

National Cooperative Highway Research Program

NCHRP Synthesis 247

**Stabilization of Existing Subgrades to
Improve Constructibility During
Interstate Pavement
Reconstruction**

A Synthesis of Highway Practice

**Transportation Research Board
National Research Council**

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National Cooperative Highway Research Program

Synthesis of Highway Practice 247

Stabilization of Existing Subgrades to Improve Constructibility During Interstate Pavement Reconstruction

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

*By Staff
Transportation
Research Board*

This synthesis will be of interest to state DOT construction, geotechnical, materials, and pavement system design engineers, engineering geologists, and research engineers, and others concerned with the constructibility of new pavements over existing subgrades. The synthesis describes current practice for the stabilization of existing subgrades to improve constructibility during interstate pavement reconstruction. It presents information regarding the methods available to evaluate and improve subgrade conditions for the purpose of meeting the constructibility requirements of a reconstruction project.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board presents data obtained from a review of the literature and a survey of the state DOTs. The synthesis reports on: subgrade evaluation methods including sampling, laboratory, and in-situ test methods, as well as

assessment of existing drainage systems; constructibility factors such as existing and proposed pavement types, available equipment, and cost effectiveness of various subgrade stabilization techniques; methods of subgrade improvement including mechanical and chemical stabilization, use of recycled and waste materials, the use of geosynthetics in reinforcement and drainage applications; and construction methods with an emphasis on innovative approaches such as novel sequencing of construction traffic, use of light weight equipment, and robotics. In addition, several case histories describing applicable pavement reconstruction projects are presented. Finally, suggestions to possibly improve the practice and the identification of research needs are also presented.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-05 staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

STABILIZATION OF EXISTING SUBGRADES TO IMPROVE CONSTRUCTIBILITY DURING INTERSTATE PAVEMENT RECONSTRUCTION

SUMMARY

The Interstate system, which was legislated by the Federal-Aid Highway Act of 1956, was initiated in July 1956. The design of the 66 000 km (41,000 mi) of interstate roadway was based on principles and data that were available at that time. By 1992, the Interstate system, which had been extended to 73 200 km (45,500 mi), was virtually complete. During this construction phase, original designs were modified; however, increased traffic, heavier loads, and other factors, as well as failure to provide adequate maintenance, led to a deteriorating condition of this part of the national infrastructure. Today, parts of the system are in dire need of rehabilitation.

Although it is desirable to rehabilitate a pavement without removing existing structural layers, sometimes the extent and causes of deterioration make complete reconstruction unavoidable. Because of limitations imposed by a typically narrow working corridor on reconstruction projects, the practical aspects of new pavement and reconstruction are quite different. One major difference is the often unavoidable use of the subgrade as a haul road for heavy equipment during reconstruction. A constructibility problem may arise when the contractor runs heavy equipment over the weak subgrade, causing rutting and failure. Thus, the issue of whether the subgrade can withstand excessive construction traffic is more crucial during pavement reconstruction than during new pavement construction, in which space permits the use of temporary haul roads. To improve constructibility, it may be necessary to stabilize the existing subgrade.

This synthesis is intended to provide information to engineers and other transportation officials on methods to evaluate and improve subgrade conditions to meet the constructibility requirements of a reconstruction project. Information was gathered through the use of a questionnaire sent to 65 transportation agencies in the United States and Canada and by a review of pertinent literature. During the literature review, very little was found that directly addresses subgrade stability issues during pavement reconstruction. Regarding the evaluation of subgrade stability, agency responses overwhelmingly indicate that first-time pavement construction protocols usually are employed during reconstruction.

A number of laboratory and in situ testing methods for evaluating subgrade soil properties are presented. In addition to traditional methods of laboratory testing of subgrade soils (i.e., Proctor compaction and California bearing ratio (CBR)), there appears to be increased reliance on nondestructive methods such as the falling weight deflectometer for subgrade evaluation of existing pavements. Furthermore, the dynamic cone penetrometer (DCP) appears to have great potential for evaluating subgrade stability before, during, and after pavement construction.

Evaluation of the subgrade before reconstruction includes an assessment of existing drainage systems and how they affect the subgrade once pavement layers are removed. Subgrade stability and pavement performance in general are drastically influenced by

moisture content. Therefore, a section of this synthesis is devoted to drainage systems, including edge and lateral drains, drainage layers, and geotextile filters, and the types of installations that are necessary to ensure that water in the subgrade is adequately controlled.

To improve subgrade stability, in addition to mechanical stabilization, additives such as lime, cement, ash, bituminous materials, and recycled waste products have been incorporated in the soil. Most of these measures, which conventionally are used in first-time construction, directly or by implication, are extended to address problems in reconstruction; they are not uniquely and specifically applicable to reconstruction.

It appears that the most common approach to solving subgrade problems during reconstruction is to undercut poor soils and replace them with more suitable materials. In some cases, the use of geosynthetics such as geogrids has proven effective for reducing the depth of undercut and, subsequently, the required thickness of overlying aggregate layers required to provide a stable working platform.

The literature review and questionnaire responses do not indicate the existence of specifications unique to reconstruction. It appears that the specifications for new pavement construction also are in force during reconstruction, possibly with some minor modifications to address site-specific problems. The prescribed use of lightweight equipment to preserve subgrade integrity is virtually nonexistent among transportation agencies, and innovations involving robotics have not yet surfaced in highway reconstruction practice.

A number of suggestions are made, most notably that pavement reconstruction projects should always start with a subsurface investigation of the load-supporting capacity of the subgrade under construction traffic. The DCP is identified as having great potential to serve in this capacity and is recommended for further evaluation and use by transportation agencies, in addition to standard drilling and sampling methods and other devices.

INTRODUCTION

BACKGROUND AND PURPOSE

New construction of highways in the United States has been limited since completion of the Interstate system. Rehabilitation of existing roads has become and will remain a dominant engineering challenge. Pavement overlaying is the preferred rehabilitation method; however, reconstruction is sometimes necessary and requires complete removal of the pavement, exposing the subgrade over all or portions of the highway alignment. The newly exposed subgrade may be structurally adequate, but when subjected to heavy loading by construction traffic its condition may be degraded. When an old pavement is removed, the subgrade often has a higher moisture content than it did during original construction. The accumulation of moisture over time results in a subgrade with a moisture content that often exceeds the optimum moisture level; therefore, the subgrade is easily disturbed by construction traffic.

Many subgrade stabilization methods address this problem:

- Mechanical improvement with grain-size modification;
- Traditional chemical stabilization (e.g., lime);
- Excavation and replacement with granular fill;
- Reinforcement with geosynthetics; and
- Use of recycled materials.

Other ways of preserving subgrade integrity include limiting the load from construction traffic through innovative construction sequencing, using lightweight construction equipment, and maintaining good subgrade drainage.

Although information abounds on the topic of soil stabilization, very little information exists that specifically addresses subgrade improvement and preservation during pavement reconstruction. The primary purpose of this study was to collect and summarize information on stabilization of existing subgrades to improve constructibility during pavement reconstruction.

SCOPE

Four aspects of subgrade stabilization during reconstruction are discussed in this synthesis:

- Subgrade evaluation methods including sampling, laboratory, and in situ test methods as well as assessment of existing drainage systems;
- Constructibility factors such as existing and proposed

pavement types, available equipment, and cost-effectiveness of various subgrade stabilization techniques;

- Methods of subgrade improvement including mechanical and chemical stabilization, use of recycled and waste materials, and use of geosynthetics in reinforcement and drainage applications; and

- Construction methods with emphasis on innovative approaches such as novel sequencing of construction traffic, use of lightweight equipment, and robotics.

METHODOLOGY

Two approaches were used to collect information for this synthesis. First, an in-depth literature review was conducted, during which it was found that there is a scarcity of information that specifically addresses subgrade stabilization during pavement reconstruction. There is, however, an abundance of general material that addresses soil stabilization and other topics included in this synthesis. Second, a detailed questionnaire was distributed to 52 United States and 13 Canadian transportation agencies. Considering the scarcity of literature that addresses subgrade stabilization during pavement reconstruction, the questionnaire responses are an invaluable source of information. The questionnaire consists of seven parts that solicit information on the following topics:

1. Design standards addressing subgrade evaluation and preparation during highway reconstruction;
2. Subgrade problems encountered and solutions employed during highway reconstruction;
3. Highway reconstruction subgrade design philosophy;
4. Subgrade evaluation methods for highway reconstruction;
5. Stabilization of weak subgrades;
6. Pavement drainage; and
7. Construction methods for maintaining subgrade integrity.

This synthesis is organized into five chapters. Following the introduction are the results of the literature survey in chapter 2, and chapter 3 summarizes the questionnaire responses. In chapter 4, case studies that depict a cross section of practices used by various agencies are discussed. Conclusions regarding the state of the practice and state of the art for soil stabilization during pavement reconstruction are presented in chapter 5, along with suggestions for improving the practice and the identification of research needs. Appendix A contains a copy of the questionnaire, and Appendix B contains a detailed summary of questionnaire results.

LITERATURE REVIEW

INTRODUCTION

The design of high-type pavements, typically for interstate highways, depends heavily on the structural capacity or load bearing characteristics of the subgrade. Subgrade parameters such as the California bearing ratio (CBR) and Hveem Stabilometer R-value traditionally have been used for determining subgrade structural numbers or parameters for designing the thickness of load bearing layers under traffic. More recently, mechanistic methods of design that involve such parameters as the soil resilient modulus are being employed to account for the subgrade behavior under repeated load applications. Accompanying these new design methods is an increased use of nondestructive field tests, such as the falling weight deflectometer (FWD) test, for evaluating pavement layer structural characteristics.

From a constructibility point of view, achieving design subgrade strength and stiffness usually is left to the contractor, as mandated by contract specifications. A great deal of information exists in the literature regarding the assessment of subgrade load carrying capacity and methods for improving this capacity to meet design requirements. Interestingly, relatively little literature addresses requirements for subgrades subjected to construction traffic, when the stresses on the soil subgrade are greater than at any other time during pavement life. Most of the literature pertains to new pavement construction, and such methods can be readily employed during pavement reconstruction. However, there are significant differences, from a constructibility standpoint, between new pavement construction and reconstruction, particularly regarding subgrade requirements. Some of the major differences include the following:

- During new pavement construction, the subgrade is readily accessible for field testing and extensive sampling, and laboratory characterization typically is performed. On the other hand, the subgrade under a pavement to be reconstructed usually is covered by base course and surface course layers. Thus, the pavement is less accessible, making sampling and field testing more difficult, especially considering the necessity for rerouting traffic. Furthermore, because of the confined condition of the subgrade, it is unlikely that the subgrade behavior during field testing will reflect its ability to support construction traffic once it is exposed.

- The construction corridor during reconstruction usually is more restricted than during new pavement construction; therefore, it may be necessary for much of the construction traffic to travel directly over the subgrade during reconstruction. The potential for subgrade failure during reconstruction, as manifested by excessive rutting, is much greater than during new construction, in which haul roads adjacent to the alignment can carry most of the heavy construction vehicles.

- New pavements are constructed from the bottom up, and elaborate construction sequencing is avoided because there is no traffic to divert. Thus, subgrade preparation and subsequent construction of the overlying courses can be conducted quickly and in an orderly manner. To reconstruct a pavement, the existing pavement must be removed and materials must be recycled. Furthermore, construction is hindered by space limitations and traffic control. Thus, the subgrade may be exposed to weather and heavy equipment for longer periods of time during reconstruction than during new construction.

- Existing pavements to be reconstructed may have existing subsurface drainage systems that can be incorporated into the new pavement. Thus, these systems must be assessed to determine their integrity and how they will be affected during construction. For example, if construction vehicles are required to travel over drainage layers, the potential for contamination by fines and the ability of these layers to provide adequate protection for the subgrade must be addressed. Furthermore, if new drainage systems, such as edge drains, are to be installed, it may be beneficial to install them some time before removing the existing pavement to reduce subgrade moisture before reconstruction. These drainage issues should be examined carefully during the design and planning stages.

- Finally, because of space and time limitations, the requirements for subgrade preservation and stabilization during reconstruction may be quite different from those encountered during first-time construction. If chemical stabilization (e.g., with lime) is proposed, the limited space available on a reconstruction job for processing and mixing the soil and lime may be too restricted. Furthermore, if the subgrade is the only route available for construction traffic, proper curing times may be unachievable.

The available literature that directly addresses subgrade problems during pavement reconstruction is meager, but it is extensive regarding subgrade evaluation, soil stabilization, and subsurface drainage; therefore, this chapter presents an overview of the literature on these topics. Much of this literature is written from the standpoint of first-time pavement construction; however, it is applicable to reconstruction as well, keeping in mind the differences mentioned previously. The literature for subgrade evaluation, soil stabilization, and subsurface drainage is extensive; therefore, it is not the intent of this chapter to provide a complete synthesis on each topic. The chapter, however, does provide important sources of information that are readily accessible and discusses the relevance of these topics to subgrade stability during pavement reconstruction. A few case histories, some of which provided the impetus for this study, are mentioned briefly in this chapter and discussed in-depth in chapter 4.

SUBGRADE EVALUATION METHODS

Proper subgrade evaluation is an extremely important precursor to pavement reconstruction so that subgrade stability under construction traffic and anticipated weather conditions can be adequately addressed during the reconstruction planning stages. Methods for evaluating subgrade soil conditions either can be very simple, such as visually inspecting pavement distress, or can involve more complex procedures, including soil sampling, laboratory testing, and in situ testing. Many of the soil testing methods used for reconstruction are the same as those used when a new pavement is being designed. This section discusses some of these methods.

Visual Inspection of Pavement to Assess Subgrade Condition

Physical distress of pavement reflects surface deterioration due to traffic, the environment, and aging. Data on pavement distress become part of the management system, which is used to plan rehabilitation projects. Most of the procedures for collecting distress data are reported in the literature (1) and focus on both portland cement concrete (PCC) and asphalt concrete pavement. Surface distress also may emanate from deterioration of the underlying pavement layers. Certain forms of pavement distress can be linked directly to subgrade soil type and, in some cases, to changing moisture conditions.

The first step in collecting distress data involves identifying the type of distress being exhibited. This can be accomplished, as a first step, by visual inspection (2). Distress identification could evolve into more detailed procedures, as described in the manual published through the Strategic Highway Research Program (SHRP) for use on long-term pavement performance projects (3). After the type of distress is identified, the causes can be investigated, some of which relate to subgrade condition. For example, pavement heaving can be caused by frost-susceptible and swelling soils (4), which certainly could present problems under construction traffic during pavement rehabilitation. Another example is evidence of recent pumping that might indicate a wet subgrade composed of fine-grained soils, which would pose difficulties for heavy vehicles traveling on the subgrade. Another resource for identifying distress types and distress mechanisms is the Federal Highway Administration (FHWA) *Highway Pavement Distress Identification Manual* (5).

Subgrade Sampling Techniques

Soil sampling is necessary for assessing the moisture susceptibility and existing condition of the subgrade. Numerous methods exist for obtaining soil samples. Some methods cause a highly disturbed soil fabric, such as the split-spoon method, which generally accompanies the standard penetration test (SPT), and auger sampling. Other methods used in cohesive soils, such as Shelby tube sampling, produce samples with a relatively undisturbed fabric. The split-spoon sampling method

that accompanies the SPT is the most used soil sampling procedure, and extensive literature on the SPT is readily available (e.g., 6–8).

Conventional split-spoon sampling, which involves driving a heavy walled tube into the subgrade soil (American Association of State Highway and Transportation Officials (AASHTO) T 206 Penetration Test and Split-Barrel Sampling of Soils and American Society for Testing and Materials (ASTM) Standard D 1586) is extensively used for subgrade investigations, the frequency of which depend on the level of weakness of subgrade as judged by the field engineer. The test typically is performed with a drill rig, which is ideal for subgrade investigations beneath an existing pavement because coring is easily accomplished. Sometimes sampling is achieved by first excavating test pits with a backhoe (9) in the shoulder area or beneath the wearing surface, down to the subgrade or approximately 7.6 cm (3 in.) lower, after which samples are collected. Typically, the test pit is excavated deeper, often by about 0.61 m (2 ft), and sampling is repeated. Test pits facilitate the procurement of large samples that can be used for compaction, CBR, and other tests. Also, if desired, “undisturbed” block samples of clayey soils can be obtained from test pits.

The decision to obtain undisturbed samples for laboratory testing is determined by the potential of the subgrade to adversely affect pavement performance or, in the case of reconstruction, the ability of the subgrade to support construction traffic without failure (excessive rutting). Disturbed samples often are adequate because testing on compacted soils in the laboratory is enough to model the behavior of the compacted subgrade. However, if marginal soils extend for significant depths below the subgrade, it may be necessary to assess the bearing capacities of these soils. Strength testing on undisturbed samples would best serve this purpose.

Although some reports do not discuss the time of sampling, others are very specific by indicating that in northern states sampling is conducted after the spring thaw, April through May. The spring thaw produces an unstable subgrade condition because the thawed soil between the pavement and the still-frozen layer below contains an excess amount of moisture; therefore, in this supersaturated condition, the subgrade soil manifests great instability and loses practically all its bearing capacity.

Laboratory Testing Methods

Problems in geotechnical engineering usually are addressed by first determining soil properties and using them to develop a solution. If proper custody and care are exercised with the soil samples so that they reflect unaltered field conditions, laboratory testing methods should yield dependable results. To evaluate the ability of a subgrade to support construction traffic, a test that indicates shear strength under simulated environmental conditions (density and moisture content) is required, such as the CBR, unconfined compression, and Hveem Stabilometer tests. Furthermore, the influence of changes in moisture content on soil behavior should be investigated to account for actual weather conditions in the field.

There is general consistency in laboratory testing methods used by transportation agencies, with most agencies performing conventional standardized tests. Field samples taken to the laboratory often are tested for plasticity, grain-size distribution, specific gravity, CBR, water content, density, pocket penetrometer strength, and sometimes unconfined or triaxial compressive strength. Generally, laboratory testing is performed according to AASHTO (10) or ASTM procedures.

These tests characterize the soil and are used to predict soil behavior as it pertains to water content and to the soil's ability to support loads from construction traffic. Unfortunately, few methods exist for highway construction that specifically relate subgrade performance under construction traffic to readily measured soil properties. There are, however, analytical methods that can be used to evaluate the trafficability of soils (11) in relation to the depth of ruts (sinkage) that develop, given certain soil and vehicle parameters. The Army Corps of Engineers continues to perform extensive work on the mobility (e.g., 12–14) of military vehicles and aircraft. Highway engineering needs a quick and easy method to determine how many passes a particular construction vehicle can take before a certain rut depth (which defines failure) develops in the subgrade. The Army Corps of Engineers developed such a program (UNSEVA) for unsurfaced airfields (15). This computer program determines the allowable number of passes for a particular aircraft, given subgrade and base CBR values. Such a program would be very useful if developed or adapted for construction vehicles during pavement reconstruction.

