated the rapid triaxial tester to be a pragmatic and cost-efficient methodology to characterize the mechanistic constitutive relations of granular base materials for performing mechanistic road structural modeling.

Title: Feasibility of Copper Slag–Fly Ash–Soil Mix as a Road Construction Material
Author(s): Vasant G. Havanagi, Sudhir Mathur, P. S. Prasad, C. Kamaraj
Date: 2007
Source/URL: *Transportation Research Record* 1989, 2007: 13-20
Description: 8 pp.
Contents: The use of waste materials in the road construction industry is gradually gaining significance in India, considering disposal and environmental problems and the gradual depletion of natural resources. The copper unit located at Dahej, Gujarat, India, produces 1,200 to 1,500 tons of copper slag per day. The large quantity of accumulated slag is dumped and left for the most part unused on costly land within the plant premises. Also, 50 to 100 tons of fly ash are produced per day from the existing captive thermal power plant. The potential use of these materials in road construction was studied initially by evaluating the materials for their physical and chemical characteristics. The waste materials were mixed with local soils in the range of 25% to 75%, and their geotechnical

characteristics were investigated. The feasibility of using these mixes in the base course of road pavement was investigated by adopting stabilization techniques. The potential of copper slag as a replacement for fine aggregates in bituminous mixes was also investigated. It was concluded that a mixture of copper slag, fly ash, and soil has the potential for use in embankment, subbase, base, and wearing courses of road pavement. The results of laboratory tests and typical technical design specifications indicating the utility of copper slag, fly ash, and soil in different layers of road pavement are discussed.

Title: Practical Approach to Criteria for the Use of Lime–Fly Ash Stabilization in Base Courses
Author(s): William F. Barstis, John Metcalf
Date: 2005
Source/URL: *Transportation Research Record* 1936, 2005: 20-27.
Description: 8 pp.
Contents: In October 2000 the Mississippi Department of Transportation (MDOT) initiated a study to evaluate the long-term performance of lime–fly ash (LFA) stabilized soil as a base course material. This study entailed performing falling weight deflectometer (FWD) tests on both newer and older pavements and coring pavement at each FWD location to observe the condition of the layers, to obtain pavement thicknesses, and to perform unconfined compressive strength (UCS) testing. Visual observation, backcalculated modulus, and in situ structural layer coefficient values showed that MDOT LFA-stabilized soil base courses have highly variable material properties and thicknesses. Recommendations were made to increase the average LFA material property values and to reduce the spread in these values by increasing the required compaction of the LFA-stabilized soil base layer to 100% standard Proctor effort, setting the required in situ Proctor UCS at 400 psi, and reducing variability by either improving the current method of field-mixed-in-place stabilization or requiring plant-mixed material with placement of the blended material via a paver. It is further recommended to increase the typical LFA-stabilized soil base layer design thickness from 6 to 8 in. and to use a 6-in. chemically stabilized subgrade layer to provide additional support to the pavement structure.

Title: Investigation of Performance of Asphalt Pavement with Fly-Ash Stabilized Cold In-Place Recycled Base Course
Author(s): Haifang Wen, Mathew P. Tharaniyil, Bruce Ramme
Date: 2003
Source/URL: *Transportation Research Record* 1819, 2003: 27-31.
Description: 5 pp.
Contents: Class C fly ash is a coal combustion product from lignite or subbituminous coal obtained as a result of the power generation process. In recent years, efforts have been made to incorporate self-cementing fly ash into cold in-place recycled (CIR) asphalt material to improve the structural capacity of asphalt pavement base layers. In this study, asphalt pavements in County Trunk Highway JK in Waukesha County, Wisconsin, were pulverized in place and mixed with fly ash and water to function as a base course. To evaluate the contribution of fly ash to the pavement's structural performance, nondestructive deflection tests were performed with a KUAB 2m-FWD falling weight deflectometer (FWD) on the outer wheelpath right after construction. The MICHBACK program was used to backcalculate the material properties of pavement layers from FWD measurements of deflection. The average moduli of the materials in the hot-mix asphalt layer, fly ash–stabilized base course, and subgrade were backcalculated. The structural capacity and structural number were also obtained from FWD test data. The structural coefficient of 0.16 was obtained for the fly ash–stabilized base course in the highway. The results of FWD testing indicate that CIR stabilization with self-cementing fly ash is an economical method of recycling flexible pavements and eliminates the need [abstract truncated]

Title: Monitoring and Evaluation of a Fly Ash Stabilized Subgrade Constructed by WisDOT
Principal Investigator(s): Tuncer B. Edil, (608) 262-3225, edil@engr.wisc.edu
Date: In progress, started 7/21/2003
Sponsor Organization: Wisconsin DOT
RiP URL: http://www.whrp.org/Research/Geotechnics/geo_0092-04-10/index.htm
Contents: One subgrade improvement method entails chemical stabilization of silt- or clay-heavy subgrade soils by the addition of fly ash. Yet the use of fly ash in subgrades remains at a nascent stage in Wisconsin, with only two experimental sections at one project site. Promising performance here, combined with success in several other states, suggest a more rigorous evaluation of the performance of fly ash-enhanced subgrades in Wisconsin is necessary. The objective of this study is to evaluate a 3- to 5-mile pavement section that will be built in 2004 with subgrade stabilization through the use of fly ash, and to compare its performance with control sections. Investigators will develop laboratory tests and field monitoring procedures, establish instrumentation and data collection procedures during construction, manage monitoring over a 30-month period, and draw conclusions. The expected benefit of this

research is data that can inform decisions on the application of fly ash stabilization of subgrades. Fly ash, if suitable and effective, may ultimately offer a cost-effective subgrade enhancement for longer-lived and better-performing pavement. Expected to finish 9/30/2008.

Title: Use of Hydrated Fly Ash as a Flexible Base Material
Author(s): Sanjaya Senadheera, Priyantha Jayawickrama, A.S.M. Ashek Rana
Date: 1996
Source/URL: *Transportation Research Record* 1546, 1996: 53-61.
Description: 9 pp.
Contents: Common uses for fly ash, such as soil stabilization and cement replacement, account for less than 20 percent of the fly ash produced in the United States. Therefore, finding other bulk uses for fly ash is important. One such potential application is hydrated fly ash as a base material. The Texas Department of Transportation (TxDOT) is working to produce specifications to incorporate hydrated fly ash as a flexible base material. High-calcium Class C fly ash has a self-hydrating capability in the presence of moisture. Class C fly ash produced from coal power plants using lignite and subbituminous coal is mixed with water, dumped in large pits, and left to hydrate for a period of 3 to 6 weeks. The result is a hard, homogeneous mass of hydrated fly ash that can be mined to produce a construction aggregate much like limestone. TxDOT has used this material on several test projects. It has a desirable compressive strength, but in some instances its adhesion to seal coats has been a problem. Laboratory studies indicate that hydration water content has a significant influence on its strength. Microscopic investigations on hydrated Class C fly ash indicate that the hydration products may depend on the curing conditions. Hydrated Class C fly ash has a potential as a flexible base material provided that the curing process is carefully managed.