In Situ Testing Methods

Subgrade sampling and laboratory testing of samples, although standardized and acceptable as methods for geotechnical subsurface investigation, have two inherent weaknesses: collecting representative samples and reproducing in situ environmental conditions in the laboratory. Consequently, attention has been focused on in situ testing.

In situ tests can be categorized into two groups: (1) tests related to the physical characteristics of soils, such as the use of a nuclear gauge to determine density and moisture content, and (2) tests used to assess subgrade structural capacity, which is manifested in the conventional subgrade modulus (k) value. This value is determined and evaluated through three approaches:

- Correlation methods (16,17)—Selecting the appropriate k value from soil classification, resilient modulus, moisture level, density, CBR, Hveem Stabilometer data (R -value), or dynamic cone penetrometer (DCP) data. A typical example of such correlated values is given in Table 1 (17a).
- Deflection testing and backcalculation, which is uniquely adapted for the design of overlays and pavement reconstruction.
- Plate load testing methods.

NCHRP Report 372 (16) provides a detailed analysis of the methods used and descriptions of field studies that guide the

TABLE 1
RECOMMENDED k -VALUE RANGES FOR VARIOUS SOIL TYPES (17a)

AASHTO Class	Description	Unified Class	Dry Density (lb/ft ³)	CRB (%)	k -Value (psi/in)
Coarse-grained Soils					
A-1-a, well graded	Gravel	GW, GP	125–140	60–80	300–450
A-1-a, poorly graded			120–130	35–60	300–400
A-1-b	Coarse sand	SW	110–130	20–40	200–400
A-3	Fine sand	SP	105–120	15–25	150–300
A-2 Soils (granular materials with high fines)					
A-2-4, gravelly	Silty gravel	GM	130–145	40–80	300–500
A-2-5, gravelly	Silty sandy gravel				
A-2-4, sandy	Silty sand	SM	120–135	20–40	300–400
A-2-5, sandy	Silty gravelly sand				
A-2-6, gravelly	Clayey gravel	GC	120–140	20–40	200–450
A-2-7, gravelly	Clayey, sandy gravel				
A-2-6, sandy	Clayey sand	SC	105–130	10–20	150–350
A-2-7, sandy	Clayey gravelly sand				
Fine-grained Soils					
A-4	Silt	ML, OL	90–105	4–8	25–165*
	Silt/sand/gravel mixture		100–125	5–15	40–220*
A-5	Poorly graded silt	MH	80–100	4–8	25–190*
A-6	Plastic clay	CL	100–125	5–15	25–255*
A-7-5	Moderately plastic elastic clay	CL, OL	90–125	4–15	25–215*
A-7-6	Highly plastic elastic clay	CH, OH	80–110	3–5	40–220*

* k -value of fine-grained soil is highly dependent on degree of saturation.

These recommended k -value ranges apply to a homogeneous soil layer at least 10 ft (3m) thick. If an embankment layer less than 10 ft (3m) thick exists over a softer subgrade, the k -value for the underlying soil should be estimated from this table and adjusted for the type and thickness of embankment material. If a layer of bedrock exists within 10 ft (3m) of the top of the soil, the k should be adjusted.

1 lb/ft³ = 16.018 kg/m³, 1 psi/in = 0.271 kPa/mm

engineer in evaluating the k -value. Such methods are the field CBR, the manually deployed Army Corps of Engineers static cone penetrometer, pocket penetrometer, and torevane (9). A subgroup in this category includes the FWD (18) and model 400 Road Rater (19), which are nondestructive deflection testing methods.

As stated in the AASHTO publication *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*: "The FWD is an impulse device that exerts a force similar in magnitude and duration to a moving vehicle tire load. By varying the weight and height from which it is dropped, the magnitude of the load can be changed. The resulting pavement deflection is measured by seven seismic deflection transducers, one of which is at the loading plate and the others at preset intervals from the loading plate" (10). The Oklahoma DOT Dynatest 8000 FWD appears in Figure 1. Figure 2 illustrates the impact weight and stressed zone beneath the pavement (20). Data from this nondestructive testing method provide information on the stiffness, weakness, and strength of the subgrade that supports the pavement and can be used for identifying the extent of and size of voids under the pavement.

Another version of FWD is the impact test developed by Striegler and Werner, in which a "weight is dropped onto a spring connected to a 350 mm [1.15 ft] diameter steel plate placed on the subgrade soil. The dynamic force exerted by this system is approximately 10 kN [2,248 lbf] and is intended to simulate traffic loading. The weight is dropped five times from 0.75 m [2.5 ft] and ten times each from 1 m and 1.25 m [4.1 ft]. The elastic deformation of the ground due to the dropping of the weight is measured during the last five loadings. A series of calculations yield the dynamic soil modulus" (21). The authors



FIGURE 1 Dynatest 8000 falling weight deflectometer owned by Oklahoma DOT.

point out that this test, as an indicator of the deformability of compacted soil, is "more suitable for cohesionless soils than for cohesive soils" because of pore pressure considerations.

In the Road Rater test (19) "a large mass is hydraulically lowered to the pavement and oscillated through a servo valve to produce a loading force" and deflections are measured by velocity sensors. Deflection data are translated into soil support values (Westergaard's modulus of subgrade reaction, k). Through the use of charts developed for this purpose, this test has proven to be a dependable tool in designing overlays for rigid, composite, and flexible pavements.

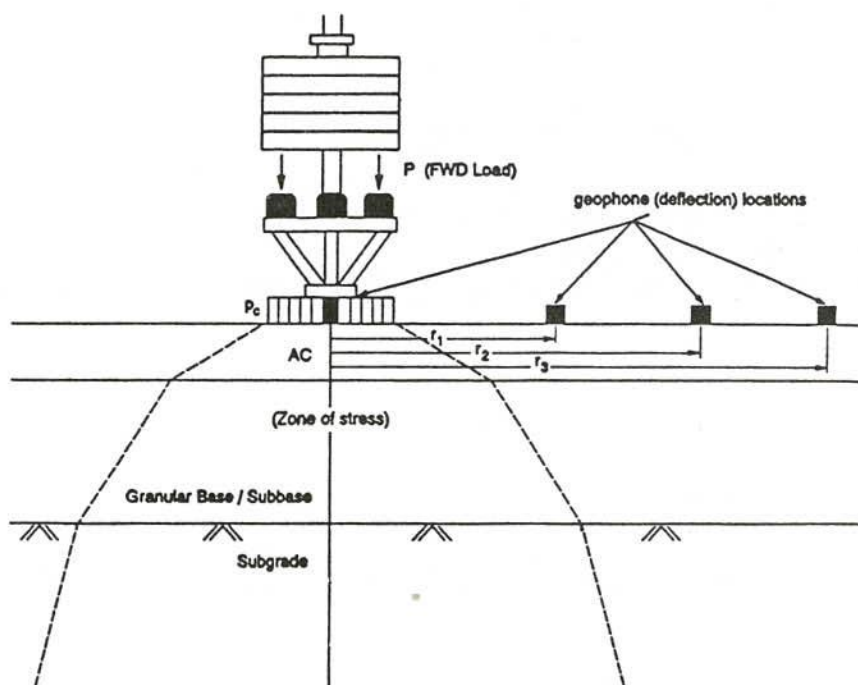


FIGURE 2 Falling weight deflectometer impact weight and deflection sensors.

Because Road Rater deflection data require temperature correction factors for greater validity, this method includes measurement of pavement temperature by means of an infrared gun, such as model R-380 RVF by Raytek (19). This method may effectively be used to predict subgrade support under construction traffic.

Structural deterioration of pavements can be analyzed by obtaining deflection data from the Dynaflect method (22), wherein subgrade stiffness reflects the existing strength of the subgrade. Subgrade strength is expressed as a soil support value, with 5.0 or higher representing good soil conditions and below 3.0 representing poor strength conditions. To obtain a more accurate picture of subgrade performance and the relative strength of the pavement layers, the term "spreadability index," a function of Dynaflect sensor readings, is introduced. The spreadability index is defined as the average of several deflections, which are measured in the center, and at varying distances from the plate, thus delineating a deflection basin. These values can be used to assess how well the subgrade will support construction traffic. A value above 55 indicates excellent strength of the pavement layers, and a value below 45 indicates poor strength.

The Dynaflect method has found wide applications (1) because it facilitates the calculation of the subgrade modulus. This method can be used to assess the stress sensitivity of the subgrade (subgrade modulus evaluation) without having to remove the pavement layers and take the measurements directly on the subgrade. This is possible because the surface and subbase moduli have very little effect on the outermost deflection sensor.

The equivalent layer thickness concept (23), an analytical procedure used in rehabilitation design in South Africa, incorporates nondestructive testing results. Road-surface deflectometer tests are used to measure surface deflection basins and calculate the subgrade effective elastic modulus. These tests lend themselves to use with overlay design curves developed for rehabilitation options.

To circumvent the removal of a large section of pavement to run the in-place CBR test or a plate bearing test, Borden et al. (24) suggest the use of the flat dilatometer to obtain the strength and stiffness characteristics of the subgrade. A flat dilatometer is a rectangular, flat, wedge-shaped penetrometer with a circular, thin steel membrane on one face (Figure 3) (25). The dilatometer test is performed, after penetration to the desired test depth, by expanding the membrane against the soil until the deflection at the membrane center reaches 1 mm (0.04 in.), which is followed by deflation. The measurement of pressures at membrane lift-off and at 1-mm deflection are used to compute parameters related to soil stiffness, strength, and type.

The benefits of the electric cone penetrometer (26) and the pavement pressuremeter (27) are similar to those of the dilatometer in that they are relatively small, invasive-type in situ tests that can be used to assess the strength and stiffness of the subgrade through in situ measurements. "The cone penetrometer test consists of pushing a series of cylindrical rods, with a cone similar to that shown in Figure 4 at the base, into the soil at a constant rate of 2 cm/sec [20 mm/sec] (0.79 in./sec).

Continuous measurements of penetration resistance on the cone tip and friction on a friction sleeve are recorded during the penetration. The piezo-cone penetrometer allows for measurement of pore water pressures in addition to point and friction resistance. The continuous profiles obtained with the cone penetrometer test allow the user to visualize the stratigraphy, to evaluate the soil type, to estimate a large number of fundamental soil parameters, and to directly design shallow and deep foundations subjected to vertical loads" (26). Thus, the test also can be used to rapidly evaluate pavement subgrade properties.

The pavement pressuremeter is a small-diameter cylindrical probe, equipped with an inflatable membrane, that is lowered into a bore hole (27). The membrane is expanded against

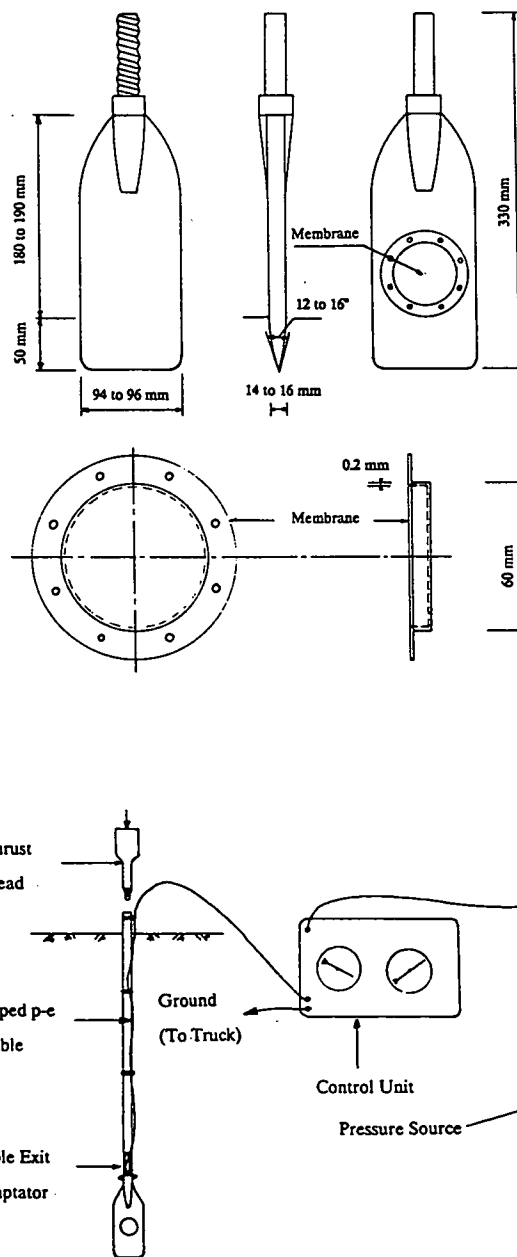


FIGURE 3 Marchetti dilatometer test apparatus (25).

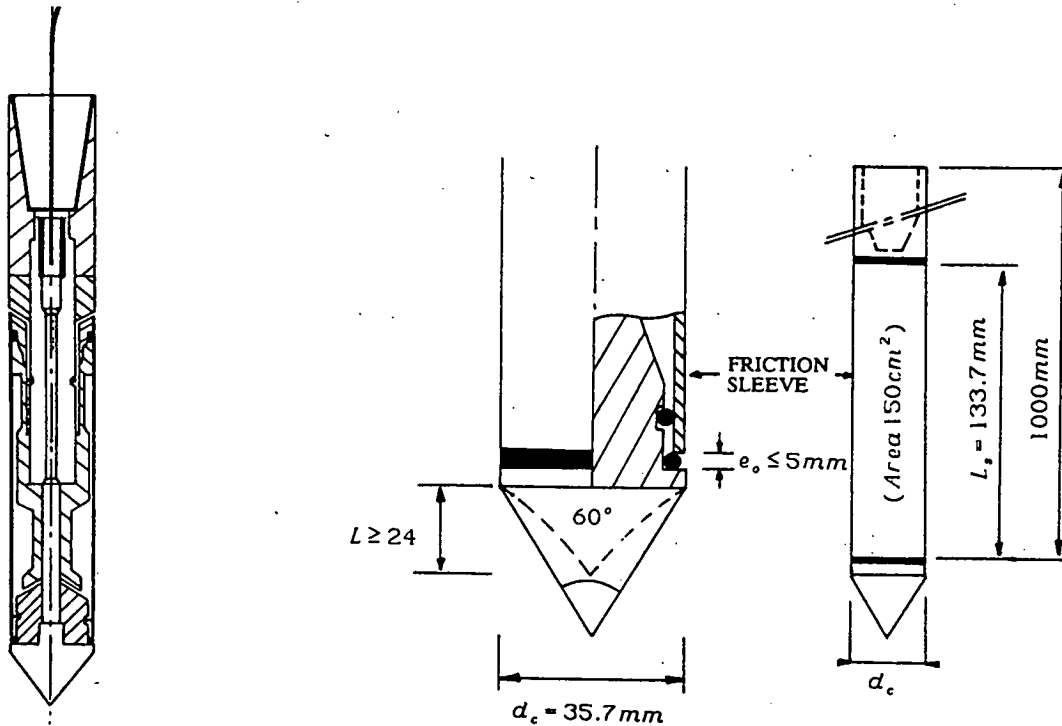
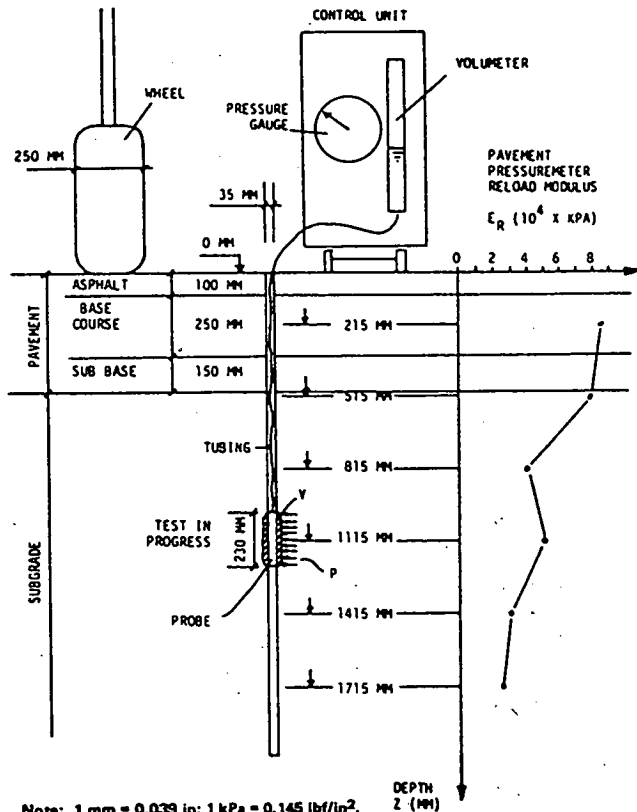


FIGURE 4 Electric cone penetrometer (26).



Note: 1 mm = 0.039 in.; 1 kPa = 0.145 lb/in².

FIGURE 5 Pavement pressuremeter test (27).

the side of the bore hole while the increase in probe volume and pressure are measured, as depicted in Figure 5 (27). Pressure-volume curves, corrected for membrane resistance and measuring system compressibility, can be used to assess the stiffness and

strength of the subgrade soil. The pavement pressuremeter test is an excellent test in that it is one of the few invasive type in situ tests that can provide a complete stress-strain curve for soil.

The DCP has been used extensively in Australia, South Africa, and other countries to determine subgrade soil strength for the purpose of designing roads. Recently, the DCP is gaining acceptance and popularity in the United States as a quick, easy, and reasonably accurate way to establish the CBR of near-surface roadbed materials (28), by means of correlations. Depicted in Figures 6 (28) and 7, the DCP is a simple, lightweight, dynamic penetration device that can be readily deployed by two persons—one for operating the equipment and the other for recording the data. The basic elements of the device are a cone rod attached to a tip, which is driven into the ground by raising and releasing a doughnut-shaped hammer that strikes an anvil attached to the top of the cone rod. The test is conducted by driving the cone vertically into the ground and recording the depth of penetration accomplished with each hammer strike. The cone rod is permanently marked in 5.1-mm (0.2-in.) increments to facilitate depth measurement. Driving energy is controlled by maintaining a consistent drop height. Test data are presented in the form of a plot of cone index (CI) versus depth, where the CI is simply the depth of penetration per blow, typically expressed in millimeters or inches per blow. Practically speaking, the test is suitable for investigating the upper 1 m (39.4 in.) of a pavement or soil profile.

The DCP has many attributes that make it attractive for pavement applications, particularly for field assessments before, during, and after construction:

- It can be easily deployed by two persons without the use of expensive drilling rigs or special equipment.