Cement and Lime Stabilization

Title: Pavement Life Cycle Benefits through Stabilization with Lime and/or Cement
Author(s): Dallas Little
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 20 pp.
Contents: Stabilization of subgrade soils with either lime [CaO or Ca(OH)2] or Portland cement is traditionally accomplished to provide a working platform and to improve the structural stability of the subgrade. If certain criteria are met, normally including achievement of a threshold compressive strength, a structural layer coefficient or a design modulus is assigned to the treated layer. The increased initial first cost of stabilization is at least partially offset by the structural contribution of the stabilized layer. However, when pavement layer alternatives are compared based on a life cycle cost analysis, not only first costs but also life cycle maintenance, repair, and rehabilitation costs must be considered. In order to properly assess the degree and timing of maintenance and repair during the analysis period; reliable, mechanistic-based damage models must be used that are capable of predicting the rate of fatigue cracking in the asphalt surface, rutting in the asphalt surface as well as in the unbound aggregates base, and permanent deformation in the subgrade. This presentation describes the impact of the stabilized layer on the performance of other pavement layers including the asphalt concrete layer, the unbound aggregate layer and the natural subgrade based on the most advanced damage models, such as those being used in the proposed update of the American Association of State Highway and Transportation Officials (AASHTO) Pavement Design Guide. The presentation justifies the mechanistic predictions of the life cycle impact of stabilization through field data from Long Term Pavement Performance (LTPP) test section pavements.

Title: Clay Mineralogy of Modified Marginal Aggregates
Author(s): Frank Bartley, Anthony Christie
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 16 pp.
Contents: Lime stabilisation has generally worked well in New Zealand, but there are reports of failures that have occurred particularly in some of the African countries.

In 2003-04, a joint engineering and geological study was carried out to determine the changes that occur when lime based additives are mixed with roading aggregate, and which of the three additives most commonly used in the Auckland region was the most suitable for particular rock types.

Samples of fresh, partly weathered and weathered rock were obtained from greywacke, basalt and andesite quarries. The properties of the samples were determined using a variety of geological and geochemical analytical techniques. Similar techniques were used to establish the changes that occurred when Portland cement, hydrated lime and Durabind were added. The engineering properties before and after stabilisation were also established using standard Proctor Needle and CBR tests.

All the samples contained some swelling clay minerals, some more than others. Chemical reactions of the additives with the swelling clays include cation exchange and, over a prolonged period, the production of new hydrated calcium aluminosilicate minerals, such as hydrogrossular, through pozzolanic reactions. The permanence of the process was also examined and it was noted that under weak acidic conditions the stabilising effect of the additives could be reversed. The study showed that some additives are more suitable for use with particular rock types and that the risk of failure may depend on the process used.

Title: Heavily Cement Stabilised Pavements Design, Construction and Performance
Author(s): John Hallett, Jim McQueen
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 16 pp.
Contents: Pavements incorporating heavily cement stabilised layers are an attractive option where soft subgrades and/or heavy traffic loads require a pavement with significant load spreading capability. The AUSTROADS Pavement Design Guide and the NZ Supplement give guidelines for the design of cemented pavement layers using tensile strain criteria at the bottom of the cemented layer to prevent fatigue cracking for the design period. For heavy traffic loads this requires a deep cemented layer, with associated cost and construction implications.

Experience has shown that if the cemented material at the crack interface is durable, it is possible to design a very economical pavement with a cracked cemented layer that will still provide a high modulus layer in the pavement. This experience includes a number of rehabilitation and road widening projects constructed in Dunedin City in the early 1980's and on SH 16 in 2004 that utilised heavily cemented sub-base layers. All projects were constructed on very soft sub-grades with options such as full depth unbound granular or structural asphaltic concrete (AC) being costly options because of material cost and the effect on services, earthworks, drainage etc.

In the Dunedin situation, the design objective was for the cemented layer in the pavement to provide sufficient tensile strength to prevent fatigue cracking for the design period. Some environmental cracking was expected and therefore the design incorporated an unbound granular basecourse to prevent reflection of these cracks through to the surface. Due to an error in the formula used to determine the tensile strength of the cemented material the design depth of the cemented layer should have been considerably greater than the constructed depth to prevent fatigue cracking and therefore it was envisaged that early failures of these pavements would ensue. However, inspection of these roads today after 23 years of trafficking shows that they are still performing well with few signs of cracking that could be attributed to reflection of cracking from the cemented layer.

The SH 16 pavements utilised heavily cement stabilised layers but were different from the Dunedin situation in that the basecourse was stabilised insitu and was pre-cracked by allowing trafficking immediately after construction. After 4 years of trafficking the pavements are performing well and have retained their design modulus value with no reflective cracking in the chip seal surface.

This paper describes the design, construction and performance of the Dunedin City and SH 16 pavements utilising heavily cement bound pavement layers.

Title: Method to Predict Resilient Modulus of Lime and Lime-Cement Stabilized Soils Used in Highway Subgrade
Author(s): Jianming Ling, Huachang Xie, Runhua Guo
Date: 2008
Source/URL: TRB 87th Annual Meeting Compendium of Papers DVD, Paper #08-2188.
Description: 10 pp.
Contents: Pavement subgrade characterizations in terms of resilient modulus (MR) and other physical properties are essential for pavement design. Researchers have suggested that MR of subgrade soil is related with soil properties, water content, and weather conditions. In this study, three experimental stages were conducted to develop the MR prediction model for both of the stabilized soils: first the changes of MR along with curing time, then the effect of

saturation change on the MR and finally the effect of dry-wet cycles. Based on the laboratory and on site test results, a synthesized model was developed to predict the MR of stabilized soils with curing time, moisture (initial saturation and saturation), and dry-wet cycles. The predicted values were close to the laboratory results and the former were consistently higher. The natural water content of the undisturbed subgrade soil was much higher than the optimum water content so the subgrade couldn't meet the design requirements before proper treatments. Both the lime-cement treatment and the lime treatment on wet and soft subgrade soils were effective, and the former performed better than the latter, which was also verified by the test roads. The majority of the strength increase of stabilized soils happens in early stages (60 days) and the strength of laboratory specimen is usually higher than that of on site stabilized soils. The proposed model was applied to predict the MR of the lime and the lime-cement stabilized soils used in highway subgrade with the on site input parameters. Because of the different curing condition between the laboratory and the site, an effective way to reduce the amount of prediction error is to calibrate and validate the prediction model with on site testing data or apply a shift factor.