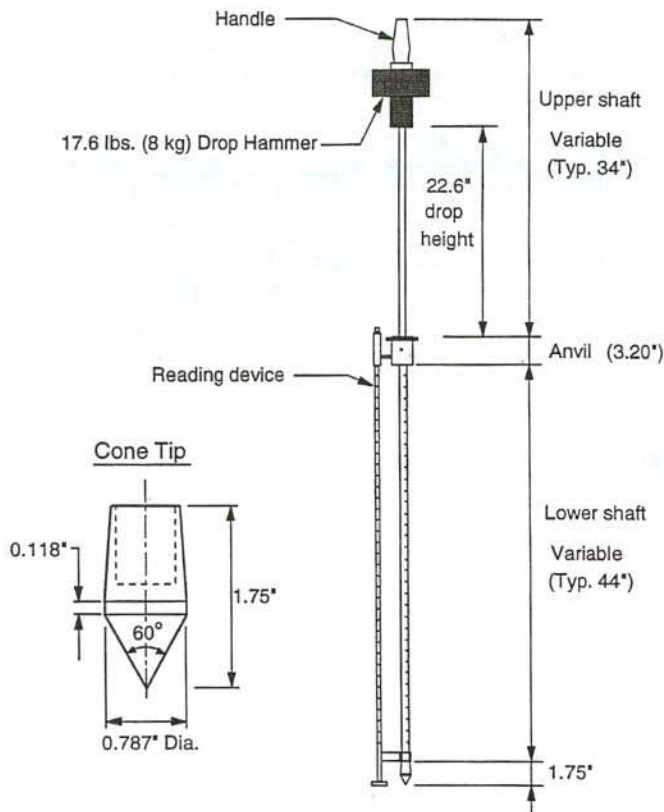


FIGURE 6 Dynamic cone penetration test apparatus (27).



FIGURE 7 Oklahoma DOT dynamic cone penetrometer.

- It can be rapidly deployed, and a large section of alignment can be investigated in a day.
- The depth of penetration is ideal for pavement structures.
- It is robust and relatively inexpensive.
- Energy for penetration can be precisely controlled and involves little operator intervention, provided verticality and a consistent drop height are maintained. The operator should have little influence on the results.
- The results are easy to interpret.
- Several correlations with commonly used soil parameters have been published.
- Very good correlations can be developed between DCP values and soil strength tests such as the CBR and unconfined compression tests.
- It is ideal for testing through core holes in existing pavements.

The DCP test has been used successfully in a number of states and in other countries to establish reliable correlations between CBR values (field and laboratory) or shear strength and DCP CI (28–32). In addition, analytical frameworks for interpreting DCP results have been developed (33) and some agencies have developed, or are developing, methods for incorporating DCP results in pavement design (34).

Another approach for evaluating subgrade stiffness is the screw-plate load test, as described by Schmertmann (35). The screw-plate is basically an auger with a single flight (screw-plate) 340 mm (1.1 ft) in diameter that is screwed into the ground to the desired testing depth and incrementally loaded at the surface to cause a bearing capacity failure below the screw-plate. Screw-plate testing offers considerable advantage over traditional methods of plate load testing because it allows for a series of plate load tests to be easily conducted with depth by simply screwing the plate deeper.

Subsurface soil conditions and other pavement components have been studied with ground penetrating radar (36). This is a noninvasive and nondestructive tool, but the method has not been widely used and the results are not entirely satisfactory. (However, with increased practice in interpreting results and improvements in data output software, it is becoming a more viable alternative for transportation applications.)

Another form of in situ testing involves proof rolling the subgrade with a heavily loaded vehicle such as a loaded 10-wheel dump truck. This can be an effective method for assessing subgrade strength during construction (37) but would not be very useful for evaluating the subgrade on a reconstruction project before removal of the overlying pavement layers.

Analyzing the aforementioned tests makes it clear that in situ testing methods have moved from static to dynamic (from the Benkelman Beam to impact), and more emphasis is placed on measuring the shear strength characteristics (e.g., by means of penetrometers) of subgrade soils. There appears to be considerable work underway to develop a heavy rolling wheel deflectometer, at high speeds, that should help quickly analyze uniformity of subgrade support at different times of the year (37a).

There are a number of in situ tests, in addition to laboratory tests, available to the engineer for assessing subgrade strength

TABLE 2

SUMMARY OF IN SITU TEST METHODS USED FOR SUBGRADE CHARACTERIZATION

Test Name	Test Type	Subgrade Characteristics Determined	References
Standard Penetration Test	Dynamic Penetration Test	Shear Strength, Soil Type	6, 7, 8
Dynamic Cone Penetrometer (DCP)	Dynamic Penetration Test	CBR, Shear Strength	28, 29–34
Electric Cone Penetrometer (CPT)	Quasi-Static Penetration Test	Shear Strength, Stiffness, Soil Type	26
Flat Plate Dilatometer (DMT)	Penetration Test	Shear Strength, Stiffness, Soil Type	25
Pavement Pressuremeter	Invasive, Bore Hole Test	Stiffness, Strength	27
Screw-Plate	Invasive, Static Plate Load Test	Shear Strength, Stiffness	35
Benkelman Beam	Static	Stiffness, Strength	39
Plate Load Test	Static Plate Load Test	Stiffness, Strength	40
German Plate Test	Nondestructive Dynamic Plate Load Test	Stiffness	21
Field CBR Test	Invasive	CBR	4
Falling Weight Deflectometer	Impact Pavement Deflection Method	Pavement Layer Elastic Modulus	18
Road Rate	Deflection, Load Oscillation	Stiffness, Support	19
Ground Penetrating Radar (GPR)	Nondestructive, Uses Electromagnetic Waves	Areas of High Moisture, Voids Beneath Pavement	36

and stiffness. Many of these tools have not been employed on reconstruction projects; nevertheless, the technology is available and can provide valuable insight into the subgrade's ability to support construction traffic. Furthermore, because of the inherent simplicity of these devices, they can be used during construction to assess the extent of any subgrade problems that arise. An example of using the DCP test in this capacity (38) is presented in chapter 4, in which selected case histories are presented. Table 2 summarizes some in situ tests that have been proposed for use in evaluating pavement subgrades.

The supporting capability of subgrade soils is a very significant factor in pavement performance. However, the wide variability of soils within a small area of a project raises a question about whether it is more economical to use the smallest supporting value when considering design and construction traffic requirements or a higher value that may lead to subgrade distress under construction traffic and the need for repair during the pavement's life expectancy. A TRB report (40) addresses this question as it applies to airfields, but the information in the report can be applied equally to highway pavements. A scenario is produced by assigning different CBR values to the subgrade and calculating the corresponding construction, maintenance, and reconstruction costs for keeping the pavement system functional. Thus, with a range of CBR values, tradeoffs are quantified and the most cost-effective and optimal design is attained.

Assessment of Existing Pavement Drainage Systems

Providing adequate drainage is extremely important in the design of a highway system. Inadequate drainage not only causes unsafe driving conditions but also serious damage to the pavement structure. Adequate drainage design provides for the control and removal of surface and subsurface water.

An integral part of evaluating a pavement before reconstruction is the assessment of existing drainage components. This is particularly important when considering the influence of construction traffic on the subgrade because drainage layers

may lie directly over the subgrade soils. The integrity of the existing drainage system will indicate the extent of subgrade moisture and whether the system will continue to provide good drainage and protect the subgrade once the drainage system is exposed. Furthermore, if construction traffic is to travel directly over an exposed drainage layer, the potential for contamination by soil fines should be considered.

Assessment of the existing drainage system starts with cataloging the drainage network (i.e., intercepting drainpipes; cutoff trenches filled with crushed stone, gravel, or sand; lateral drains; edgedrains; drainable bases; and any geotextiles used) (40a). The performance of a drainage system usually is estimated and backcalculated based on "symptoms" evident in the field, such as high moisture content in and softness of the subgrade. The installation of edgedrains and a longitudinal drainage system has been mentioned in the research. The following example was given at a pavement rehabilitation conference: "Prior to concrete resurfacing a longitudinal drainage system was added which consisted of an excavated trench, a perforated 4-inch diameter slotted under-drain pipe, plastic filter cloth and pea-gravel backfill and laterals" (1). As stated in NCHRP Report 367, "Sometimes one year prior to PC concrete pavement reconstruction the PCC is recycled and used to stabilize the subgrade and an underdrain is installed in a 1 m deep trench" (40a).

A comprehensive review of subsurface drainage systems is provided in an FHWA publication by Moulton (41) and in *NCHRP Synthesis 239: Pavement Subsurface Drainage Systems* by Christopher and McGuffey (42). In recognizing the dominant role subsurface drainage plays in pavement performance (e.g., inadequate and poor drainage systems lead to pavement distress), the synthesis covers design and construction issues. The role of separation layers and edgedrains and the use of drainable bases and geotextile separators is assessed. Retrofitting is mentioned as a procedure for extending pavement life, and poor construction techniques are identified as leading factors in reducing pavement life. Identification of field conditions and planned corrective actions in view of roadway drainage and pavement distress appears elsewhere (42a).

A comprehensive field assessment recently was completed in Oklahoma (43). Measurements of performance and efficiency of drainage systems (drainable base and edgedrain) in five test pavement sections were assessed and their performance was compared with performance predictions based on design and theory. Mathematical modeling and user-friendly computer programs for assessing drainage system performance were developed during this study.

Ahmed et al. (44) performed an extensive study of pavements in Indiana that included the use of field visual surveys and television probes for evaluating pavement drainage systems. The researchers developed a methodology for evaluating drainage conditions and formulated several recommendations for construction of drainage systems to ensure maximum performance and facilitate routine inspections. For example, to easily accommodate internal television probes and cleaning operations, Ahmed et al. recommended that Y rather than T type connections be constructed at pipe junctions in the drainage system. They emphasized other important features of a good drainage system, including proper maintenance of pipe outlets, proper filter materials around drainage conduits to prevent clogging, and sealing of joints to reduce infiltration. Field instrumentation data were collected and used for calibrating and verifying a computer program, PURDRAIN, which is capable of predicting moisture migration in unsaturated media. Models incorporated in PURDRAIN predicted values of the soil-moisture characteristic function that compared well with measured values. Details on drainage considerations, with emphasis on open-graded permeable bases, are discussed further in a report on soil stabilization (45).

The use of geosynthetics, when properly designed, can have a beneficial effect on pavement drainage by reducing pavement deterioration and movement. The placement of a deep vertical fabric to act as a moisture barrier (46) and the use of geogrids to stabilize subgrades (47) are two examples of geosynthetic use. An example of the latter is explained in detail in chapter 4.

METHODS OF SUBGRADE IMPROVEMENT

Under certain circumstances, reconstruction implies the need for subgrade strength improvement and the application of methods to accomplish this. Typically, this need arises from requirements to sustain construction traffic, rather than from pavement structural requirements. Thus, in evaluating subgrade strength beneath an existing pavement scheduled for reconstruction, it is important to consider that subgrade stabilization may be required even if the current subgrade strength is acceptable from the standpoint of pavement structural design. This consideration is sometimes overlooked when reconstruction projects are planned.

Unfortunately, there are no standard methods for determining the level of performance required for a subgrade to sustain excessive construction traffic that often results from space limitations during reconstruction. However, tools exist for establishing standard methods. Useful techniques and valuable lessons learned by transportation agencies are presented in this

synthesis. Whenever the ability of a subgrade to support construction traffic is in question, contingencies for stabilization or preservation of the subgrade should be planned.

Some improvements are conducive to upgrading soil conditions, such as the incorporation of admixtures. Some improvements are beneficial to the subgrade, such as the improvement of drainage and reinforcement by geosynthetics. Improvements that can be applied during first-time construction equally can be considered in the rehabilitation process. However, their cost and limited space may make such improvements prohibitive and may dictate the use of other avenues of improvement.

Mechanical and Chemical Stabilization

The literature on mechanical and chemical stabilization, which covers a period of at least 60 years, is extremely extensive. The literature includes such topics as mechanical and aggregate stabilization; cement, lime, and ash stabilization; bituminous stabilization; and stabilization with randomly reinforced fibers (45–62). More recently, use of recycled and waste materials, especially as a result of environmental concerns such as the preservation of landfill space, is widespread, and many of these materials are encountered in the literature. A comprehensive report on recycled materials for application in highway engineering (63) identifies the four basic byproducts—agricultural, domestic, industrial, and mineral—and their applications in highway construction. The report includes guidance into the environmental, legislative, and regulatory aspects of these materials. The American Road and Transportation Builders Association published an excellent review of construction practices for subgrade and pavement recycling (64), which covers cement, fly ash, lime, and mechanical stabilization.

Another waste product identified with highway construction is recycled tires (65). Although crumb rubber derived from tires typically is associated with asphalt paving materials, shredded tires have found limited use as fill materials and aggregate replacements and in combination with geotextiles for drainage purposes. Research on the use of tire chips as a road bed material indicates that for satisfactory pavement performance, a soil layer with a thickness of 1 m (3.3 ft) should be placed above the chips to minimize compression and unwanted tensile strains below the pavement (66). Furthermore, in some instances, tire chip embankments have spontaneously combusted; therefore, caution should be used in designing tire chip fills (67). Although tire chips may be used for constructing fills, their application for stabilizing a road bed during reconstruction appears infeasible given the necessity of soil cover to reduce unwanted compression of the chips. Shredded tires also have been found to be effective at reducing frost penetration into pavement subgrades (68).

A subgrade stabilization project requires that the physico-chemical characteristics of the soil be matched with the type of admixture to be used. In the field, in situ mixing, rarely plant mixing, is used often. At times an injection method, which comes under the category of grouting, is used. Grouting involves pumping a flowable cement-fly ash mixture or other

chemicals through pipes or tubes that have been advanced into the subsurface. The grout tends to fill the void space and adds integrity to the soil by means of cementation or densification of the existing soil. In certain instances, the use of a flowable mixture of a low-strength concrete-type material can be used as "flowable fill" (69,70). Traditionally, flowable fill has been used as a quick patch method for utility cuts in urban environments, but it may have useful applications as a quick fix of problem spots in the subgrade during pavement reconstruction.

With the advent of more powerful recycling equipment, the viability of deep (≥ 0.38 m (1.25 ft)) in situ cement stabilization is being explored as an inexpensive reconstruction alternative (71). In Australia, test sections continue to be constructed as part of the national highway network. This method, which is discussed in greater detail in chapter 4, involves recycling the existing pavement and mixing the pavement materials with cement and a significant portion of underlying subgrade soil. Recycling to depths exceeding 0.38 m (1.25 ft) are possible, and a short time after construction, a stable traffic surface results. This method appears to have great potential for application to the pavement building process on U.S. highways; however, as Donald et al. (72) emphasize, when using cement stabilization in any process, the possibility of shrinkage cracks and their effect on pavement performance must be considered. This is especially true where cement contents exceeding 4 percent by weight are used.

A method of improving subgrade performance that does not require exposing the subgrade is the "crack and seat" or "break and seat" technique. This method involves breaking the concrete pavement to form large blocks that are forced, by means of heavy compactors, into the subgrade to provide strength (73,74). Crack and seat refers to jointed pavement (JPCP), and break and seat can be used with jointed or continuous pavement (CRCP). These methods reduce vertical movement by restoring subgrade support (74a).

Novel techniques of subgrade stabilization continue to be developed for various soil conditions. One interesting technique for sand subgrades is the use of vertical reinforcing elements (i.e. galvanized rods), which precludes the need for removing a soil layer (75). Also, plasma arc technology has advanced to the point at which it can be applied to civil engineering works in the form of in situ soil vitrification. Potential applications include slope stabilization, groundwater removal, and subgrade stabilization (75a).

In summary, extensive literature exists on the numerous methods available for improving or preserving subgrade so that it can withstand surface loads. The main difference between using these methods during reconstruction, as opposed to during new pavement construction, is the influence of construction traffic coupled with the practical difficulties of working under space limitations typically associated with reconstruction projects.

Geosynthetics

The use of geosynthetics to reinforce pavement layers has been gaining attention in recent years. Geotextiles and geogrids

are two forms of geosynthetics that have served as separation and reinforcement layers, respectively, in paved roads. Separation refers to the ability to prevent the migration of subgrade soil into a coarser base course, whereas reinforcement refers to the ability to provide additional stiffness as a result of increased tensile strength to the reinforced layers. Both types of geosynthetics have been used to reinforce unpaved roads; however, because a substantial amount of subgrade deformation is required to mobilize the tension resistance of geotextiles, their use has been generally limited to a separation function in paved roads. Reinforcement of unpaved subgrade by geotextiles is a promising approach for improving trafficability during reconstruction. Koerner (76) provides an excellent review of design practices associated with the use of geotextiles, geogrids, and other geosynthetics in pavement construction.

Another class of geosynthetics, referred to as geomembranes, are practically impermeable to water and are produced in a variety of forms, including asphalt-impregnated geotextiles, polypropylene sheets, and polyethylene sheets. These materials are used to meet drainage requirements in rehabilitation projects by protecting the subgrade from moisture intrusion or escape (46) and by encapsulating the subgrade layer in a way that produces a more uniform and even distribution of load (stress).

Peters (77) conducted research on the cause of heaves at transverse cracks in asphalt concrete pavements and found that subgrade soil expansion results from rainfall infiltration and is aggravated by initially low water contents and overcompaction during construction. Peters recommends the use of a 12-mil polyethylene geomembrane during reconstruction to maintain constant water content in the subgrade soil and indicates that compaction at moisture contents greater than optimum is desirable. This illustrates an important dilemma. On the one hand, it may be desirable to compact an expansive clay subgrade wet of optimum moisture to minimize heaving after construction; on the other hand, the subgrade may not adequately sustain construction traffic at moisture contents much greater than 1.5 percent above optimum (9). It appears that in dealing with expansive clay soils, there is a need to use higher moisture contents, thinner lifts, and lighter equipment to construct a pavement with a stable subgrade. Little information was discovered in the literature pertaining to the use of lightweight equipment or other innovations, such as robotics, for preserving subgrade integrity.

European Reconstruction Practices

A review of Europe's experience with rehabilitation projects (78-81) reveals the following:

- The rehabilitation work deals primarily with the top part of pavements (surface and base), but subgrade improvements and their relationship to constructibility are not mentioned.
- Remotely related to the subgrade is the introduction of a thick "blanket" granular layer 20 to 90 cm (8 to 35 in.) between the subgrade and the treated base course (80). This layer has two functions. First, the layer provides protection

against frost and, as such, the pavement structure is designed to extend downward to about 100 percent of the total expected frost depth. Second, the layer provides some subbase drainage. In the latter case, fines have to be controlled.