Title: Durability of Cement Stabilized Low Plasticity Soils
Author(s): Zhongjie Zhang, Mingjiang Tao
Date: February 2008
Source/URL: *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 134 No. 2: 203-213.
Description: 11 pp.
Contents: Three testing methods for predicting the durability of cement-stabilized soils—the tube suction (TS), 7-day unconfined compression strength (UCS), and wetting–drying durability tests—were tested and compared for their correlations and influence factors using a problematic low plastic silt clay from subgrade commonly encountered in Louisiana. A series of samples was molded at six different cement dosages (2.5, 4.5, 6.5, 8.5, 10.5, and 12.5% by dry weight of the soil) and four different molding moisture contents (15.5, 18.5, 21.5, and 24.5%). The test results indicate that the water–cement ratio of cement-stabilized soil had the dominant influence on the maximum dielectric value (DV), 7-day UCS, and durability of stabilized samples tested, although the dry unit weight of cement-stabilized soil could cause the variation of the results. This study confirms that TS, 7-day UCS, and wetting-drying durability tests are equivalent in predicting durability, and tentative charts to ensuring the durability of cement-stabilized low plasticity soils are developed using their 7-day UCS or the maximum DV values.

Title: Experimental Analyses and Statistical Modeling of Cementitiously Stabilized Subgrade Soils
Author(s): Pranshoo Solanki, Naji Khoury, Musharraf M. Zaman
Date: 2008
Source/URL: TRB 87th Annual Meeting Compendium of Papers DVD, Paper #08-2473.
Description: 22 pp.
Contents: A laboratory study was undertaken to evaluate the effectiveness of different percentages of hydrated lime, class C fly ash (CFA) and cement kiln dust (CKD) as soil stabilizers. Cylindrical specimens were compacted and cured for 28 days at a constant temperature and controlled humidity. At the end of the curing period, specimens were tested for resilient modulus (Mr), modulus of elasticity (ME), unconfined compressive strength (UCS), moisture susceptibility (tube suction test) and three-dimensional (3-D) swell. The CKD-stabilized specimens exhibited a higher increase in Mr, ME and UCS values than the corresponding values of lime- and CKD-stabilized specimens. On the contrary, lime-stabilized specimens show highest improvement in moisture susceptibility and swelling characteristics. Statistical analyses were then performed to develop correlations between the Mr values and soil-additive mix properties. Validation of this regression model using additional soil results offered statistically promising results.

Title: Assessment of In Situ Quality of Chemically Stabilized Material Layers in Northern Ohio
Author(s): Dallas Little
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 13 pp.
Contents: If subgrade soils treated with either lime [CaO or Ca(OH)2] or Portland cement achieve threshold compressive strengths and modulus values, these layers are capable of providing a substantial structural contribution to the composite pavement system. A pressing need in pavement design and analysis is to define how the stabilized layer should be considered in a mechanistic-empirical pavement design scheme. This paper describes back-calculated pavement design values from successfully performing chemically stabilized material (CSM) layer in the demanding climate of northern Ohio. This region endures some of the most demanding environmental conditions required of CSM layers due to the number of freeze thaw cycles and the depth of frost penetration. The back-calculated values represent the CSM layer properties after performing the pavement structure for from about seven

to nine years at the time of testing. Backcalculated approximations of structural layer coefficients were made following the American Association of Highway and State Transportation Officials (AASHTO) standards.

Title: Cement Stabilization of Aggregate Base Material Blended with Reclaimed Asphalt Pavement
Author(s): W. Spencer Guthrie, Ashley V. Brown, Dennis L. Eggett
Date: 2007
Source/URL: *Transportation Research Record* 2026, 2007: 47-53.
Description: 7 pp.
Contents: The effects of reclaimed asphalt pavement (RAP) content and cement content on the strength and durability of recycled aggregate base materials typical of the I-84 pavement reconstruction project performed in Weber Canyon near Morgan, Utah, were investigated. The laboratory work was based on a full-factorial experimental design, including five RAP contents, five cement contents, and three replicate specimens of each possible treatment. Measurements of unconfined compressive strength (UCS) and final dielectric value in the tube suction test (TST) were used to assess material strength and durability, respectively. These data, together with dry density measurements, were evaluated through an analysis of variance (ANOVA). The results of the ANOVA performed on the UCS data indicate that UCS decreases from 425 to 208 psi as RAP content increases from 0% to 100% and increases from 63 to 564 psi as cement content increases from 0.0% to 2.0%. Similarly, the final dielectric value decreases from 14.9 to 6.1 as RAP content increases from 0% to 100% and decreases from 14.0 to 5.8 as cement content increases from 0.0% to 2.0%. Increasing RAP contents generally correspond to decreasing dry densities. With design criteria requiring 7-day UCS values between 300 and 400 psi and final dielectric values less than 10 in the TST, the results of this research suggest the use of RAP contents in the range of 50% to 75% and a cement content of 1.0% for this material.

Title: Laboratory and Field Evaluation of Base Stabilization Using Cement Kiln Dust
Author(s): Zhiming Si, Caroline H. Herrera
Date: 2007
Source/URL: *Transportation Research Record* 1989, 2007: 42-49.
Description: 8 pp.
Contents: Laboratory and nondestructive field tests were conducted to evaluate the effectiveness of cement kiln dust (CKD) as a stabilizer for a limestone base. The test results showed that CKD has promise as a stabilizer for the base material if it is used properly. The comparative performances of CKD and other traditional stabilizers such as lime, cement, and fly ash were also investigated during laboratory and field testing. The unconfined compressive strength (UCS) increased substantially when the dosage of CKD was increased. The UCS also increased substantially over time because of the formation of more cementitious products through pozzolanic reactions and cementitious material hydrations. The dielectric value measured in the tube suction test is a good indicator of moisture susceptibility of base materials. It increased with increasing amounts of CKD after a short-term curing period; conversely, and beneficially, it decreased because of chemical reactions within specimens after a long-term curing period. Therefore, it appears that the tube suction test is not effective for evaluating moisture susceptibility of CKDstabilized base materials. The seismic modulus increased substantially with addition of CKD for the same reasons the UCS increased. Conductivity and colorimetry tests indicated that sulfate content increased with the amount of CKD added. A low resistivity value of CKD-stabilized base materials indicated that they cannot be used as backfill material. The field pavement evaluation indicated that the lime-stabilized section exhibited the highest modulus, followed by the CKD-stabilized section. The other three sections yielded similar layer modulus values. In general, the modulus of all sections decreased over time.