- Even if the aforementioned granular layer fails as a frost heave preventive and drainage measure, it does contribute to subgrade support. By extrapolation, it may be advanced that this layer will help support construction traffic. To ensure the minimum level of support, a subgrade bearing value of 45 N/mm² (45.3 psf) and a blanket layer bearing value of 120 N/mm² (121 psf) are specified. Plate load tests (German Standard Test DIN 18134, June 1990) can be used to verify these values, which are higher than U.S. requirements and which should be attained in addition to compaction control.

- Similar to the use of a granular blanket is the use of a platform made of select material for which a design catalogue or table is provided (78). The support characteristics are measured by a Dynaplate test (impulse generator), which simulates the dynamic loading caused by the passage of a 130 kN axle at 60 km/hr (78).

- Edge and longitudinal drains are installed and outletted to the drainage system.

- Reconstruction is preferable to restoration of surface courses (81). Recycling PCC into a lower course base and granular blanket or using the old aggregate base as part of the cement-treated base are not uncommon.

- In certain instances, to protect pavement from frost heave and excess moisture, the grade line was raised by 0.9 m (3 ft) above the natural ground level, and in cuts, where soft soils were encountered, the roadway was excavated below grade and backfilled with select material.

- Pavement conditions are monitored and determined primarily by deflectograph or FWD measurements (79). Structural rather than visual factors trigger rehabilitation.

KNOWLEDGE-BASED ARTIFICIAL INTELLIGENCE OR EXPERT SYSTEM APPROACH

Development of an expert system is a long-term process that requires the establishment of a database to deal with the problem at hand. The literature search did not reveal information that satisfactorily addresses the subgrade stabilization problem. However, the literature does include articles on pavement evaluation and maintenance. The scarcity of published papers and reports in the area of subgrade rehabilitation to improve constructibility is attributed to two factors: the narrowness of the topic, which excludes first-time improvements, and the implementation of onsite, quick-fix decisions by field engineers. These quick fixes often are not considered sophisticated enough to be publishable; therefore, what should lend itself to an artificial intelligence system, in reality, does not.

Laguros et al. (82) deals with the problem of prioritizing maintenance decisions based on the needs and function of the pavement section, but subgrade rehabilitation is not specifically identified.

Ritchie (83) treats pavement overlay design problems by using expert systems. A prototype of the system OVERDRIVE details this design when pavement structures consist of up to three layers.

Corby et al. (84) presented a multiexpert system (ERASME) for pavement defect diagnosis and rehabilitation. The system is structured into knowledge modules, called specialists, which cover about 20 specialties. Hall et al. (85) developed a computerized system for evaluating mechanisms that have caused distress in concrete highway pavements to identify rehabilitation techniques to alleviate the distresses and preventing their recurrence. This type of system should indicate subgrade condition and whether the subgrade will support construction traffic without the need for substantial improvements.

STATE OF THE PRACTICE: QUESTIONNAIRE RESPONSES

INTRODUCTION

This chapter summarizes responses to the questionnaire distributed to transportation agencies in the United States and Canada. The lack of information in the literature on subgrade stabilization during pavement reconstruction emphasizes the importance of this survey. Response was reasonably good, with a total of 49 out of 65 agencies (75 percent) responding. Of the 49 respondents, 41 represent state departments of transportation (DOTs) (52 questionnaires sent) and 8 represent agencies from Canadian provinces (13 questionnaires sent).

The respondents provide a good geographic representation across the United States and Canada. A summary of respondents and a tally of the number of questions answered by each is provided in Table 3. Because the information in this chapter was derived from questionnaire responses prepared by one or more individuals from various agencies, there might be gaps in some responses (i.e., respondents did not necessarily answer every question). However, the information provided gives an excellent indication of the state of the practice pertaining to subgrade stability during reconstruction.

CHAPTER ORGANIZATION

The questionnaire appears in Appendix A; agency responses are summarized in Appendix B. Chapter 3 encompasses four major topics. The applicable sections and the parts of the questionnaire involved follow:

- Problem Overview (Questionnaire Part 2), which presents some typical problems and practices associated with soil subgrades during pavement reconstruction.
- Subgrade Evaluation Methods (Questionnaire Part 4), which is divided into subsections on subgrade soil sampling (Part 4, Section I), laboratory soil testing (Part 4, Section II), field testing (Part 4, Section III), and existing drainage system assessment (Part 3, Question 5; Part 6).
- Methods of Subgrade Improvement and Preservation (Questionnaire Part 3, Question 1; Parts 5, 6, and 7), which addresses stabilization with granular materials, chemical stabilizers, geosynthetics for stabilization, use of recycled materials, and construction methods and sequencing.
- Constructibility Factors (primarily Questionnaire Parts 2 and 3), which lists a number of issues pertaining to the subgrade that must be addressed and that influence the viability of various reconstruction alternatives.

PROBLEM OVERVIEW

The first question on the questionnaire asked for a brief description of typical subgrade problems and solutions employed

during pavement reconstruction. As expected, the responses were quite varied and were primarily a function of geographic region and location, prevailing soil conditions, and agency protocol. In this section, examples of subgrade problems and solutions encountered during pavement reconstruction are presented.

In the southeastern United States, respondents from Georgia and South Carolina indicated that their agencies generally do not engage in interstate pavement rehabilitation that involves full-depth replacement. In Georgia, very little pavement has had to be removed in rehabilitation work and no subgrade improvement has been performed on interstate reconstruction. Apparently South Carolina has not used reconstruction as a rehabilitation alternative for interstates. Similarly, in Alabama, subgrade stabilization to improve constructibility generally has not been used during rehabilitation. In Mississippi, it was indicated that on one interstate project, a short section with expansive soils was treated during reconstruction to reduce moisture entering the subgrade; in one instance, the pavement was removed with the base course left intact.

Farther up the eastern seaboard in New Hampshire, subgrade problems during reconstruction are rarely encountered because interstate highways are constructed with a layer of granular base course materials at least 1.2 m (4 ft.) thick. These base materials usually are adequate after some reworking, and the subgrade is rarely exposed during reconstruction. Vermont roads are similar to New Hampshire in this regard. Presumably, the freely draining nature and the intrinsic strength and stiffness of these granular base courses enable them to hold up well under construction traffic. Furthermore, base course layers of the thickness mentioned provide considerable protection for the underlying subgrade. Hawaii, Wisconsin, and Michigan reported that few subgrade problems are encountered during interstate reconstruction.

In general, the preferred method of rehabilitation is to use pavement overlays. Texas, Minnesota, and other states opt for unbonded concrete overlays when possible. In Washington, reconstruction is used primarily for PCC pavements, whereas asphalt pavements are rehabilitated by overlays.

Subgrade problems, which include soft spots, shrinking and swelling, and frost-susceptible soils, most often are due to the presence of water in soils with a significant fines content. For sandy soils (i.e., cohesionless), a lack of moisture also can cause instability due to the absence of apparent cohesion. The most prevalent problem is encountering water-induced soft spots in the subgrade. A common remedy is to excavate the problem soil and replace it with more suitable material. This practice is widely used and can involve replacement with suitable onsite materials or select fill, and sometimes a geotextile separator is installed. In Washington, for example, on jobs where extensive poor soils are encountered, it has proven cost-

TABLE 3
SUMMARY OF QUESTIONNAIRE RESPONDENTS AND NUMBER OF RESPONSES

State or Province Represented	Number of Responses to Questions for Each Part of Questionnaire						
	Part 1 (3) ¹ Design Standards	Part 2 (1) Subgrade Problems	Part 3 (7) Design Philosophy	Part 4 (10) Subgrade Evaluation	Part 5 (3) Subgrade Stabilization	Part 6 (2) Pavement Drainage	Part 7 (3) Construction Methods
Alabama	0	0	0	0	0	0	0
Alaska	0	0	0	0	0	0	0
Arizona	2	1	7	9	3	2	3
Arkansas	0	0	6	7	3	2	3
California	3	1	7	9	2	1	1
Connecticut	0	1	7	8	2	2	0
Florida	0	1	5	6	0	0	2
Georgia	0	0	0	0	0	0	0
Hawaii	0	1	7	3	3	2	3
Idaho	1	0	4	4	1	0	0
Illinois	0	1	6	9	3	2	3
Indiana	3	1	6	8	3	2	3
Kansas	0	1	4	9	3	2	3
Louisiana	0	1	7	7	3	1	2
Maine	2	1	4	3	2	0	3
Maryland	3	0	4	5	0	0	0
Massachusetts	1	1	5	7	3	0	0
Michigan	0	1	7	8	3	1	3
Minnesota	0	1	0	10	3	2	3
Missouri	3	1	6	7	3	2	1
Mississippi	0	0	0	0	0	0	0
Nebraska	0	1	5	6	3	2	3
Nevada	0	1	6	9	3	2	3
New Hampshire	1	0	0	0	0	0	0
New Jersey	0	0	0	0	0	0	0
New Mexico	0	1	6	10	3	2	3
New York	1	1	6	8	3	2	3
North Carolina	0	1	7	9	2	2	0
North Dakota	0	1	5	9	3	2	3
Oklahoma	0	1	7	9	3	2	3
Oregon	0	0	4	6	2	1	1
Pennsylvania	1	1	6	9	3	2	3
Rhode Island	0	1	5	10	3	0	2
South Carolina	0	0	0	0	0	0	0
Texas	0	1	6	4	3	2	3
Virginia	0	1	7	9	3	2	2
Vermont	0	1	5	9	3	2	3
Washington	1	1	5	8	3	2	2
West Virginia	1	1	7	7	3	2	2
Wisconsin	0	1	6	10	3	2	3
Wyoming	0	1	6	8	3	2	1
Alberta	0	1	6	7	3	0	1
British Columbia	0	0	0	0	0	0	0
Manitoba	2	1	5	7	2	0	0
Newfoundland	0	1	6	6	0	2	3
Nova Scotia	0	1	7	9	3	2	1
Ontario	1	1	7	9	3	2	3
Quebec	2	1	7	10	3	1	1
Saskatchewan	3	0	6	9	3	2	3
Percent Response ²	21	73	69	64	72	62	58

Notes:

¹Part 1 didn't solicit specific information in question format. Rather documentation was requested. The number in parentheses indicates three forms of documentation requested. For all other parts in the questionnaire, the number in parentheses refers to the number of questions asked.

²Percent response for each part of the questionnaire is based on a total of 49 respondents.

effective to excavate 0.6 to 0.9 m (2 to 3 ft) of soil and place a geotextile separator, followed by select filling and pavement construction. Oregon and Quebec use geotextiles in a similar manner.

In addition to subgrade reworking (scarification and re-compaction) and excavation and replacement methods, some states such as Texas, Oklahoma, and Nevada use lime, fly ash, or another chemical additive to improve the behavior of fine-grained soils and highly plastic clays. Chemical additives make the soil more workable by reducing plasticity and moisture content and, in some cases, add stability by means of cementing action. In Nova Scotia, construction loads on the subgrade may be limited if rutting due to overstressing is observed. Some agencies specify or encourage the use of light-weight equipment and minimization of construction traffic on exposed subgrades. Often, specifications call for crowning the subgrade to facilitate drainage and avoid saturation of the soil.

In most instances, subgrade maintenance is the responsibility of the contractor, and remedial measures are mandated by specifications, those typically used in first-time pavement construction. Sometimes remedial measures become part of the project design if subgrade soil problems are known to be extensive before reconstruction begins. There are a variety of problems and approaches associated with subgrade stabilization during reconstruction. Additional details of various approaches for solving this problem are discussed throughout the remainder of this synthesis.

SUBGRADE EVALUATION METHODS

This section summarizes information on preconstruction evaluation of pavement subgrades and drainage systems. Included are discussions on subgrade sampling, laboratory testing, field testing, and assessment of existing drainage systems.

Before rehabilitation, subgrade evaluation of an existing road can be approached in a variety of ways. The approach may not necessarily include sampling or testing but can be based on a historical assessment of performance by reviewing maintenance records and by making visual observations. For example, if a section of roadway was extensively patched because

of settlement, it is likely that a soft compressible subgrade is present. State transportation agencies generally use a combination of subgrade evaluation techniques that include field and laboratory testing, as indicated in Table 4. Only a handful of agencies rely solely on historical assessment and visual observation.

For roads with existing drainage systems, about 55 percent of responding state DOTs inspect and clean the systems before reconstruction. As shown in Table 4, about 16 percent of these DOTs indicated that integrity testing of existing drainage systems is performed as well, and 37 percent indicated that often the drainage system is replaced completely.

Subgrade Soil Sampling

Proper evaluation of an existing pavement subgrade often involves soil sampling. Knowledge of the physical properties and behavioral tendencies of existing subgrade soils allows engineers and contractors to develop appropriate subgrade preservation and stabilization schemes.

Agencies were asked to indicate which sampling methods and applicable standards are part of their standard sampling protocol. As shown in Table 5, for obtaining pavement and subgrade samples, coring and test borings are used the most, by about 65 percent of respondents. Undisturbed samples are obtained by 33 percent of respondents; split-spoon samples are obtained by 41 percent. Roughly one-third of the agencies indicated that test pits are part of their standard protocol for sub-surface investigation.

Survey inquiries about sampling frequency revealed that corings and test borings typically are performed on intervals in the range of one every 152 m (500 ft) to 610 m (2,000 ft), depending on the project size and engineering judgment. On very large projects, the interval may be extended to as much as one test hole per 1.6 km (1 mi). Where existing pavements exhibit a great deal of subgrade-related distress and where geology is complex, shorter intervals are used.

Regarding maximum sampling depths, typically samples are obtained up to 0.31 m (1 ft) to 1.5 m (5 ft) below the top of the subgrade. Some agencies obtain a single spoon or tube

TABLE 4
SUMMARY OF QUESTIONNAIRE RESPONSES ON SUBGRADE AND DRAINAGE SYSTEM EVALUATION

Subgrade Evaluation Approach	Number of Respondents Who Indicated That This Approach is Used	Percent of Respondents
Subgrade		
(1) Historical Assessment and Visual Inspection	31	63
(2) Field Testing	20	41
(3) Laboratory Testing	30	61
(1) Only	6	12
(2) or (3)	33	67
(1), (2) and (3)	14	29
Drainage System		
(1) Inspection and Cleaning	27	55
(2) Integrity Testing	8	16
(3) Complete Replacement	18	37

TABLE 5
SUMMARY OF QUESTIONNAIRE RESPONSES ON SAMPLING METHODS

Method	Number of Respondents Indicating Use	Percent of Respondents	Range of Frequency of Use	Range of Maximum Depth Sampled ³
Pavement Coring	32	65	1/152 m-1/1.6 km	0.91-1.5 m
Test Borings	31	63	1/61 m-1/1.6 km	0.30-3 m
"Undisturbed" Tube Sampling	16	33	4/project ¹ , Engineers Discretion	0.46-1.5 m
Split-Spoon Sampling	20	41	1/61 m-1/1.6 km	0.30-3 m
Test Pits	18	37	NA ²	NA ²

Notes:

¹Limited response. ²No detailed information provided. ³Depth as measured from top of pavement for coring and top of subgrade for all others.

sample from the top of the subgrade, whereas others sample continuously to greater depth. Rarely are samples obtained beyond a depth of 1.8 m (6 ft) below the top of the subgrade unless special circumstances exist, such as the presence of poor soils and in proposed cut or fill sections. Deeper investigations generally are associated with construction of new sections of alignment rather than reconstruction projects in which changes in vertical grade are unlikely. When asked about preferred times of the year for sampling, about 15 percent of the agencies indicated that spring and, in some cases, fall are desired because of the high moisture conditions (i.e., the worst-case scenario). About 29 percent of respondents indicated that sampling is performed when the ground is not frozen; 18 percent indicated that sampling times are dictated by project scheduling; and 35 percent indicated that they have no preference for the time of sampling.

Standards of practice published by AASHTO and ASTM are used most to guide sampling operations and associated activities. In some cases, in-house standards are followed.

Laboratory Testing

In Part 4, Section II, of the questionnaire, agencies were asked to list all laboratory tests that are part of their protocol for subgrade investigations before pavement reconstruction. Information on the extent of use and applicable standards for each test was also requested. Of the 49 agencies responding, 38 provided answers to the laboratory testing questions, which are summarized in Table 6. A wide variety of laboratory tests are listed; however, it appears that most agencies rely predominantly on soil index property tests for classification purposes. Slightly less than half the respondents rely on moisture-density testing to evaluate optimum moisture content (OMC) and maximum dry density (MDD) for compaction purposes. About half the respondents use either the Hveem Stabilometer (R-value) test, CBR, or limerock bearing ratio (LBR, in Florida) to evaluate the structural integrity of subgrade soils. Unconfined compression, triaxial shear, and direct shear tests are used to a limited degree to evaluate soil shear strength. Resilient modulus testing is performed by some agencies to evaluate the subgrade modulus. A number of other tests for evaluating physical and chemical properties of soils are performed on a limited basis by some agencies. Included are tests to evaluate the organic content of a subgrade and its potential to be stabilized with lime or cement.

Many respondents from the United States indicated that they follow AASHTO standards for most test procedures. Respondents from Canada indicated that they follow ASTM and AASHTO standards. Some U.S. agencies also rely on internal standards, but by far the AASHTO standards are most widely used. For example, out of 30 state agencies, 22 rely heavily on AASHTO standards; 11 use ASTM, in-house, and AASHTO standards; 4 incorporate ASTM and other standards; and 4 rely solely on in-house standards that are likely hybrids of AASHTO and ASTM standards.

Seasonal variations in subgrade moisture content can lead to drastic changes in soil mechanical properties; therefore, agencies were asked how these seasonal changes are addressed through laboratory testing. Only seven agencies indicated that they specifically perform mechanical property tests on saturated soils to simulate a worst-case scenario, such as the spring thaw. On the other hand, 18 agencies do perform CBR or Hveem Stabilometer (R-value) tests if the standard procedure calls for a period of soaking. One agency indicated that swell and collapse tests are performed to evaluate soil response to water; another agency allows frozen samples to be taken, noted, and used. Others indicated that they are developing a protocol to address seasonal changes in soil properties.

Finally, the question was posed as to whether minimal acceptance criteria based on results of laboratory tests are used to determine the suitability of subgrade soils. Roughly one-fourth of the agencies responded affirmatively, with widely ranging criteria. For example, Arizona requires an R-value of 15 or greater, and Nevada requires an R-value of 45 and a plasticity index below 10. California requires a minimum R-value of 10, otherwise some form of subgrade stabilization is required. Where poor subgrade conditions exist, Virginia requires that a working platform with a minimum CBR value of 30 be constructed.

Some states, such as Illinois, base their acceptance criteria on the results of several tests, including Atterberg limits, CBR, grain-size analysis, compaction, and organic content. Illinois requires the following:

- An immediate CBR (Illinois bearing ratio, IBR) value greater than 6,
- A plasticity index less than 10,
- A silt content less than 65 percent,
- A compacted dry density exceeding 95 percent of the standard Proctor dry density, and greater than 14 kN/m³ (90 pcf).

TABLE 6

SUMMARY OF QUESTIONNAIRE RESPONSES ON LABORATORY TESTING

Test Method	Number of Respondents Who Use It			Total Number of Respondents	Percent of Respondents ¹
	Rarely	Sometimes	Always		
Liquid Limit	1	9	20	30	79
Plastic Limit	1	8	21	30	79
Shrinkage Limit		2		2	5
Natural Water Content		2	20	22	58
Grain-Size Analysis		8	24	32	84
Specific Gravity		1	1	2	5
Unit Weight		1	4	5	13
Organic Content		4	1	5	13
Loss on Ignition		1		1	3
pH		1		1	3
Calcium and Magnesium		1		1	3
Resistivity		1		1	3
x-ray		1		1	3
Chem.		1		1	3
Sand Equivalency	1	2		3	8
Minimum Cement Content		1		1	3
Minimum Lime Content		1		1	3
Lime Stabilization		4		4	11
Soil Cement Design		2		2	5
Moisture-Density		2	15	17	45
Swell Testing		1		1	3
Collapse Testing		1		1	3
Pocket Penetrometer			1	1	3
Laboratory Vane Shear		1		1	3
Field Vane Shear		1		1	3
R-Value		4	5	9	24
CBR		6	3	9	24
LBR			1	1	3
Unconfined Compression		6		6	16
Field Unconfined Compression		1		1	3
Direct Shear Test		3		3	8
Triaxial Compression	1	1		2	5
Consolidation Test		1		1	3
Elastic Modulus			1	1	3
Permeability		2		2	5
Resilient Modulus	1	3	1	5	13

Notes: ¹Based on a total of 38 agencies who responded to this section of the questionnaire.

New York, on the other hand, designs its pavements assuming a subgrade resilient modulus of 27 MN/m² (4 ksi). Subgrade soils that cannot meet this requirement are excavated and replaced. New Mexico uses a different approach, in which a design R-value is selected for a project and monitored during construction. If R-values determined during construction do not meet design criteria, samples are obtained and a remedy is sought.

Other states address subgrade problems as they are encountered during reconstruction. For example, North Carolina has no minimum acceptance criteria for subgrade soils; however, for poor soils the state requires aggregate stabilization to form a suitable working platform for construction traffic. Pennsylvania uses proof-rolling during construction with a 89-kN (10-ton) roller to evaluate subgrade suitability. About one-third of the respondents indicated that no laboratory testing criteria are used to evaluate the subgrade before pavement reconstruction; about one-quarter of the respondents did not respond to this section of the questionnaire.

Field Testing

When asked about field testing for evaluating subgrade soils before pavement reconstruction, the method most often cited by the agencies was the FWD test. Of those responding to this part of the questionnaire, nearly two-thirds of respondents indicated that the FWD is routinely used to evaluate pavement and subgrade properties. About one-third of respondents have used ground penetrating radar (GPR), to various extents with varying degrees of success, primarily to detect voids beneath the pavement. Respondents also indicated that they have used GPR to identify areas of high subgrade moisture and to locate buried pipes beneath pavements with excessive moisture-induced distress.

Questionnaire responses indicate increasing reliance on nondestructive testing methods for evaluating conditions below the pavement surface during rehabilitation projects. As backcalculation methods improve and a larger database is established, FWD use is expected to be more widespread because of

TABLE 7
SUMMARY OF QUESTIONNAIRE RESPONSES ON FIELD TESTING

Test Method	Number of Respondents Who Use It			Total Number of Respondents	Percent of Respondents ¹
	Rarely	Sometimes	Always		
Dynamic Cone Penetration		2	2	4	13
Static Cone Penetration		4		4	13
Hand Penetrometer	1			1	3
Standard Penetration Test		3	3	6	20
Field Vane Shear Test		3		3	10
Benkelman Beam		2		2	7
CLEGG Impact Hammer		1		1	3
Road Rater		1		1	3
Falling Weight Deflectometer		10	9	19	63
Dynaflect		1		1	3
Nuclear Moisture Testing			1	1	3
Ground Penetrating Radar		10		10	33

Notes: ¹Based on a total of 30 agencies who responded to this section of the questionnaire.

its intrinsic rapidity. Some states noted limited and experimental use of other nondestructive techniques, such as seismic testing; however, at present there does not appear to be widespread use of such methods.

Invasive type tests continue to be used, with the cone penetration test (CPT) becoming more prevalent. Although few respondents listed the standard penetration test (SPT) as a routine field test, many indicated that split-spoon samples are routinely obtained, as discussed previously, and presumably SPTs are conducted simultaneously. Cone penetrometers are gaining popularity, with nearly a third of the respondents indicating that they use one or more of the following: the static cone penetrometer, dynamic cone penetrometer (DCP), and hand penetrometer.

For reasons discussed in chapter 2, the DCP is expected to gain in popularity during the next decade. For example, Minnesota DOT has been actively researching and employing the DCP for several years, and Oklahoma DOT is currently developing design protocols for the DCP test for roads with low traffic volumes. Other field tests are used to lesser degrees, as indicated in Table 7.

Questionnaire responses on field testing do not indicate uniform use of testing standards by agencies. AASHTO, ASTM, and in-house standards were cited with similar frequency.

Existing Drainage System Assessment

As discussed in the literature review, an existing drainage system directly affects subgrade integrity and pavement reconstruction practices. Subsurface drainage was discussed previously in connection with Table 4, which gives information about the level of evaluation used. Evaluating the performance of existing subdrains by visual observation of outlet pipes and pavement condition seems most prevalent. A few states use video cameras for evaluating drainage systems; others indicated that most existing interstates in need of reconstruction have no drainage systems.

METHODS OF SUBGRADE IMPROVEMENT AND PRESERVATION

Subgrade improvement has long been a part of pavement construction, particularly in areas where fine-grained problem soils exist. Distress to the subgrade is worst during the construction process, when soils are exposed to heavy equipment and weather. Providing adequate subgrade support can be challenging and sometimes requires soil stabilization beyond simple mechanical means.

This section summarizes responses to questions about soil stabilization during reconstruction of interstate pavements. Responses indicate that many of the agencies have had little experience with soil subgrade stabilization during pavement reconstruction. Their answers, therefore, are based partly on their standard procedures for the construction of new pavements. In fact, some agencies indicated that their subgrade requirements for new pavement construction are the same as those for full-depth pavement reconstruction. The goal of stabilization is the same for pavement reconstruction and for new construction; therefore, in this synthesis little distinction is made between stabilization methods applied during new pavement construction and those applied during pavement reconstruction.

A common approach to subgrade stabilization is to simply excavate poor quality soils and replace them with select fill, thus lowering the subgrade and forming a stable subbase. This may or may not be the most economical method, depending on select fill availability. For example, in New York state, where glaciation resulted in numerous deposits of good quality aggregate materials, the preferred method of stabilization is to undercut with aggregate replacement. However, in states such as Oklahoma and Texas, chemical stabilization (e.g., lime and fly ash) is common because of a scarcity of quality aggregate sources.

Subgrade stabilization also can be achieved through the use of geosynthetics. Geogrids can be used to reinforce subgrade soils and aggregate base courses, and geotextiles can be incorporated in separation, filtration, and reinforcement functions.

Other means of maintaining subgrade integrity include minimizing construction loading by reducing construction traffic, using lightweight equipment, and maintaining good drainage by means of existing underdrains and subgrade crowning.

Stabilization With Granular Materials

In many states, quality aggregate materials are blended with poorer quality soils and compacted to create a stable subbase. In addition, aggregate layers with and without separators, such as geotextiles, are used to build a working platform above the subgrade. These layers confine the subgrade soil and reduce the destructive impact of construction traffic and weather.

Aggregate may consist of natural or crusher-run gravel, rubblized concrete, recycled asphalt concrete (RAP), furnace slag, or other materials. The use of recycled materials appears to be increasing in many applications—road building and refurbishing are no exception, as shown in Table 8. For example, RAP is used in Wyoming for temporary surfacing to carry traffic over soft soils. Use of recycled municipal waste materials also is increasing. For example, in New York state, recycled container glass is allowed in some aggregate applications. Other states are investigating these materials.

Chemical Stabilizers

Chemical additives such as lime and fly ash are commonly used for stabilizing soil in many parts of the United States. As indicated in Table 8, more than 60 percent of respondents indicated that their agencies have used lime; some agencies also use portland cement. Recycled additives such as cement kiln dust, lime kiln dust, and by-product lime are being used to a limited degree. Fly ash use has increased, with about one-fifth of the respondents indicating its use.

Geosynthetics for Stabilization

Many state DOTs are using geosynthetics in pavement structures for separation, filtration, and reinforcement applications, all of which can improve trafficability during and after construction. As shown in Table 8, woven and nonwoven geotextiles appear to be used most often in subgrade applications, usually for the purpose of separation/filtration between fine-grained subgrade soils and overlying aggregate base materials. In addition, geosynthetics can be designed to reinforce the pavement structure. Several DOTs are using geogrids, some experimentally. Geogrids, which serve only to reinforce pavement subgrade soil and aggregate layers, are used most often to reinforce an aggregate layer, thus reducing the required layer thickness. One agency indicated some experience with using geocells to provide a highly confined granular layer. Geocells usually are more expensive than geogrids and geotextiles and probably would be cost-prohibitive for

reconstruction of significant lengths of pavement, except under extreme circumstances.

Construction Methods and Sequencing

Part 7 of the questionnaire solicited information on the use of innovative construction sequencing practices, special equipment (such as lightweight vehicles and robotics), and other practices to maintain subgrade integrity during reconstruction. Overwhelmingly, the responses indicate that many practices used during reconstruction are the same as those used during new construction. The prescribed use of lightweight equipment to preserve subgrade integrity is virtually nonexistent among transportation agencies, and innovations involving robotics have not yet surfaced in highway reconstruction practice. A few respondents mentioned that their agencies use lightweight equipment, but this practice appears to be rare. One state respondent indicated that lightweight equipment sometimes is used with geotextiles. Other states recommend lightweight equipment under certain circumstances. In some specifications, the engineer in charge has the authority to limit vehicle loads on the subgrade if excessive distress is noted.

Most agencies have specifications requiring the contractor to ensure that subgrade integrity is maintained. The contractor can achieve this using a variety of practices, some of which are included in most state specifications. Practices mentioned by respondents are as follows:

- Backdumping of road base materials onto the subgrade;
- Closing lanes to construction traffic as needed for repair and preservation;
- Building temporary haul roads to keep traffic off the subgrade and occasionally placing limits on haul road boundaries;
- Construction phasing to limit the time the subgrade is exposed;
- Providing working space by diverting interstate traffic to retrofitted frontage roads;
- Providing a moisture barrier with materials such as rubberized asphalt; and
- Providing good drainage by constructing a proper cross slope or crown on the subgrade, sealing the subgrade surface with a steel drum roller, and using diversion ditches.

CONSTRUCTIBILITY FACTORS

This section summarizes questionnaire responses pertaining to constructibility issues. Several factors must be considered when planning a rehabilitation strategy for an existing pavement, particularly if reconstruction is the only appropriate alternative (i.e., the pavement structure has deteriorated so much that overlaying strategies are not recommended).

Often, constructibility as it pertains to the stability of the subgrade under construction traffic is not addressed sufficiently

TABLE 8
SUMMARY OF QUESTIONNAIRE RESPONSES ON SUBGRADE STABILIZATION

Method or Additive	Number of Respondents Indicating Use	Percent of Respondents ¹
Methods Involving Recycled Material Additives		
Recycled Asphalt Pavement (RAP)	15	39
Recycled Concrete ²	11	29
Rubblized Concrete	7	18
Break and Seat Concrete	1	3
Recycled Glass	1	3
Furnace Slag	1	3
Fly Ash	7	18
Cement Kiln Dust	1	3
Lime Kiln Dust	2	5
Hydrated Byproduct Lime	2	5
Carbide Lime	1	3
Calcium Sulfate Hemihydrate	1	3
Salvaged Soil-Aggregate Base	1	3
Methods Involving Other Additives		
Lime	23	61
Cement	8	21
Aggregate	2	5
Calcium Chloride	2	5
Methods Involving Geosynthetics		
Geosynthetics ³	28	74
Geotextiles ⁴	19	50
Non-Woven Geotextile	8	21
Woven Geotextile	8	21
Geogrids	14	37
Geocell	1	3
Other Methods		
Undercut and Replace	9	24
Construction Surcharge	1	3

Notes:

¹Based on a total of 38 agencies who responded to this section of the questionnaire.

²Includes rubblization, break and seat, and non-specified uses.

³Includes geotextiles, geogrids and geocells.

⁴Includes non-woven and woven geotextiles.

during the design process. This issue usually is left to the contractor to handle. In fact, about one-third of respondents indicated that end-product specifications are used during pavement reconstruction and that the responsibility for subgrade stability lies with the contractor. In such situations, the potential for unexpected conditions and resulting change orders increases, unless constructibility factors have been identified in the contract documents. However, the engineer's careful consideration of constructibility factors during the design process will alert the contractor to potential construction traffic problems and allow potential problems to be addressed in the contract documents. The result will be better planning, fewer change orders, and, most likely, better pavement performance. Factors influencing the constructibility of a new pavement that must be considered when planning and implementing a pavement reconstruction project are as follows:

- Climatic conditions (i.e., arid versus temperate);
- Pavement type and condition;
- Subgrade soil type (i.e., fine-grained versus granular, plasticity index, and fines content);

- Existing water content of subgrade soils compared with the standard Proctor OMC and plastic limit;
- Existing density of subgrade soils compared with the standard Proctor MDD;
- Current subgrade strength as indicated by a CBR or field test (e.g., DCP) and that obtained at the OMC and MDD;
- Soil reactivity to potential chemical stabilization methods (e.g., lime);
- Space limitations within the construction corridor and whether most construction traffic will travel over the subgrade;
- Recycling options for existing pavement layers;
- Availability of select fill materials; and
- Availability of lightweight construction equipment and low-contact-pressure equipment.

Most agencies do not have a formal protocol that addresses subgrade stabilization during reconstruction. In fact, roughly 40 percent of the agencies responding indicated that they relied mainly on incumbent practitioner protocols for evaluating existing subgrades and potential improvement methods for pavement reconstruction projects. It appears that most agencies

rely mainly on specifications used in evaluating the subgrade for new construction and encourage (by means of specifications and special provisions) construction practices that will preserve subgrade integrity. However, subgrade preservation during reconstruction often is more challenging than subgrade preparation during first-time construction because of space limitations and complexities associated with recycling and other activities not likely to occur during first-time construction. The preceding discussion points to the need for evaluating the subgrade before and during reconstruction.

Rehabilitating a section of interstate usually involves incorporating the existing pavement as a base course layer, which has many benefits. Although there are many approaches for incorporating existing pavement, the most attractive approach appears to be to overlay the existing pavement after appropriate subsurface or surface treatment, such as grinding, crack sealing, or undersealing.

An asphalt concrete pavement may be recycled and incorporated in the subgrade as a means of soil stabilization, millings may be compacted over the soil to provide a stable base, or asphalt concrete may be rejuvenated and recompact as the primary pavement course. PCC pavements also can be recycled by breaking up the pavement and seating it with heavy rollers, the "break and seat" method, or by crushing the pave-

ment and creating a granular material that can be used as an aggregate material, the rubblization method. The primary reason for using the break and seat method is to minimize reflective cracking in asphalt concrete overlays. The idea is to fracture a concrete panel and seat the resulting blocks into the subgrade, which creates an irregular pattern of joints and eliminates preferential cracking at the transverse joints associated with the monolithic panels. Thus, there is a tradeoff between improved pavement ride quality and reduced structural integrity of the concrete panel that acts as the base course.

Successful application of the break and seat method depends, to a large extent, on subgrade integrity. A subgrade with excessive moisture may lack sufficient shear strength to provide adequate pavement support. Furthermore, by breaking the concrete slab, the ability of the slab to bridge soft spots in the subgrade is reduced. Rubblization destroys the slab action of the existing pavement and causes it to revert to a granular base.

Based on questionnaire responses, it appears that the most common methods for evaluating various recycling/rehabilitation alternatives from an economic standpoint are a simple unit cost comparison and a life-cycle cost analysis. However, the remedy can be dictated by the agency's cash flow at the time of rehabilitation.

SELECTED CASE STUDIES

CASE 1: I-80 IN PENNSYLVANIA

This case history is based on a report prepared by the Pennsylvania DOT (9). This is an important case history because it addresses certain problems that are unique to subgrade stabilization during reconstruction.

The Scenario

In 1985 the eastbound lanes of Interstate 80 (I-80), Section 026, were reconstructed after considerable difficulty caused by subgrade instability. The rehabilitation strategy called for removal of an existing concrete pavement and subbase and replacement with new material. Subgrade instability was observed after limited exposure to construction traffic. The solution to this problem called for undercutting approximately 80 percent of the alignment. The difficulties encountered on the eastbound lanes led to an extensive field and laboratory investigation of soils to determine the causes of subgrade problems and to prepare for similar problems during construction of the westbound lanes. A number of valuable lessons were learned.

Subgrade Soils

Test pits revealed that at the top of the subgrade to a depth of about 0.45 m (1.5 ft), a brown, silty, clayey sand with sandstone rock fragments existed. This material was found to be excessively moist and poorly graded, and even though a large percentage of rock fragments were present, ruts on the order of 0.15 m (6 in.) formed after one proofrolling pass of a backhoe. The material was found to have a laboratory CBR value of about 2 at the standard Proctor maximum dry density, and the field CBR was as low as 0.5. Apparently, the rock fragments were merely floating in a matrix of fines and did little to enhance strength. The CBR values for this material were far below the design value of 5 for the new pavement; therefore, this material was determined to be unsuitable.

Below the brown layer was a layer of gray sandy clay with some rock fragments. This was a material of medium to high plasticity. Although the average of the laboratory-soaked CBR values for this material (compacted to the Proctor maximum dry density) was close to that required by design, the material was found in the field to be excessively moist (1.5 percent to 2 percent above the optimum moisture content) with a lower density than required. Therefore, in addition to being inadequate for supporting construction traffic, this material did not meet design requirements of the new pavement, which required a CBR value of at least 5.