Title: Concrete Sludge Powder for Soil Stabilization
Author(s): Zhang Jinxi and Tadashi Fujiwara
Date: 2007
Source/URL: Transportation Research Record 2026, 2007: 54-59.
Description: 6 pp.
Contents: Concrete sludge is one industrial waste produced from ready mixed concrete plants. Every year a large quantity of concrete sludge is produced in Japan. At the same time, practical disposal options in large scale for the concrete sludge are limited and the cost for disposal is very high. Furthermore, the disposed concrete sludge also may cause serious environmental and land-use problems. A new way to recycle the concrete sludge and reuse it in a large amount is much desired. This study is to develop an innovative technology to cost-effectively recycle concrete sludge and use the recycled material in road construction. The suitability and effectiveness of the dried sludge powder as a soil stabilizer to improve the load-bearing strength for a clay soil with high moisture content were studied by experimental tests. The tests results show that adding the dried sludge powder to the selected soil with high moisture content can significantly decrease the water content, plastic index and frozen heave of the soil while

greatly improves the load-bearing strength. The stabilizing effectiveness of the dried sludge powder is greater than that of the quick lime in early stages. However, in order to obtain the best benefit and the best construction quality, some measures should be taken.

Title: Effectiveness of Portland Cement and Lime in Stabilizing Clay Soils
Author(s): Jan R. Prusinski, Sankar Bhattacharja
Date: 1999
Source/URL: *Transportation Research Record* 1652, 1999: 215-227.
Description: 13 pp.
Contents: Pavement subgrades constructed with clay soils can cause significant pavement distress because of moisture-induced volume changes and low subgrade support values. Lime is well known for its ability to stabilize plastic clays; however, portland cement also provides highly effective clay stabilization, usually with the added benefit of higher strength gain. Stabilizing clays with cement or lime can improve subgrade properties at a lower cost than either removing and replacing material or increasing the base thickness to reduce subgrade stress. The clay soil stabilization mechanism for the calcium-based stabilizers portland cement and lime is reviewed. These materials modify soil properties through cation exchange, flocculation and agglomeration, and pozzolanic reaction. Additionally, cement provides hydration products, which increase the strength and support values of the subgrade materials as well as enhance the permanence of the treatment. Comparative laboratory and field performance studies by others, focusing on stabilization of clay soils with portland cement or lime, are critically reviewed. Several factors affecting stabilization are discussed, including stabilizer test procedures, dosage effects to soil properties, mixing, compaction, and gradation and pulverization. Additionally, durability of cement and lime as stabilizers is reviewed, including wetting and drying, freezing and thawing, leaching, and long-term field performance. The research reviewed indicates that, if proportioned and applied properly, both cement and lime can effectively improve the engineering properties of clay soils over the life of a pavement. The results presented provide a guide to the engineer about the property changes to expect when using portland cement and lime with regard to volume stability, strength, and durability.

Title: Assessment of In Situ Structural Properties of Lime-Stabilized Clay Subgrades
Author(s): Dallas N. Little
Date: 1996
Source/URL: *Transportation Research Record* 1546, 1996: 13-23.
Description: 11 pp.
Contents: Lime-stabilized clay subgrades are used almost routinely in Texas to facilitate construction and to provide a foundation for aggregate base courses and hot mix surfaces. Research sponsored by the Texas Department of Transportation demonstrates that the in situ moduli and strength improvements afforded by lime stabilization of these layers are often significant and deserve structural consideration. A study of the range of modulus values determined from falling weight deflectometer deflection data and supported by in situ dynamic cone penetrometer data for 40 pavement subgrades indicates that the lime-stabilized subgrades provide a level of stiffness and strength that is similar to that of an unbounded aggregate base. This substantiates previous literature suggesting that properly designed and constructed lime-stabilized subgrades should be assigned AASHTO structural coefficients in the same range as unbound aggregate bases, that is, between 0.10 and 0.14.

Nontraditional and Chemical Additives

Title: Chemically Stabilized Soils
Principal Investigator(s): Randy Ahlrich
Date: In progress, started 1/1/2008
Sponsor Organization: Mississippi Department of Transportation
RiP URL: http://rip.trb.org/browse/dproject.asp?n=14805
Contents: Current Mississippi Department of Transportation (MDOT) design procedures use CBR values and unconfined compressive strength values to characterize chemically treated soils. The new Mechanistic-Empirical Pavement Design Guide (MEPDG) uses elastic modulus (E) and resilient modulus (Mr) values to characterize chemically treated soils. These strength test methods do not evaluate or quantity the effects of in-place density or various moisture conditions. BCD proposes to conduct laboratory evaluations that will quantity the effects of compaction and moisture conditions on the strength of chemically treated soils for typical Mississippi DOT highways. This laboratory evaluation will supplement the ongoing MDOT State Study 170 “Implement the 2002 Design Guide for MDOT.” This research will be used in conjunction with the new MEPDG to optimize pavement structural sections and to provide data to improve construction specifications. This research will enhance MDOT’s

capabilities to design highways and will provide material properties that can be used to predict pavement performance. Expected to finish 12/31/2009.

Title: Validation and Refinement of Chemically Stabilization Procedures for Pavement Subgrade Soils in Oklahoma
Principal Investigator(s): Amy Cerato, (405) 325-5625; Gerald A. Miller, (405) 325-5911, gamiller@ou.edu; Donald R. Snethen, (405) 744-6328
Date: In progress, started 2007
Sponsor Organization: Oklahoma Department of Transportation
Contents: The goal of this research project is to assist the state in validating and improving the recommendations of OHD L-50 "Soil Stabilization Mix Design Procedure." The proposed research will primarily focus on AASHTO Soil Group Classifications falling under the fine-grained soil category (i.e. A-4 to A-7). It is expected that the results of testing on fine-grained soils may be intuitively extended to address variability found in fines of the A-2 soil class. Granular soils in the A-1 category and fine sandy soils of the A-3 category are not included in this proposal. In addition to the exclusions mentioned above, soils containing appreciable levels of sulfate will be excluded as these soils are not recommended for stabilization using calcium-based chemical additives. Expected to finish in 2008.