On the basis of the laboratory and field study, a set of criteria was developed to define areas that might require undercutting along the westbound alignment yet to be constructed. Results indicated that undercutting subgrade soils might be necessary if (1) the field or laboratory CBR value is 7 or less; (2) the water content is 1.5 percent or more above optimum; or (3) the density is less than 85 percent of standard Proctor density, especially if the material consists of more than 20 percent fines. Other factors considered were whether an area was in a fill or cut section (fill being more susceptible to undercutting), the presence of coal, and the condition of the pavement.

One of the engineers involved in the project (9) compared computations of undrained bearing capacity using a cohesion value determined from a correlation with CBR values with the pressure under truck wheel loads. Interestingly, for soils with a CBR of 3, the undrained bearing capacity was determined to be 510 kPa (74 psi), whereas the estimated bearing pressure under a tandem wheel load was 503 kPa (73 psi). Thus, soil with a CBR of 3 would begin to shear on the first pass of a loaded truck. For soils with CBR values of 5 and 7, the corresponding bearing capacities were 848 kPa (123 psi) and 1,186 kPa (172 psi), respectively. On the basis of these numbers, soils with a CBR value of 5 might be expected to fail after a few passes of a loaded truck, whereas soils with a CBR value of 7 might be expected to undergo several passes before failing. Although this simple static analysis does not consider the dynamic character of construction loading on the soil, it does provide a convenient means for analyzing subgrade instability and for comparing CBR and its relationship to performance under traffic.

Problems and Solutions

After the extensive soil investigation, it appeared that the primary causes of subgrade instability were excessive moisture and low density. It was believed that the materials would have performed adequately with moisture reduction, compaction, and reduced construction traffic loading; however, this was not possible because of the narrow corridor available for construction. This important aspect generally distinguishes reconstruction from new construction, because with new construction, there usually is sufficient working space to process fill materials. For the case in point, although existing materials were less than ideal, most of them probably could have been used if space had been available to spread, dry, and process the excessively moist materials.

Another major setback that results from a narrow reconstruction corridor is that construction vehicles often have no

alternate routes; therefore, the subgrade is exposed to excessive construction traffic. This was the case with the I-80 rehabilitation.

Several options for remedying the situation were developed by the Pennsylvania DOT. A few of the seriously considered options are discussed. The first option was to overexcavate the unsuitable subgrade and replace it with select fill materials. Experimenting with this option, it was determined that a 0.61-m (2-ft) undercut was required to obtain a stable working platform.

Another option involving geogrid was tested on an experimental basis in the field. The experimental section was constructed by excavating 0.15 m (6 in.) of subgrade, placing a layer of geogrid over the subgrade, and backfilling with aggregate materials (2A subbase) recycled from the old pavement. The treatment was applied to the full 7.3-m (24-ft) pavement width and under the 1.3-m (4-ft) and 3.0-m (10-ft) wide shoulders. It was found that the performance was unsatisfactory and that after about eight passes of loaded trucks, wheel ruts began to form. Ruts were repaired by backblading with a dozer, but eventually the geogrid was exposed between ruts and extensive splitting of the geogrid was observed. Tests with an additional layer of geogrid in one case and with a thicker aggregate layer above the geogrid in another case also proved to be inadequate. It was suggested that using the geogrid with an undercut of 0.3 m (1 ft) probably would work well; however, the contractor quickly pointed out that the unit cost for this option was close to that for the 0.61-m (2-ft) undercut option. Thus, the geogrid option was dismissed in favor of the 0.61-m (2-ft) undercut and replacement option.

Another option considered was to stabilize the subgrade with lime or cement. A cost analysis was performed, assuming that 0.45 m (1.5 ft) of subgrade were to be stabilized with 7 percent cement. The estimate revealed that this option would cost about 75 percent of the cost of the excavation and replacement option; however, many uncertainties led to the rejection of this option. These included uncertainty about achievable mixing depths, influence of rock fragments on mixing, the weather, and the effect of delays caused by the curing period.

Summary

It was found that achieving moisture reduction in the wet subgrade materials by reworking these soils was hindered by the narrow confines of the reconstruction corridor. Furthermore, the use of geogrids, although effective for increasing subgrade stability, proved to be less cost-effective than the excavation and replacement option that was implemented. This option called for a 0.61-m (2-ft) undercut, adjusted according to field conditions, and replacement with select fill at an estimated cost of \$24.6/m² (\$20.60/yd²). This case history of the eastbound lanes of I-80 emphasizes the need to thoroughly evaluate the load-carrying capacity of existing subgrades when reconstruction projects are initiated. In this case, if the problems resulting from excessive moisture in the subgrade were identified before initiating construction, the construction problems encountered may have been anticipated.

CASE 2: I-70 IN PENNSYLVANIA

This case history is based on a 1995 research report prepared by Pennsylvania DOT (47). Research was conducted to evaluate the use of geogrids to stabilize soft subgrade materials during interstate rehabilitation. In the end, geogrid implementation was considered a success.

The Scenario

In 1989, section A-10 of Interstate 70 (I-70) underwent reconstruction. The preliminary geotechnical investigation indicated areas of soft subgrade along the alignment. A study was undertaken to compare the performance and costs of geogrid stabilization with those of the alternative, undercutting and replacement. The evaluation, which lasted until the spring of 1995, involved eight test sections. Two of the test sections were used as controls with standard undercutting and backfilling, whereas geogrid stabilization was implemented in the remaining six sections. During construction, plate bearing tests were conducted on the subgrade and subbase materials in the test sections. In addition, inclinometer casings were installed in all test sections to evaluate the effects of construction equipment and traffic on pavement material performance.

Subgrade Soils

The soil investigation was conducted on the shoulder, with the assumption that the soil profile on the shoulder was similar to the soil profile beneath the pavement. The investigation consisted of standard penetration testing, index property tests, and determination of the moisture-density relationship. Soils in the test sections were classified according to AASHTO as either A-4(3) or A-6(5). These fine-grained soils were of low to moderate plasticity, with PI values of 9 and 12 percent, respectively. A minimum blow count of 8 was obtained during standard penetration testing, which gave an equivalent CBR value of 1.6.

Pavement Design

The pavement design in areas where the subgrade was stable called for a 0.10-m (4-in.) densely graded subbase, a 0.10-m (4-in.) open-graded base, and a 0.33-m (13-in.) PCC surface pavement. In areas of unstable subgrade, an undercut of 0.18 m (7.0 in.), which added 0.18 m (7 in.) of densely graded subbase under the standard design pavement, was required. A geogrid alternative reduced the undercut to 0.05 m (2 in.); thus, regarding pavement structural integrity, the geogrid was assumed to be equivalent to 0.13 m (5 in.) of undercut/replacement. Two types of biaxial geogrids were tested during this study: (1) Miragrid 5-T (37 kN/m = 2,500 lb/ft tensile strength) and (2) Tensar SS-1 (19 kN/m = 1,300 lb/ft tensile strength). Figure 8 (47) shows typical design cross-sections; geogrid placement is demonstrated in Figure 9 (47).

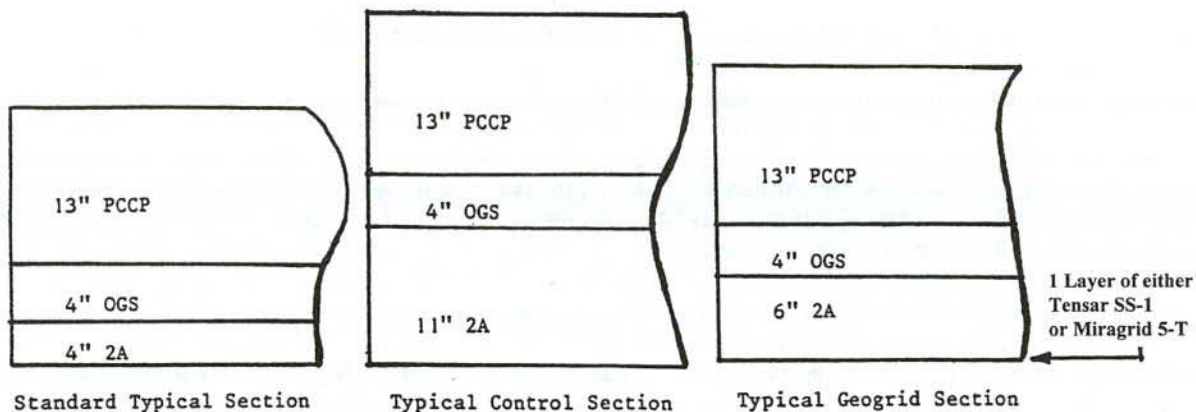


FIGURE 8 Typical design cross sections (47).

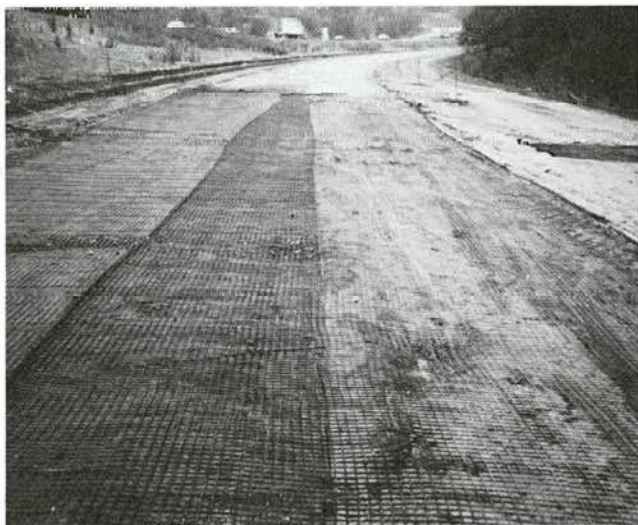


FIGURE 9 Geogrid placement on the exposed subgrade (47).

Results of the Study

Two locations along the alignment were eliminated from the comparative study of the different subgrade stabilization techniques because the extent of unstable soil conditions was very large, requiring extensive undercutting and fill placement. At one of these areas, where a silty clay-loam was found ($PI = 8$), the in-place moisture content of the subgrade soil was 27.3 percent, which was about 10 percent above the optimum moisture content. In addition, the geogrid, as initially designed, actually failed at this site. To remedy the situation, an undercut of about 0.61 m (2 ft) and backfilling in combination with two geogrid layers was used.

In all test sections, the geogrids performed well under construction traffic. A testimony to this performance was revealed when inclinometer readings for shoulder areas that had been prepared with and those that had been prepared without geogrid reinforcement were compared. Shoulder sections were heavily used by construction equipment, and it was observed, by means of inclinometer readings, that where geogrid reinforcement extended through the shoulder, little or no displacements were indicated. However, where geogrid was not extended through the shoulder area, large displacements were

observed. This observation actually prompted the use of additional geogrid in the shoulder, where inclinometer casings were present. In general, inclinometer readings showed minor movement under the roadway and verified that geogrid sections performed according to design. Results of plate bearing tests confirmed these findings.

Some important construction issues were emphasized in the Pennsylvania DOT research report as a result of problems encountered. Important issues to consider include adequate storage provisions for geogrid and proper planning for geogrid installation procedures. Manufacturer's recommendations usually call for a 2-week exposure limit to prevent ultraviolet degradation. During installation, it is important to prevent traffic from traveling directly over the geogrid because repeated passes with rubber-tired vehicles can damage the geogrid. Thus, fill must be dumped over previously placed subbase and pushed ahead over the exposed geogrid. At least 0.15 m (6 in.) of subbase placed over the geogrid is recommended before opening the area to construction traffic. It also was found that changing from using "spreader box" placement in unreinforced areas to using the placement technique in geogrid reinforced areas caused added delays. Finally, it was found that the more rigid geogrid is easier to roll out on the subgrade, and to achieve the proper tension in the geogrid, care must be given to the fill placing operation.

Summary

The study concluded that geogrids should be considered as a cost-effective alternative to undercutting and replacing poor subgrade material. Pennsylvania DOT realized a savings of \$2.02/m² (\$1.69/yd²). Furthermore, the study indicated that geogrid-reinforced subgrades perform satisfactorily under construction traffic.

CASE 3: SUBGRADE STABILITY INVESTIGATION WITH THE DYNAMIC CONE PENETROMETER

The following summarizes important results of a subgrade stability investigation conducted by the Oklahoma DOT (38). After achieving the finished grade on a state road project,

unstable materials were noticed under certain portions of the alignment, particularly where the finished grade was the same as the existing ground surface elevation. The Soils & Foundations Branch of the Oklahoma DOT Materials Division was asked to investigate the problem and make recommendations. This request was made approximately 3 months before the bid date for the surfacing contract; thus, there was some pressure to complete the investigation rapidly. Questionable subgrade zones were found along a 4.8-km (3.0-mi) section of the alignment. To maximize the efficiency of the investigative effort, it was decided to rely primarily on the DCP test for defining the extent of the problem.

Geotechnical Investigation

The DCP was used to rapidly assess the statistical variation of CBR values in the upper 0.61 m (24 in.) of the subgrade. A total of 71 DCP tests were performed at the center line of the westbound lane. Spacing between successive DCP tests was random and varied between 15.2 m (50 ft) and 91.4 m (300 ft), with an average of 68.3 m (224 ft). CBR values at each test location were established for each 0.15-m (6-in.) depth interval by averaging the DCP cone index (CI) over this interval and incorporating a correlation to convert CI to CBR. The goal was to delineate soft spots and assess overall subgrade stability along the alignment. For this purpose, the subgrade stability was related to the CBR as follows:

<i>Very Good Stability</i>	<i>CBR = 20 to 30 percent</i>
<i>Fair to Good</i>	<i>CBR = 10 to 20 percent</i>
<i>Questionable to Fair</i>	<i>CBR = 5 to 10 percent</i>
<i>Poor</i>	<i>CBR < 5 percent</i>

In addition to DCP tests, four test borings were drilled along the alignment to obtain soil samples for classification, CBR tests, and determination of natural water content.

The investigation revealed that the soil consists primarily of moderately plastic clays with some sand and that plasticity indices are on the order of 10 percent to 40 percent in the upper 0.61 m (2 ft) of the subgrade. In some locations, the natural water content exceeds the plastic limit, which indicates a subgrade of low stability. The DCP proved to be very effective at delineating the general nature of subgrade stability. It was found that about 50 percent of the DCP CI values in the upper 0.15 m (6 in.) of the subgrade along the alignment resulted in computed CBR values less than 15 percent, with many values falling in the 5 to 10 percent range, which indicates that stability under construction traffic would be questionable along a large portion of the alignment. Stabilization with fly ash was chosen to remedy this problem.

Recommendations

It was recommended that this section of the alignment be test rolled with a minimum of two complete coverages of a heavy pneumatic tired roller. The roller was to be loaded with

enough ballast to obtain a load of not less than 44.5 kN (10,000 lb) per wheel in accordance with Oklahoma DOT specifications. Areas that fail to perform adequately during test rolling are to be undercut and recompacted at the optimum moisture-density conditions or replaced with more suitable material. Furthermore, it was recommended that the top 0.20 m (8 in.) of subgrade be treated by adding approximately 18 percent fly ash by weight.

Summary

This case history demonstrates that the DCP is an effective tool for rapidly assessing subgrade stability, leading to quick implementation of sound engineering solutions to improve subgrade stability. Oklahoma DOT is in the process of broadening the DCP-CBR and other DCP correlations for use with soils in pavement design and other applications such as the one presented here. This tool is simple to use and easy to interpret, and it can rapidly provide a great deal of information about the subgrade over significant portions of pavement alignments. For these reasons, it is believed that this device will probably be increasingly used by transportation agencies.

CASE 4: RECYCLED CONCRETE FINES FOR IMPROVING WET SUBGRADES

North Dakota has gained considerable experience with recycling PCC pavements since it started to do so in 1983. This case history describes an innovative use of recycled crushed concrete fines for improving subgrade stability. This case history was extracted from *TRB Synthesis 154: Recycling of Portland Cement Concrete Pavements*. The information presented (86) was condensed from three recycling projects, two on I-94 and one on I-29.

Stabilization with Recycled Concrete Fines Aggregate

On each of the three aforementioned projects, either a plain jointed concrete or a continuously reinforced concrete pavement existed. The concrete pavements were broken with whip hammers, diesel-driven hammers, and resonant pavement breakers. Broken concrete was then passed through a crushing plant and screened so that the coarse aggregate was nominally in the range of 4.75 mm (#4 sieve) to 25.4 mm (1 in.) and the fine aggregate was less than 4.75 mm. About 1.5 percent to 3 percent of material passing the #200 sieve was produced by crushing; therefore, aggregate was washed to remove most of this crusher dust. The crusher plant converted about 60 percent to 65 percent of the broken concrete into coarse aggregate and 35 percent to 40 percent into fine aggregate. The fine aggregate was found to hinder mixing of fresh concrete because it increased water demand significantly, making it difficult to control the water-cement ratio. Furthermore, because the recycled fines were angular, their presence in the mix made finishing

difficult. On the other hand, these same properties made the concrete fines ideal for improving subgrade stability. And presumably there was a significant amount of these fines available, considering that about 35 percent of the recycled pavements, whose lengths ranged from 17.2 km (10.7 mi) to 21.2 km (13.2 mi) and whose thicknesses ranged from 0.20 m (8 in.) to 0.30 m (10 in.), ended up as fines.

When the pavement was removed on each of the three projects, the subgrade was found to be wet. At two sites, after removal of the aggregate subbase, the subgrade was scarified with a disk harrow, and concrete fines were mixed in to facilitate the drying process. Depths of scarification were between 0.15 m (6 in.) and 0.61 m (24 in.). After mixing with the concrete fine aggregate, the subgrade soils were recompact to 90 percent of maximum dry density (based on AASHTO T 180). Existing aggregate base that had been removed and windrowed also was mixed with recycled concrete fines and compacted to provide 4 in. of stable aggregate base. At the third site, a heavy clay-type soil was encountered and treated by disking and mixing with 3 percent each of fly ash and lime, by weight. The treated subbase was on the order of 0.15 m (0.6 in.) in thickness, but in certain areas, 1 m (3 ft) or more had to be treated to stabilize the clayey soils. A 0.13-m (5-in.) thick compacted layer of crushed recycled asphalt concrete mixed with 35 percent PCC fines by weight was placed above this treated subbase. This resulted in a stable paving surface.

Summary

North Dakota's experience indicates that recycling of PCC pavements is an economic rehabilitation option. The crushed concrete fines (percent finer than #4 sieve) were found to be unsatisfactory for mixing in new concrete because their high water-absorption potential and angularity adversely influence the water-cement ratio and the finishing properties of the mix, respectively. However, the fines were very effective in drying and stabilizing wet subgrades. In addition, when mixed with asphalt concrete and compacted, the resulting layer was found to set up very well, providing an excellent paving surface. This case history shows how an otherwise useless, but plentiful, product can be incorporated into a reconstructed pavement to improve subgrade stability and create a stable paving surface.