Title: Stabilization Mechanisms of Nontraditional Additives
Author(s): Jeb Tingle, J. Kent Newman, Steve Larson, Charles Weiss, John Rushing
Date: 2007
Source/URL: *Transportation Research Record* 1989, 2007: 59-67.
Description: 9 pp.
Contents: Because of the high cost of quality construction materials, transportation engineers are often forced to seek alternative designs using substandard materials, commercial construction aids, alternative pavement materials, and innovative design practices. Nontraditional soil stabilization additives are being marketed as viable solutions for stabilizing marginal materials as a low-cost alternative to traditional construction materials. Nontraditional additives are diverse in their composition and the way they interact with soil. Unfortunately, little is known about their interaction with geotechnical materials and their fundamental stabilization mechanisms. The objective of this research was to advance current understanding of the chemical and physical bonding mechanisms associated with selected nontraditional stabilizers. The research consisted of conducting qualitative analyses of hypothesized stabilization mechanisms, examining historical literature for supporting documentation, and performing laboratory experiments to improve the understanding of how these nontraditional additives stabilize soils. Laboratory experiments included image analyses, physical characterization, and chemical analyses to determine the primary constituents of the mineral, soil, stabilizer, and stabilized soil composite. The focus of this effort was to provide insight into the proposed mechanisms by using the laboratory data to examine proposed mechanisms from the historical literature and to provide additional hypotheses for the interaction between nontraditional additives and different soil types.

Title: Procedure for Evaluating Stabilization of Road Materials with Nontraditional Stabilizers
Author(s): Alex T. Visser
Date: 2007
Source/URL: *Transportation Research Record* 1989, 2007: 21-26.
Description: 6 pp.
Contents: In response to the need to find cost-effective stabilizers, a large number of chemical products are being marketed as potential solutions. Traditional laboratory tests have not been able to predict the performance of these materials satisfactorily. A solution is for suppliers to construct experimental sections several hundred meters long. However, that becomes an expensive exercise, since each type of soil in a region would have to be used. An evaluation technique has been developed that allows test panels to be constructed in the field at low cost with a range of soils and stabilizers and that takes into account local environmental conditions and traffic. The aim of this paper is to present this evaluation technique and the results with a range of stabilizers and soils. The paper describes construction of the 1- 3-m test panels and the subsequent testing protocol. Several materials, ranging from sandy to clayey, were tested with different generic stabilizers, such as polymers, enzymes, and ionic soil stabilizers. Control panels without additives were also constructed. The testing regime conducted over 8 months included regularly measuring the following: the in situ California bearing ratio with a dynamic cone penetrometer, both at the in situ moisture content and after soaking for 2 h; density and moisture; and permeability. Visual observations about performance were also noted. The test panel procedure is a cost-effective solution for evaluating the potential strength gain of stabilizers with a range of soils. As is known, stabilizers must be tailored to soil properties, because stabilizers do not all have the same effect.

Title: Subgrade Stabilization Alternatives to Lime and Cement
Principal Investigator(s): John L. Daniels, (704) 687-3248, jodaniel@uncc.edu
Date: In progress, started 7/1/2006
Sponsor Organization: North Carolina Department of Transportation
RiP URL: http://rip.trb.org/browse/dproject.asp?n=12093
Contents: The primary objective of this project is to test subgrade soil stabilization alternatives to lime and cement. Evaluation of non-traditional additives currently on the market indicate that modified lime and cement is the most promising alternative to unmodified lime and cement. As part of the NCDOT Technical Assistance Agreement in 2005, three chemical additives were selected: Polarset, Darracel, and Gilco Accelerator. This project seeks to perform laboratory and field tests and then to provide North Carolina with a well-defined implementation plan, including recommended mix design procedures, quality control/assurance criteria, and proposed specifications. The ultimate goal of this work is the ability to proceed with subgrade stabilization even during cold weather. Expected to finish 6/30/2009.

Title: Stabilization of Clay Soils with Nontraditional Additives
Author(s): Jeb S. Tingle, Rosa L. Santoni
Date: 2003
Source/URL: *Transportation Research Record* 1819, Volume 2, 2003: 72-84.
Description: 13 pp.
Contents: A laboratory experiment was conducted to evaluate the stabilization of low- and high-plasticity clay soils with nontraditional chemical or liquid stabilizers. Clay soil specimens were mixed with various stabilization products and compacted using a gyratory compaction machine to approximate ASTM D1557 moisture–density compaction. Each specimen was subjected to wet and dry testing following a 28-day cure. Twelve nontraditional stabilizers were evaluated, including an acid, enzymes, a lignosulfonate, a petroleum emulsion, polymers, and a tree resin. Additional specimens were stabilized with Type I portland cement and hydrated lime for comparison with traditional stabilizers under the same mixing, compaction, and curing conditions. Analysis of the test data consisted of determining the average strength, in terms of unconfined compressive strength, of three replicate specimens of each mixture. The average strength of the three replicates of each additive was compared with the average strength results of the remaining nontraditional additives, the traditional stabilization results, and a series of control specimens that were not stabilized. The experiment results indicate an increased strength of some nontraditionally stabilized specimens when compared with that of both the control series and the traditional stabilization alternatives. Other nontraditional stabilizers did not demonstrate significant increased strength compared with that of the control series for the conditions of this experiment. Many of the stabilized specimens were highly susceptible to moisture, indicating the potential for poor performance when exposed to adverse environmental conditions, whereas a few specimens demonstrated excellent performance when exposed to moisture. Specific product categories are recommended for stabilizing low- and high-plasticity clay soils.

Title: Evaluation of Chemical Modifiers and Stabilizers for Chemically Active Soils—Clays
Author(s): Thomas M. Petry, Braja Das
Date: 2001
Source/URL: *Transportation Research Record* 1757, 2001: 43-49.
Description: 7 pp.
Contents: Of the types of soils that occur in nature, clay soils are the most physicochemically active. Their natural tendencies to change volume with moisture level changes cause billions of dollars of damage annually to transportation facilities. Methodologies to modify and stabilize their damaging behavior have been widely sought. In fact, there is evidence of clay soil stabilization in antiquity. Because these problematic soils are chemically active and their behavior can be improved through the application of chemical agents, a multitude of these agents have been applied. Some of these agents are naturally occurring, some are derived by manufacture, and some are the waste products of manufacturing processes. Why these clays are chemically active, how agents can be applied to improve the behavior of clays, and why the agents proposed should be evaluated are reviewed. Minimum requirements for adequate testing and evaluation are provided.

Title: Mechanisms of Soil Stabilization with Liquid Ionic Stabilizer
Author(s): Lynn E. Katz, Alan F. Rauch, Howard M. Liljestrand, Jacqueline S. Harmon, Kristine S. Shaw, Harold Albers
Date: 2001
Source/URL: *Transportation Research Record* 1757, 2001: 50-57.
Description: 8 pp.

Contents: Numerous commercial suppliers are marketing liquid chemical products for stabilizing pavement subgrade and base soils. These nontraditional chemical stabilizers may offer viable alternatives for stabilizing sulfate-rich soils where conventional lime or cement treatment can lead to excessive soil expansion. Typically sold as concentrated liquids that are diluted in water before application, these products may be less expensive to use than lime or cement. However, many transportation agencies are hesitant to specify nontraditional liquid stabilizers without better information on the stabilizing mechanisms and documented field experiences. To identify the mechanisms associated with one class of these products, a representative ionic soil stabilizer and a sodium montmorillonite clay were selected for a detailed physical-chemical study. Laboratory testing included chromatography, spectroscopy, X-ray diffraction, electron microscopy, and standard titration analyses. These tests have shown that the principal active constituents of the selected ionic stabilizer are d-limonene (a by-product of citrus processing) and sulfuric acid, which react to form a concentrated, low-pH solution of sulfonated limonene. The observed changes in clay chemistry following treatment indicated that this product would stabilize a soil by altering the clay lattice. The result is the formation of a more highly weathered, less-expansive clay structure. On the basis of this understanding of the underlying mechanisms, ionic stabilizers applied at sufficiently high application mass ratios may improve the properties of certain soils on some highway construction projects.

Design and Performance

Title: Computerized Aided Modeling of Soil Mix Design to Predict Characteristics and Properties of Stabilized Road Base
Principal Investigator(s): Charles Berryman, Wayne Jensen
Date: In progress, started 7/1/2008
Sponsor Organization: Nebraska Department of Roads
RiP URL: http://rip.trb.org/browse/dproject.asp?n=17016
Contents: Considerable data exists for soils that were tested and documented, both for native properties and properties with pozzolan stabilization. While the data exists there currently is no database for the Nebraska Department of Roads to retrieve this data for predicting soil properties. The conventional method used to determine soil properties, such as maximum laboratory density and optimum moisture content, is tedious, labor intensive and time consuming. When soil stabilization is involved, more time and efforts are needed to determine maximum laboratory density, optimum moisture content and optimum pozzolan content. The objective of this project is to develop a computerized model to predict the soil properties of a given GI soil type using additives for soil stabilization. The model will be able to predict the maximum laboratory density and optimum moisture content of native soil. Additionally the model will determine an optimum pozzolan percentage of soil stabilization. Expected to finish 6/30/2009.

Title: Practical Application of Stabilisation Design Theory in Pavement Construction and Rehabilitation Projects
Author(s): William Gray
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 19 pp.
Contents: The engineering principles supporting the design of pavements incorporating stabilised elements are well documented and generally understood in the New Zealand pavement engineering industry.

Typically stabilised elements are incorporated into a pavement as either modified or bound pavement layers. The current design guidelines documented in Austroads and the Transit New Zealand Supplement allow designers to consider how modified or bound pavement layers will perform under project conditions, and to optimise project solutions.

Pavement designers in New Zealand generally acknowledge that the published fatigue relationships for bound pavement layers, particularly bound layers utilising cement or lime, can produce conservative design solutions requiring deeper bound pavement layers. Designers and contractors will often assume that a stabilised pavement layer is only modified to avoid checking for fatigue. Whilst this can be a practical approach, it does assume that in the field the construction works do actually achieve a modified solution. Such an approach can also risk missing the benefits of bound layers in pavement solutions.

Over the last 20 years, the author has been involved with a large number of pavement projects that have utilised stabilised elements. Post construction performance data he has obtained from a number of constructed pavements suggests that the performance of stabilised pavement layers in the field often falls somewhere between that expected for modified and bound materials in Austroads.

Pavements that the current design guidelines would suggest should have failed are continuing to perform well and in the manner expected in the original design.

In this paper the author discusses how pavement designers can use stabilised elements in pragmatic pavement design solutions, making effective use of both current published design guidelines and physical performance data. This approach can allow designers and pavement owners to understand the risk profiles associated with design solutions that do not necessarily achieve all the standards in current design guidelines, but can be expected to produce pavements that perform and are affordable.

Title: Constructing Pavements using Recycled/Stabilised Material—Practical Aspects
Author(s): David Collings
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 12 pp.
Contents: The benefits of reusing the material in existing roads for pavement rehabilitation and/or upgrading have been well recognised and recycling is becoming increasingly popular worldwide. The advent of large machines capable of recycling almost any pavement to depths up to 0.5m has promoted this popularity and millions of square metres of pavement are treated annually using this technology. However, some projects are more successful than others. Where problems occur, the cause can usually be traced to ignorance, inexperience and a general lack of attention to detail during either the design or the construction phase of the project, or both.

This paper takes a critical look at what is needed for a recycling project to be labelled "successful". Planning (project inception, pavement investigation and design) is considered separately from execution and some areas where problems are commonly encountered are highlighted.

Project inception, investigation and design aspects include:

- A clear definition of the performance requirements for the new pavement
- An appreciation of the project environment
- The composition of the existing pavement (materials and structure), variability within the pavement and an understanding of the failure mechanism
- The nature of the material that falls within the recycling horizon, consistency and potential for treating with various stabilising agents
- The need for truly representative samples for stabilisation design
- The potential / limitations of different stabilising agents
- The limitations of various empirical and analytical pavement design methods
- Constructability concerns and the need for clear project specifications

Construction aspects include:

- A fundamental understanding of the recycling process and the potential /limitations of large recycling machines
- Deployment of appropriate machines and trained personnel
- Quality versus quantity. The importance of doing it right first time.
- The various steps in recycling / stabilising that demand attention to detail (spreading, mixing, placing, compacting, levelling, finishing, curing, trafficking)
- Quality management and implementing a comprehensive process control programme that rings warning bells

Title: The Performance of New Zealand Basecourse Aggregates and Glass Aggregate Mixtures Found from Repeated Load Triaxial Testing
Author(s): Greg Arnold, David Alabaster, Jayden Ellis, Jason Lowe
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 18 pp.
Contents: Repeated Load Triaxial (RLT) tests at many different combinations of confining stress and vertical cyclic stress for 50,000 loading cycles were conducted on a range of granular and glass aggregate mixtures. Results are analysed to predict the number heavy axle passes to achieve a rut depth limit that denotes failure. In the last 2 years at least 100 RLT tests have been conducted on TNZ M4 compliant and non compliant aggregates. This paper reports trends in results with observations on why some basecourse aggregates perform better than others. Different percentages of crushed glass and aggregate were also tested and results are reported. Results from RLT tests in some cases are surprising and early established theories of what makes a good basecourse do not always apply. Overall the Repeated Load Triaxial test has proven ability to rank and predict the performance non traditional aggregates including waste and recycled materials. The introduction of the RLT test into Transit New Zealand specifications will allow more use of these non traditional materials in road construction.