CASE 5: AUSTRALIAN EXPERIENCE WITH DEEP IN SITU CEMENT STABILIZATION

This case history is based on a paper (68) published in the proceedings of a 1994 conference sponsored by the Australian Road Research Board. Although the construction practices discussed may be more complementary to Australian road building practices, the technology has great promise for simultaneous, composite subgrade stabilization and base course construction on roadways everywhere.

The Scenario

A 6-km (3.7-mi) trial section of the national highway network, on Sturt Highway, in Australia was recycled using a deep cement stabilization process. Extensive characterization of the existing pavement and subgrade materials was accomplished using state-of-the-art field and laboratory testing methods, including dynamic cone penetration (DCP) and friction cone penetration tests and resilient modulus testing. Extensive postconstruction evaluations, including deflectograph and FWD measurements, were initiated.

Existing Pavement Profile

The existing pavement structure consisted of slightly more than 25 mm (1 in.) of a bituminous layer, below which was about 230 mm (9 in.) of poorly graded natural gravel. A red-brown clay silt or light brown calcareous clay silt subgrade of low plasticity extended from a depth of 250 mm (10 in.) to about 0.75 m (2.5 ft). Below this was a hard and dry silty clay material. Subgrade layers were determined to have CBR values of 8 to 10 based on cone penetration test results. On the basis of resilient modulus and other modulus testing, a subgrade modulus value of 80 MPa (835 tsf) was estimated. This value is consistent with CBR values determined using DCP test correlations.

Recycled Pavement Design

Composite samples of the existing pavement structure were obtained by augering to a depth of about 0.41 m (16 in.). Composite samples were well graded and contained about 10 percent fines and 50 to 60 percent gravel. The plasticity index ranged from 4 to 9 percent. The optimum moisture content and maximum dry density were determined, and resilient modulus and unconfined compression tests were performed on samples compacted to 95 percent of the maximum dry density to determine an appropriate cement content. A blended cement (80 percent portland cement, 20 percent fly ash) content of 3 percent was tried initially, but 4 percent was decided on based on unconfined compression test results. Because the subgrade investigation was conducted in the summer, a subgrade modulus value of 50 MPa (522 tsf) was used for design to allow for seasonal wetting. Mechanistic analyses using upper and lower bound solution models gave a range of recycled pavement depth of 0.35 m (13.8 in.) to 0.38 m (14.8 in.).

Construction

Recycling was accomplished using a CMI RS500 recycling machine. Mixing to a depth of about 0.38 m (15 in.) was accomplished in a single pass. The recycler was equipped with computer-controlled spreaders with a capacity of 365 kN (41 tons), and the cement binder was applied at a rate of 29 kg/m² (58 lb/yd²). Compaction was accomplished using six passes of

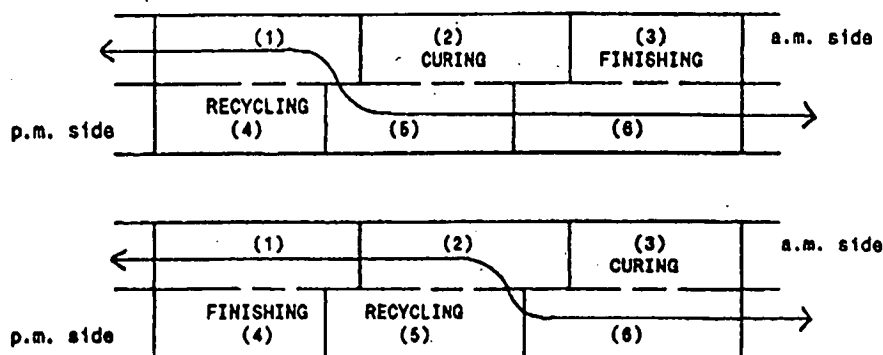


FIGURE 10 Proposed traffic control and construction sequence to maximize curing time (71).

a 147-kN (16.5-ton) vibrating padfoot roller immediately behind the recycler. The surface was graded to below the level of the padfoot imprints, rolled with two passes of an 107-kN (12-ton) vibrating smooth drum, and, following final trim, was subjected to a 156-kN (17.5-ton) multitired roller to achieve surface tightness. Following recycling, a lane was immediately opened to traffic; however, because of raveling that occurred under heavy freight vehicles, it was determined that a 4- to 6-hour curing period was desirable. The construction and traffic control sequence proposed to maximize curing time is shown in Figure 10 as a system of staggered lots.

Postconstruction Evaluation

The structural condition of the pavement was evaluated after 1 month using FWD and deflectograph testing. Deflections measured with a Lacroix deflectograph were well below the 20-year design deflection of about 0.89 mm (0.035 in.). The average deflection over the test section was about 0.066 mm (0.0026 in.), with a rare spike in the deflectograph reaching as high as 0.216 mm (0.0085 in.). These results indicated a marked improvement over preconstruction pavement riding quality. One-month FWD tests resulted in small deflections, thus indicating a stiff, competent pavement structure. In addition, FWD tests were performed at various times after construction, immediately following compaction, and after elapsed times of 1, 7, and 16 days. During the first 24 hours, pavement stiffness increased nearly one order of magnitude, from

roughly 958 MPa (10,000 tsf) to 9,580 MPa (100,000 tsf). On average, 7-day stiffness values were nearly another order of magnitude higher, and 16-day stiffness values were similar to the 7-day values.

Summary

The project was considered successful, and an additional 71 lane-km (44 lane-mi) on the national highway network were slated for similar recycling at the time. Costs for deep recycling were nearly one-third the cost of the next best alternative, which was to use a granular overlay.

During pavement reconstruction on U.S. interstates, deep cement stabilization technology could be implemented to reduce offsite material demands and provide a stable working platform for construction traffic. The Australian experience demonstrates that with a short curing period, deep cement stabilization can be used to recycle existing aggregate layers and to incorporate subgrade soil to create a thickened subbase capable of sustaining heavy construction loading. Although this technology looks very promising, its potential for successful implementation during reconstruction must be evaluated on a site-specific basis. Most important, consideration must be given to ambient soil and weather conditions, as with all soil stabilization design scenarios. Two crucial aspects of the soil must be evaluated: (1) the degree to which the soil will react with the cement and (2) whether sulfates, which reduce the benefits of cement stabilization, are present.

CONCLUSIONS

Many pavements in the United States and abroad are being rehabilitated because of the condition of the highway infrastructure. As rehabilitative activities increase, complete reconstruction, as opposed to building up existing pavement, is becoming prevalent. Reconstruction of pavements poses considerably greater challenges to engineers because severe space limitations within the reconstruction corridor often create a need to use the subgrade to carry construction traffic. The goal of this synthesis study was to identify the state of the practice in subgrade evaluation and stabilization during pavement reconstruction. Several conclusions regarding the state of the practice were developed based on a review of the literature and questionnaire responses from various transportation agencies.

- A literature review revealed very few published articles that specifically address the problem of subgrade stabilization during reconstruction. This may be partly attributed to the fact that the preferred rehabilitation alternative is to build upon the existing pavement whenever possible; therefore, complete reconstruction is relatively rare. In addition, preserving subgrade integrity often involves on-the-job decisions, which are frequently the responsibility of the contractor. For these reasons, the technical literature lacks this type of information.

- For reconstruction projects, transportation agencies usually employ subgrade specifications written for new pavement construction. These often are end-product specifications that place the responsibility for maintaining subgrade integrity with the contractor.

- Conventional methods of subgrade evaluation and stabilization used for new construction typically are used during reconstruction, with the exception that nondestructive methods of subgrade evaluation are sometimes employed over existing pavements.

- Conventional subgrade soil sampling and laboratory testing are an important part of the reconstruction evaluation process, particularly in determining the existing moisture content and moisture susceptibility of the subgrade.

- Nondestructive in situ methods are related to pavement condition analyses, such as those conducted with the FWD, which measures overall distress at the surface. Some analytical procedures following the use of an in situ test method, such as Dynaflect, are suggested to single out subgrade support when deflection basin measurements are made. However, because of a lack of acceptance, these procedures appear to be experimental. Therefore, the portion of distress attributed to or emanating from the subgrade becomes a matter of judgment, as is a realistic determination of the improvement required by the subgrade.

- Numerous penetration test methods, including the dynamic cone penetrometer (DCP), dilatometer, and electric cone penetrometer, are available for providing rapid assessment of

subgrade conditions. The DCP is an excellent tool for this purpose and probably will increase in popularity.

- Undercutting and replacing weak subgrade soil with better or select material is often done when subgrade stabilization is necessary.

- Chemical modification of subgrade soils with lime is a common practice for drying out and improving wet subgrade soils. Portland cement and fly ash are used to lesser degrees for subgrade improvement. Deep in situ cement stabilization shows promise as a reconstruction technique for simultaneously producing a stable subgrade and pavement base course.

- The use of geosynthetics, particularly geotextiles and geogrids, in combination with select materials is becoming more widespread as a cost-effective means to create a stable construction platform over the subgrade.

- Recycling of existing pavements and use of recycled materials from other sources are viable options in pavement reconstruction. Examples include the use of recycled PCC pavement as base course aggregate and fine aggregate for drying out wet subgrade soils and the use of industrial ashes, such as fly ash or kiln dusts from lime and cement manufacturing plants, as chemical additives.

- The prescribed use of lightweight vehicles for subgrade preservation is rare among transportation agencies, and the use of robotics for this purpose appears to be nonexistent.

- Evaluation of moisture conditions and assessment and improvement of drainage systems are recognized as important parts of the reconstruction process.

A number of important issues pertaining to the evaluation and treatment of the subgrade must be considered when designing a reconstructed pavement. It is extremely important to properly evaluate the existing subgrade, not only regarding its structural function in the new pavement, but also regarding how well it will perform under construction traffic. Following are some suggestions that may be considered.

- A proper investigation of subgrade soils should include sampling of subgrade soil materials along the alignment at intervals and to depths consistent with the geology of the area. Typical ranges for these sampling parameters being used in practice are listed in chapter 3.

- If subgrade stability is in question, the in situ moisture content of existing subgrade soils must be determined and compared with the optimum moisture conditions determined from moisture-density testing. Excessive moisture is the main cause of subgrade instability and may be the single most important parameter for evaluating subgrade stabilization options. For example, if space or climatic limitations along the reconstruction corridor prevent proper drying and recompaction of existing soils, an alternative, and often more costly,

method may have to be used. Anticipating these situations can prevent unexpected delays and cost overruns.

- If subgrade stability is a possible concern, a proper laboratory testing protocol should be followed. This should include, in addition to in situ moisture content determination, the following: index property testing, evaluation of moisture-density relationships, and testing to evaluate subgrade integrity under adverse moisture conditions. If chemical stabilization is considered, testing should be performed to determine the soil and additive compatibility and the optimum additive content.

- Where chemical stabilization is considered, attention to curing and mixing requirements is necessary to avoid unanticipated time delays.

- Certain soil parameters should be considered as indicators that a subgrade stability problem may occur during pavement reconstruction. Soils with excessive fines or poorly graded soils that contain excessive moisture or that are susceptible to precipitation should be considered candidates for possible problems during reconstruction. Soils containing significant fines and those with in situ water contents 1.5 percent or more above the optimum moisture content, determined from compaction testing, should be evaluated for stability. Moisture-susceptible soils with CBR values below 7 should be considered suspect. Dry sands also may be problematic.

- The DCP deserves further attention because it is fast and easy to use and provides reliable estimates of CBR. The DCP is uniquely suited to investigating the top 1 m of a soil profile.

- Evaluation and refurbishing of existing drainage systems should continue to be a normal part of the pavement reconstruction process. In addition, construction practices that promote drainage away from the subgrade should be incorporated if precipitation is likely. These practices include maintaining appropriate cross slopes or crowning subgrade soils (5 percent slope is often used in Europe), sealing the subgrade to promote runoff, and using diversion ditches to direct water away from the roadway.

- Recycling of existing pavement materials usually is considered for rehabilitation projects. Methods of recycling and the materials produced should be evaluated in terms of space availability, climatic limitations, compatibility with

subgrade preservation, and structural demands of the pavement design.

- Space limitations along the reconstruction corridor should be carefully considered when planning construction traffic sequencing and planning for subgrade stabilization alternatives. If sufficient space is not available to minimize construction traffic over the exposed subgrade, a stabilization or preservation contingency should be developed, especially for fine-grained soils.

- If subgrade stability is questionable but space permits, provisions should be made to limit construction traffic on the subgrade. For example, a temporary haul road or sequencing to minimize traffic could be used on the exposed subgrade soil.

- In weighing subgrade stabilization alternatives, the use of geosynthetic reinforcement, such as geogrids and geotextiles, should be considered for reducing the amount of excavating and replacing unsuitable materials. In comparing the costs for these two alternatives, careful consideration should be given to the availability of suitable recycled onsite fill materials and the cost of importing additional fill. As highlighted in chapter 4, when fill requirements become excessive, the cost benefits of geosynthetics should be seriously considered.

- The Australian experience demonstrates that deep in situ cement stabilization may be a cost-effective alternative for pavement rehabilitation. If the equipment and technology exists, this option should be considered.

- The use of lightweight vehicles should be considered as a subgrade preservation alternative during reconstruction.

- Research should be conducted to assess the viability of innovative technologies, such as the use of robotics in highway reconstruction, for two reasons: (1) to minimize the impact of construction activities on the exposed subgrade and (2) to develop standardized approaches for predicting and designing for the stability of subgrades under excessive construction traffic.

- Engineers and contractors are encouraged to publish their pavement reconstruction experiences, particularly experiences with innovative methods of subgrade evaluation and preservation during reconstruction.

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GLOSSARY

aggregate interlock—A load transfer mechanism whereby the shear is carried by the aggregate-aggregate interface.

break and seat—The breaking up of Portland cement concrete pavement and the seating of it in the base/subbase/subgrade with heavy rollers.

California bearing ratio (CBR)—A comparative measure of the shearing resistance of soil and aggregates.

cone penetrometer—A device by which a cone is continuously pushed into the soil and the resistance to penetration is measured.

deflections—Vertical deformation of a pavement under an applied load.

dilatometer—A flat-blade, full-displacement penetrometer with an inflatable steel diaphragm used for measuring the lateral response of soil to loading.

equivalent layer thickness (ELT)—An analytical procedure used in the rehabilitation of pavements.

geosynthetics—Synthetic engineering fabrics or membranes (geogrids, geomembranes, and geotextiles) used for the separation, filtration, drainage, and reinforcement of earth materials.

infiltration—The act of gaining access, as with water or incompressible solids, to portland cement concrete pavement joints.

k—Modulus of subgrade reaction calculated from plate bearing test data.

pocket penetrometer—A device that is pushed directly into the soil to measure the unconfined compressive strength by means of a calibrated spring.

rubblization—Crushing portland cement concrete pavement into granular form that can be used as aggregate material.

skewed joints—A variation of a transverse contraction joint often used in plain undoweled pavements and placed at an angle so that no two wheels of a vehicle traverse the joint simultaneously.

split-spoon sampling—A field sampling technique (ASTM D 1586) to obtain relatively undisturbed samples.

spreadability index—A factor that measures deflection of subgrade and surfacing materials under an applied load.

stabilization—A method of upgrading or improving standard soils.

stabilometer R value—Value that indicates the resistance of compacted materials to plastic deformation (Hveem stabilometer).

subbase—The foundation layer of soil immediately above the subgrade and consisting of imported soil or modified in-place soil.

subgrade—The in-place foundation layer of soil on which the pavement rests.

torevane—A shear vane device.

APPENDIX A

Questionnaire

National Cooperative Highway Research Program

NCHRP PROJECT 20-5
TOPIC 27-03

STABILIZATION OF EXISTING SUBGRADES DURING INTERSTATE PAVEMENT REHABILITATION TO IMPROVE CONSTRUCTIBILITY

DATE: _____

AGENCY RESPONDING:

Person: _____

Title: _____

Address: _____

PERSON TO WHOM QUESTIONS ABOUT THE RESPONSE SHOULD BE DIRECTED:

Name: _____

Title: _____

Phone: _____

PLEASE RETURN COMPLETED QUESTIONNAIRE AND ANY SUPPORTING DOCUMENTS TO:

(Mail) Dr. Joakim G. Laguros, PE
School of Civil Engineering & Environmental Science
University of Oklahoma
202 West Boyd Street, Room 334
Norman, OK 73019-0631
(Fax) (405) 325-4217

DIRECT TELEPHONE INQUIRIES TO:

Dr. Joakim G. Laguros, PE at (405) 325-4254 or

Dr. Gerald A. Miller at (405) 325-4253 or

if you like, leave a message with the main office
at (405) 325-5911

NOTE: For the purpose of this survey, the term "subgrade" refers to any soil materials under the pavement that are subject to stabilization during reconstruction. In the case of an existing improved soil subbase of exceptional quality, the issue of reuse or preservation during reconstruction is of importance and so "soil subgrade" carries the same connotation as "soil subbase" in this questionnaire.

NCHRP Synthesis Topic 27-03 Questionnaire

Agency Reporting: _____

INTRODUCTION

The objective of this synthesis is to summarize information about subgrade stabilization during interstate pavement rehabilitation to improve constructibility. During rehabilitation of an existing Interstate highway, it is often necessary to completely remove all or a portion of the pavement down to the subgrade. Many of these subgrades are structurally sufficient when exposed and new pavement structures can be adequately designed for their existing condition. However, a constructibility problem often occurs when the contractor runs heavy construction equipment over the subgrade as a haul road leading to rutting and failure.

Many methods have been used to stabilize subgrades for construction traffic. The most common method has been to undercut and remove the clayey soils and replace them with granular borrow. Other methods incorporate the use of geosynthetics and lime, cement, or fly ash additives to stabilize the subgrade soils. Limiting the amount of construction traffic on the subgrade by specific sequencing of construction operations and using relatively lightweight construction equipment can also be effective.

PART 1 DESIGN STANDARDS ADDRESSING SUBGRADE EVALUATION AND PREPARATION DURING HIGHWAY RECONSTRUCTION

Please provide copies of currently employed testing and design standards pertaining to subgrade evaluation and preparation for pavement reconstruction. Please highlight sections, if any, that address the effect of construction traffic on the subgrade and sections that address evaluation of existing pavement drainage systems. Also, please include documentation, if any, that provides specifications, guidelines or provisions regarding construction traffic on highway subgrade soils.

Please check the following documentation that applies:

Subgrade Evaluation Standards (i.e. sampling, field and laboratory testing), Attached _____ []

Subgrade Design Standards, Attached _____ []

Construction Traffic Specifications, Guidelines or Provisions Pertaining to the Subgrade, Attached _____ []

PART 2 SUBGRADE PROBLEMS ENCOUNTERED AND SOLUTIONS EMPLOYED DURING HIGHWAY RECONSTRUCTION

Describe specific problems and the solutions employed pertaining to subgrade evaluation and preparation for pavement reconstruction. Comment on how the effect of construction traffic on the subgrade is addressed and how pavement subdrainage is handled. Also, discuss any quality control/quality assurance procedures that may apply. Please attach additional sheets as necessary. Any relevant reports you can furnish will be appreciated.