Title: Evaluation of Stabilization of Sulfate Soils in Texas
Author(s): Pat Harris
Date: May 2008
Source/URL: Texas Transportation Institute, http://tti.tamu.edu/documents/5-4240-01-1.pdf
Description: 60 pp.
Contents: This implementation project was developed to provide technical support to the Texas Department of Transportation (TxDOT) in developing subgrade soil mixture designs in high sulfate soils and to monitor the performance of projects constructed following the guidelines established in Project 4240. Secondly, the researchers were to assess equipment needs of the TxDOT districts, train laboratory personnel in mix design procedures in high sulfate soils, and provide educational materials for TxDOT to train additional personnel. Mix designs of high sulfate soils for two projects, in the Austin and Laredo Districts, are reported as technical support to districts. The construction and subsequent reevaluation of the project in Eagle Pass is reported to give TxDOT a record of the construction process used in the high sulfate soil on the Second Street project and shows how the project has performed since construction. Evaluation of the 3-D swell procedure shows the test to be repeatable if the density and water source are tightly controlled. A review of the equipment needed for adequate testing of the high sulfate subgrade soils showed that all required equipment can be obtained at minimal cost to TxDOT.

Title: Comprehensive Field Studies to Address the Performance of Stabilized Expansive Clays
Author(s): Anand J. Puppala, Gautham S. Pillappa, Laureano R. Hoyos, Deepti Vasudev, Deepti Devulapalli
Date: 2007
Source/URL: *Transportation Research Record* 1989, 2007: 3-12.
Description: 10 pp.
Contents: This work was conducted as part of a research study for the City of Arlington, Texas, to explore and develop alternative stabilization methods for sulfate-rich soils located in southern parts of the city. As a result of a literature review of sulfate-rich expansive soil treatments and comprehensive laboratory studies, four stabilizers were recommended for field treatment studies: sulfate-resistant cement (Type V), low-calcium Class F fly ash with Type V cement, ground granulated blast furnace slag, and lime mixed with polypropylene fibers. The four stabilizers, along with control lime treatment, were used to modify subsoil near Harwood Road in South Arlington. Rigid pavements were then constructed on the stabilizers' sections, and these sections were instrumented with strain gauges and pressure cells. Pavement instrumentation was then monitored to address load transfer mechanisms and stabilized materials' compression behavior under traffic loads. Elevation surveys were also conducted to evaluate swell movements of the treated subsoils. X-ray diffraction analyses were conducted on treated subgrade specimens to address the formation of ettringite mineral. On the basis of these evaluations, the performance of the four stabilization methods was compared with that of the control lime section.

Title: Forensic Case Studies on Low-Volume Roads in Texas
Author(s): Zhiming Si, Caroline H. Herrera
Date: 2007
Source/URL: *Transportation Research Record* 1989, 2007: 327-335.
Description: 9 pp.

Contents: Three forensic investigations were conducted to determine the causes of premature pavement failure. Specific causes for both longitudinal and transverse cracking, fatigue cracking, and sulfate-induced soil heave problems were identified and verified through a series of nondestructive field and laboratory evaluation tests. Conclusions were made, and recommendations are proposed to the districts to help them select a strategic rehabilitation plan to prevent the same problems from recurring. In Case I, the transverse cracking was believed to be due to either the shrinkage cracks of the very stiff treated caliche base or the shrinkage cracks in the lime-treated subgrade. The longitudinal edge cracks were attributed to edge shrinkage cracking due to wetting and drying cycles and heavy agricultural vehicles traveling along the pavement edge. The major cause for severe fatigue cracking in Case II was identified to be the very open structure of a lightweight seal coat beneath the hot-mix asphalt surface combined with weak support of the subgrade. A lack of sufficient support for the pavement under loading facilitated its fatigue failure. On the basis of Case III, stabilization of high-sulfate-bearing soil with calcium-based stabilizers alone is not recommended because of high swell potential and low residual unconfined compressive strength. The combination of lime and fly ash proved to be the best stabilizer for the soil with high sulfate content, provided that special precautions are taken during the mix design and construction process.

Title: Development of Stabilizer Selection Tables for Low-Volume Roads: Arlington, Texas
Author(s): Martin Phillips, Anand J. Puppala, Keith Melton
Date: 2003
Source/URL: *Transportation Research Record* 1819, 2003: 85-94.
Description: 10 pp.
Contents: Expansive soil movements cause damage to low-volume traffic roadways, which is attributed to the low rigidity of the materials used in the pavements. Several treatment methods have been used to stabilize expansive, soft subsoils, which have yielded mixed results due to the presence of sulfates. Because of the ambiguity of these results, the city of Arlington, Texas, established a task force of researchers and practitioners in the area of soil stabilization to develop matrix tables of the various treatment methods and their applicability to stabilize expansive, soft, and sulfate-rich soils. Extensive literature compiled on the stabilizers, several new and previous research studies on stabilizers, and the expertise of the task group members were considered in the evaluation process. The task force developed seven matrix-form selection tables that showed various treatment methods and if their applications were acceptable or unacceptable for the 12 types of soft and sulfate-rich subgrade soils. A summary of the tables was prepared, along with guidelines on how to use these tables to screen the potential stabilizers for pavement construction projects.

Title: Engineering Behavior of Stabilized Soils
Author(s): Robert L. Parsons, Justin P. Milburn
Date: 2003
Source/URL: *Transportation Research Record* 1837, 2003: 20-29.
Description: 10 pp.
Contents: Stabilization of soils is an effective method for improving soil properties and pavement system performance. For many soils, more than one stabilization agent may be effective, and financial considerations or availability may be the determining factor on which to use. A series of tests was conducted to evaluate the relative performance of lime, cement, Class C fly ash, and an enzymatic stabilizer. These products were combined with a total of seven different soils with Unified Soil Classification System classifications of CH, CL, ML, and SM. Durability testing procedures included freeze–thaw, wet–dry, and leach testing. Atterberg limits and strength tests also were conducted before and after selected durability tests. Changes in pH were monitored during leaching. Relative values of soil stiffness were tracked over a 28-day curing period using the soil stiffness gauge. Lime- and cement-stabilized soils showed the most improvement in soil performance for multiple soils, with fly ash–treated soils showing substantial improvement. The results showed that for many soils, more than one stabilization option may be effective for the construction of durable subgrades. The enzymatic stabilizer did not perform as well as the other stabilization alternatives.

Title: Stabilization of Weak Clay with Strong Sand and Geogrid at Sand-Clay Interface
Author(s): Brajam M. Das, Kim H. Khing, Eun C. Shin
Date: 1998
Source/URL: *Transportation Research Record* 1611, 1998: 55-62.
Description: 8 pp.
Contents: The load-bearing capacity of a weak clay subgrade can be increased by placing a strong granular base course of limited thickness on top of the clay layer. The load-bearing capacity can be increased further, or the thickness of the granular base course can be reduced, by separating both layers by a geogrid. Laboratory model test results for the ultimate bearing capacity of a rigid strip loading on the surface of a granular soil underlain by a soft

clay with a layer of geogrid at the interface of the two soils are presented. The optimum thickness of the granular soil layer and the critical width of the geogrid layer required to derive the maximum benefit from the reinforcement were determined. Model test results on the permanent settlement of the rigid strip load caused by cyclic loading of low frequency are presented.

Unpaved Roads

Title: Geosynthetic Stabilization of Weak Subgrade
Principal Investigator(s): Eli Cuelho, (406) 994-7886, elic@coe.montana.edu.
Date: In progress, started 3/1/2008
RiP URL: http://www.wti.montana.edu/Projects.aspx?id=f9a60684-a78a-4124-be61-bbdbbf895c2f
Sponsor Organizations: Montana Department of Transportation; NAUE GmbH & Co. KG; University Transportation Center program
Contents: The use of stiff geosynthetics in unpaved roads on soft subgrade is known to provide a reinforcing benefit to the road, allowing better distribution of applied loads and increased bearing capacity. However, there is not yet an accepted standard design technique that incorporates the material properties of the geosynthetic in the design to account for the reinforcement it provides. Therefore, design of a geosynthetic unpaved road should take into consideration the results of preceding laboratory and field investigations. This project aims to construct test sections in the field to investigate the relative benefit of various geosynthetics available on the market to an unpaved road. The location of the test sections is in Lewistown, Montana at the TRANSCEND research facility operated by the Western Transportation Institute. A prepared and placed subgrade will provide equivalent conditions for each test section; likewise the gravel surfacing along the entire test bed will be uniform. Controlled traffic loading with frequent rut profile measurements will indicate performance benefits of each geosynthetic in the test sections. Additionally, post-traffic examination of the geosynthetic will provide invaluable information regarding the performance and installation survivability of the geosynthetics. This effort is jointly sponsored by the Montana Department of Transportation (MDT); NAUE GmbH & Co. KG, a geosynthetic manufacturer based in Germany; and the University Transportation Center (UTC) program (part of the Research and Innovative Technologies Administration of the USDOT). NAUE is sponsoring the construction and monitoring of four test sections; while MDT is sponsoring the construction and monitoring of an additional seven test sections. The UTC program will provide support to the overall effort. Data collected and conclusions drawn from these parallel projects will be summarized in an integrated final report. This project represents the NAUE portion of the overall effort. Expected to finish 2/28/2009.

Title: Stabilization Techniques for Unpaved Roads
Author(s): William H. Bushman, Thomas E. Freeman, Edward J. Hoppe
Date: 2005
Source/URL: *Transportation Research Record* 1936, 2005: 28-33.
Description: 6 pp.
Contents: An amendment to Virginia House Bill 1400, Item 490, No. 1h, calls for the Virginia Transportation Research Council to “continue its evaluation of soil stabilizers as an alternative to paving low-volume secondary roads.” In response, promising soil stabilization products were evaluated with the relatively new technique of deeply mixing chemical additives into unpaved roadbeds. This work is based on the construction of a 1.75-m-long trial installation on Old Wheatland Road in Loudoun County, where seven commercially available stabilization products were applied to the unpaved road. A rigorous evaluation of treatment performance will provide the basis for recommendations to the Virginia Department of Transportation’s operating divisions regarding improvements to the maintenance practices for gravel roads. Results thus far indicate that the introduction of soil stabilizers through deep mixing is a promising technique. The life-cycle cost analysis indicates that constructing a standard bituminous surface-treated roadway and maintaining it as such is much more cost-effective than using any of the products in this trial. Further, the analysis indicates that using the bituminous surface treatment alternative is also much more cost-effective than maintaining an unpaved road.

Title: Stabilizing Unpaved Roads with Calcium Chloride
Author(s): Stephen Monlux
Date: 2003
Source/URL: *Transportation Research Record* 1819, 2003: 52-56.
Description: 5 pp.
Contents: The U.S. Department of Agriculture Forest Service has stabilized unpaved road surfacing materials with relatively high concentrations of calcium chloride salt. The percentage of calcium chloride is higher than that traditionally used for dust abatement or aggregate base stabilization. Up to 2% pure salt by weight of aggregate was

mixed into the top 2 in. (50 mm) of both aggregate and native road surfaces. The results were monitored for 2 to 4 years. The stabilized road surfaces resisted raveling and washboarding for several seasons and significantly reduced road blading and aggregate loss. As a result, calcium chloride stabilization may be a cost-effective treatment for roads with daily traffic volumes less than 200. Other benefits include reduced surface erosion and sedimentation; improved safety from reduced dust, raveling, and washboarding; and less frost penetration. Encouraged by these results, the Forest Service is conducting additional evaluations to determine the cost-effectiveness of surface stabilization with both magnesium chloride and calcium chloride in different environments and with different aggregate materials.

Waste Minimization

Title: Quantifying the Benefits of Waste Minimisation in Road Construction
Author(s): John Patrick, Haran Moorthy
Date: June 2008
Source/URL: *New Zealand Institute of Highway Technology Recycling & Stabilisation Conference: Better Roads for a Sustainable Environment, 2008.*
Description: 15 pp.
Contents: This paper reports on research, carried out for Land Transport New Zealand, which developed a methodology for quantifying the benefits of minimisation of wastes from road construction. The research included development of a tool for RCAs to make informed decisions on adopting waste minimisation strategies during road construction.

The benefits of waste minimisation can be direct, in terms of cost savings; by using a lower wastage construction technique or by recycling materials and thereby reducing the quantity of material going to a landfill. More indirectly, there are benefits in reducing the quantities of construction materials and energy required or reducing the produced emissions.

The paper will describe the methodology that was developed for assessing waste minimisation in road construction. The methodology encompasses estimating the:

- energy (including waste)
- traffic delay
- emissions
- resource depletion

associated with different road construction techniques and then assigning dollar values to them.