Agency Reporting: _____

PART 2 (CONTINUED)

Please check the following that apply:

No subgrade problems have been identified during highway reconstruction _____ []

Supporting reports are attached _____ []

PART 3 HIGHWAY RECONSTRUCTION SUBGRADE DESIGN PHILOSOPHY

Please check those that apply:

1. Prior to highway reconstruction, having determined that an existing subgrade is suitable to support a new pavement structure, our agency attempts to preserve the subgrade integrity during construction by:

- (a) limiting construction traffic on the exposed subgrade _____ []
 (b) planning for a subgrade stabilization scheme to address construction traffic _____ []
 (c) requiring the use of lightweight construction equipment _____ []
 (d) all of the above _____ []

2. Our agency has a standard protocol for evaluating an existing subgrade and the methodology involves:

- (a) historical assessment of the subgrade performance prior to reconstruction _____ []
 (b) field testing (e.g. ground penetrating radar, falling weight deflectometer, etc.) prior to reconstruction _____ []
 (c) laboratory testing on subgrade samples prior to reconstruction _____ []
 (d) all of the above _____ []

3. Our agency relies *partly/mainly* (circle one) on incumbent practitioner protocols in lieu of agency protocols for evaluating existing subgrades and potential improvement methods for pavement reconstruction. Please comment _____

4. Our agency employs end-product specifications that give the contractor the burden of ensuring adequate subgrade properties prior to repaving:

(a) yes [] (b) no []

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PART 3 (CONTINUED)

5. Evaluating, refurbishing and/or rebuilding of pavement drainage systems is an integral part of our design protocol for highway reconstruction and most often includes:

- (a) integrity testing on the existing drainage system _____ []
 (b) inspection and cleaning of the existing drainage system _____ []
 (c) complete replacement of the existing drainage system _____ []
 (d) installation of pavement edge drains _____ []
 (e) use of an open-graded base course _____ []
 (f) use of geosynthetics for filtration and drainage _____ []
 (g) all of the above _____ []

6. Please comment on your agencies approach to evaluating the cost effectiveness of various alternatives for subgrade improvement during pavement reconstruction; especially with regard to balancing pavement performance with the costs associated with design and construction. _____

7. Please provide other comments pertaining to your organization's design philosophy about subgrade evaluation and preparation for pavement reconstruction (please attach supporting documentation if available). _____

Supporting documents attached _____ []

PART 4 SUBGRADE EVALUATION METHODS FOR HIGHWAY RECONSTRUCTION

1. Subgrade Soil Sampling Methods

1. Of the following, please check those that are included in your organization's subgrade sampling protocol for highway rehabilitation projects and list the AASHTO, ASTM or other standard that is followed.

- | | |
|---|-----------------|
| (a) Pavement Coring _____ [] | Standard: _____ |
| (b) Test Borings _____ [] | Standard: _____ |
| (c) "Undisturbed" Tube Sampling _____ [] | Standard: _____ |
| (d) Split-Spoon Sampling _____ [] | Standard: _____ |
| (e) Test Pits _____ [] | Standard: _____ |
| (f) Other (Specify) _____ [] | Standard: _____ |

2. For each method employed, please indicate the general frequency of sampling along the highway alignment (e.g., one undisturbed sample per 1000 feet of highway at the centerline). _____

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PART 4 I. Subgrade Soil Sampling Methods (CONTINUED)

3. For each method employed, please indicate the general depth of sampling (e.g., undisturbed samples are typically continuous from top of subgrade to 3 feet below). _____

4. Please indicate the time of year preferred for obtaining soil subgrade samples and the reason for this preference. _____

5. Please provide any additional comments and supporting documentation pertaining to your organization's protocol for soil sampling for subgrade evaluation prior to highway reconstruction. _____

Supporting documents attached _____ []

II. Laboratory Testing of Subgrade Soils

1. Please list all laboratory tests that are part of your organization's testing protocol for subgrade soil evaluation prior to pavement reconstruction. Indicate the AASHTO, ASTM or other specification followed. Also, indicate the conditions necessary, if any, surrounding the use or exclusion of a particular test.

TEST TYPE	USAGE (ALWAYS, SOMETIMES)	APPLICABLE STANDARD	COMMENTS

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PART 4 II. Laboratory Testing of Subgrade Soils (CONTINUED)

2. Please discuss whether or not, and how seasonal variations of subgrade properties are addressed through laboratory testing. _____

3. Does your organization's testing protocol specify a minimal acceptance criteria, i.e. CBR > 5? _____

III. Field Testing

1. Please list all field tests (e.g., falling weight deflectometer, cone penetrometer, etc.) that are part of your organization's testing protocol for subgrade soil evaluation prior to pavement reconstruction. Indicate the AASHTO, ASTM or other specification followed. Also, indicate the conditions necessary, if any, surrounding the use or exclusion of a particular test.

TEST TYPE	USAGE (ALWAYS, SOMETIMES)	APPLICABLE STANDARD	COMMENTS

2. If applicable, please elaborate on your organization's use of nondestructive testing techniques such as Ground Penetrating Radar (GPR), seismic testing, and sonic testing for evaluating the subgrade condition. For example, the use of GPR for identifying pockets of high subgrade moisture. _____

PART 5 STABILIZATION OF WEAK SUBGRADES

1. If your organization utilizes recycled materials for subgrade stabilization during highway reconstruction, please describe the material and how it is used. Examples include Recycled Asphalt Pavement (RAP), ceramics, rubberization, fly ash, kiln dust, etc. _____

Agency Reporting: _____

PART 5 (CONTINUED)

2. If your organization utilizes geosynthetics for subgrade stabilization during highway reconstruction, please describe the type and properties of the geosynthetic and its use. Examples of geosynthetics include woven and nonwoven geotextiles, geogrids, etc. _____

3. Describe any other approaches your organization uses for subgrade stabilization during highway reconstruction including traditional approaches such as lime stabilization. Please provide supporting documentation if necessary. _____

Supporting documents attached _____ []

PART 6 PAVEMENT DRAINAGE

1. Please describe your organization's evaluation protocol for determining the viability of existing pavement subdrainage systems, during highway reconstruction. _____

2. Describe the major aspects of subdrainage design that your organization addresses for pavement reconstruction projects. Mention the design methods employed and provide supporting documents that may be helpful. _____

Supporting documents attached _____ []

PART 7 CONSTRUCTION METHODS FOR MAINTAINING SUBGRADE INTEGRITY

1. Please describe any innovative construction sequencing practices that your organization employs to reduce the traffic on the soil subgrade during pavement reconstruction. _____

Agency Reporting: _____

PART 7 (CONTINUED)

2. Please describe your organization's construction practices concerning the use of special construction equipment (such as lightweight vehicles and robotics) for reducing the impacts of construction traffic on the subgrade during pavement reconstruction. _____

3. Please describe other maintenance practices that your organization employs to preserve the soil subgrade during pavement reconstruction, such as subgrade crowning to reduce infiltration. _____

Please provide any supporting documentation that you think may be helpful to us in analyzing this questionnaire.

Supporting documents attached _____ []

THANK YOU FOR YOUR TIME AND EFFORT!**We would appreciate your response by May 31, 1996.**

APPENDIX B

Summarized Responses to Questionnaire

TABLE A-1**Part 1 Design Standards Addresssing Subgrade Evaluation and Preparation**

Respondent	Subgrade evaluation standards	Subgrade design standards	Construction traffic specs, guidelines or provisions
Arizona	Y	Y	
California	Y	Y	Y
Hawaii	AASHTO T-190. Evaluation of the soils report for the original construction on project is adequate for reconstruction projects.		
Idaho	Y		
Illinois		Mechanistic Pavement Design	
Indiana	Y	Y	Y
Maine	Y	Y	
Maryland	Y	Y	Y
Massachusetts	Y		
Missouri	Y	Y	Y
New Hampshire	No questionnaire but attached document		
New Mexico	Material Investigation Guidelines Sec 207 Subgrade preparation	Design R Value computation Data sheet with tests on surfacing	
New York			Y
Oklahoma	Y		
Pennsylvania	Y		
South Carolina	Does not use reconstruction as a rehabilitation alternative		
Washington			Y
West Virginia	Attachment I		
British Columbia	Nothing on questionnaire but only the executive summary.		
Manitoba	Y	Y	
Ontario			Y
Quebec	Y	Y	
Saskatchewan	Y	Y	Y

TABLE A-2

Part 2 Subgrade Problems Encountered and Solutions Employed

Respondent	1. Problems and solutions employed
Arizona	Poor soils - overexcavated or use geogrid; Expansive soils - water proof membrane. Construction traffic not restricted.
California	Reconstruction is only used when dictated by grade change, realignment, vertical controls or structural requirements in excess of those provided by a rehabilitation strategy. Soft or wet subgrade is removed and replaced, lime treated, placed with subgrade enhancement fabric or grids and by incorporating positive drainage.
Connecticut	Remove and replace most of poor subgrade soils to counterbalance the effects of construction traffic. Underdrains are used to provide pavement subdrainage.
Florida	No evaluation specific to maintenance of construction traffic is performed.
Illinois	See attached sheet
Indiana	Wet subgrade soils, subgrade soils with low CBR, organic/ compressible matter. See documents attached.
Kansas	Investigations are based on sampling techniques that are limited in number of sites investigated due to cost or practical consideration, i.e., cannot perforate pavement with core holes. Spot treatment - time consuming
Louisiana	The construction traffic is handled by specified working table (subgrade layer) to which no structural value is given. No specific drainage is provided for subgrade during construction but may be by the way of permeable base.
Maine	Dry conditions (any layer) - water application or CaCl ₂ . Subgrade drainage by ditching or underdrain installation
Michigan	Very few subgrade problems. The pavement is inspected during project design to identify probable subgrade induced distresses that are subsequently investigated during construction. No existing drainage systems that require investigation. Areas damaged by construction equipment are undercut and backfilled with granular material.
Minnesota	Many Interstate roadways were constructed over plastic soils (A6, A7). Problems encountered upon removal of the existing pavement structure. The underlying subgrade soils were generally poor and recompacted. Reworked and dried to meet density requirement (AASHTO 99) for high moisture soil. This can be difficult if the weather is wet. To facilitate reconstruction (1) unbonded concrete overlays were initiated so as to avoid construction in and over the subgrade soils, (2) In those areas where unbonded overlay is not feasible, the pavement structure must be removed and replaced. The subgrade soils are removed and replaced with a layer of granular soils (< 12% passing #200).
Missouri	For reconstruction projects the existing pavement is evaluated to determine if it can be incorporated as part of new pavement. If total reconstruction is the chosen alternative the pavement is designed the same way as a new corridor using current design standards and no existing pavement is incorporated into the new facility.
Nebraska	Design for base material will be the same as the original design. In silt-clay soil sections the subgrades will have granular foundation course. In the granular soil sections, embankments are stabilized in the upper 6 in. of the embankment. Existing subgrades are always scarified, mixed and recompacted as a pay item. Special provisions provide for side-placement methods, to limit traffic on foundation course constructed of asphalt millings, to prevent over compaction and restriction of internal drainage. Subdrainage is provided by policy based on subgrade plasticity index. 15<PI<30 = granular subdrains, 200 -250 ft. intervals. PI>30 or PI=30 use perforated pipe in trench.
Nevada	Encounter soft, high water content, frost and salt heave susceptible, expansive and collapsible subgrade. Build construction platform by use of fabric and granular and raw material. Overexcavate and place with new material. Use lime treatment, use moisture barrier geotextiles. Recommend use of light weight vehicles.
New Mexico	On a reconstruction project the traffic is usually placed on a surfaced detour. Any subgrade soft spots encountered with construction equipment are subexcavated and replaced with design r-value material.
New York	see attached memo
North Carolina	see attached
North Dakota	Subgrade recommendations based on soil samples. Subcut sections adjusted in the field. Quality control not a factor
Oklahoma	High PI soils (PI>30) are usually lime treated. Non plastic soils (sand) are usually flyash treated. High type facilities often use an open graded drainage layer. The lab recommends locations if pipe underdrains are needed. Wet subgrade uncovered in rehab construction is addressed in ODOT Std Constr Spec a)Subgrade Method 'B' Subsection 310, b)Undercut and replace with approved material Subsection 202, c)Proof Rolling Subsection 203

TABLE A-2**Part 2 Subgrade Problems Encountered and Solutions Employed**

Respondent	1. Problems and solutions employed.
Oregon	Problems in many areas. Subexcavating, installing geotextile and granular subbase material. Little is done with subdrainage unless there is a specific water source to deal with.
Pennsylvania*	Construction traffic, drainage.
Rhode Island	High water table, frost heaves. Low occurrences of clay type soils, organic peats, etc., leave the area with generally granular soils. Construction traffic is not of great concern to subgrade. Layers of compressible materials (peats etc.) are removed as they usually do not extend to significant depths. Silty soils may alter the design. Soil stabilization not necessary and has not been performed.
Texas	Provide thicker unbonded PCC pavement above weak / wet subgrade.
Vermont	Pavements are designed for frost, so base and subbase thicknesses are generally great enough that any future reconstruction activities would not necessitate traffic placement on subgrade. Poor subgrades are compensated for by using additional sand borrow, underdrain or subbase.
Virginia*	In localized areas where subgrade stabilization is required to provide suitable construction platform, the addition of portland cement to subgrade soil in 10% by volume is employed. Total reconstruction is rare. Existing subgrade is adequate to support construction traffic without appreciable damage. Very poor or very wet subgrade is removed and replaced with granular material. Rehabilitation of subsurface drainage system involves placing perforated PVC pipe along pavement edges or shoulders and backfilled with an open-graded stone. FWD is used to characterize subgrade condition. Soil test borings for subgrade support conditions.
Washington	Undesirable subgrade is removed. If undesirable material is excessive, remove material to 2 - 3 ft, place a geotextile and good quality material. Reconstruction is seldom. Have only reconstructed PCCP. Most ACP rehabilitation is overlays.
Wisconsin	Subgrades are evaluated during design phase for stability deficiencies and need for corrective action. Open graded bases are used for high volume highways. Hauling on open graded bases is limited. Require contractor to provide haul road.
Wyoming	Drill holes with continuous sampling and shelly tubes are used to sample subgrade. An estimate of whether subexcavation and geotextile or edge drains are necessary to stabilize soft soils is based on type of soils, in-situ moisture, unconfined tests, vane shear tests, SPT's and CPT. Prediction of whether subexcavation of soft soils will be necessary is difficult, since soils may be dry and stiff during the investigation, but become soft when surfacing is removed and soils become wet during spring. Field inspectors may also remove soils that are stable. Often, if surfacing is removed, inspectors will subexcavate 0.6 m or more. If heavy construction equipment can be kept on the exposed subgrade, this can be eliminated.
Alberta	No pavement subdrainage used other than granular crushed base course or uncrushed granular fill (pit run).
Manitoba	Localized frost susceptible soils, high ground water table and high organic contents. Traffic is maintained by gravelling the top of subgrade and drying up the surface. Density is checked to ensure it meets specs. Allowance is made in the design to address the above mentioned issues. Lime was used occasionally to dry up the surface.
Newfoundland	Weak/wet subgrades are excavated and replaced with adequate material, e.g., 0.5 to 1.0 m thickness of quarried rock.
Nova Scotia	Undercut and replace with granular material where there is rutting. Separators (geotextiles) are used where clays are encountered to separate gravels from underlying clay material. Size of loads are limited if severe overstressing is encountered. Proof rolling when there is indication of overstressing.
Ontario	Subgrade condition is determined from historical data and soil sampling by a soil investigation crew which selects and submits samples for testing. Testing can include gradation, moisture content, Atterberg limits, Proctor moisture and density. In extreme cases and where embankments are to be constructed further sampling and testing is carried out to determine the in-situ undrained shear strength, the sensitivity rating using field vane tests and lab vane tests on disturbed and undisturbed samples, the stability & compressibility as well as denseness using Standard Penetration Test. In sensitive areas contractor may be instructed to back dump and grade to a specific depth prior to any equipment running over the sections. Geotextile, drainage and/or hydrated lime have also been used.
Quebec	On very soft subgrade (soil classified MH, CH, or high water content): traffic prohibited, use of geotextile, first layer of sand very thick (600 mm minimum) allowing traffic to circulate, cross slope required as soon as possible on top of subgrade.

* Documents attached

TABLE A-3
Part 3 Highway Reconstruction Subgrade Design Philosophy

Respondent	1. To preserve subgrade integrity by				2. Standard protocol for evaluating existing subgrade			
	a. limit traffic on exposed subgrade	b. subgrade stabilization	c. lightweight equipment	d. Others	historical field assessment	lab testing	All	
Arizona	Y				Y	Y	Y	
Arkansas						Y	Y	
California	Y	Y	Y			Y	Y	
Connecticut		Y			Y			
Florida	Y							
Hawaii					Y			
Idaho			Y			Y	Y	
Illinois	Y	Y			Y	Y	Y	
Indiana	Y						Y	
Kansas		Y			Y			
Louisiana	Y					Y	Y	
Maine	Y				Y	Y	Y	
Maryland		Y			Y	Y	Y	
Massachusetts	Y				Y	Y	Y	
Michigan	Y	Y			Y	Y	Y	Y damaged areas must be constructed to requirement for new construction per std spec Y Visual
Minnesota	Y	Y			Y	Y	Y	
Missouri	Y	Y			Y	Y	Y	
Nebraska	Y	Y			Y	Y	Y	
Nevada					Y	Y	Y	
New Mexico	Y	Y	Y		Y	12 in. coring 2 ft into subgrade	Y	
New York	Y	Y	Y		Y	Y	Y	
North Carolina	Y	Y			Y	Y	Y	
North Dakota	Y	Y	Y		Y	Y	Y	
Oklahoma	Y	Y			Y	Y	Y	
Oregon	Y	Y			Y	Y	Y	
Pennsylvania	Y				Y	Y	Y	
Rhode Island					Y	Y	Y	
Texas	Y	Y			Y	Y	Y	
Vermont					Y	Y	Y	
Virginia	Y	Y						
Washington					Y	Y	Y	
West Virginia	Y				Y	Y	Y	
Wisconsin	Y	Y			Y	Y	Y	
Wyoming	Y	Y	Y		Y	Y	Y	
Alberta	Y				Y	Y	Y	
Manitoba					Y	Y	Y	
Newfoundland	Y				Y			
Nova Scotia	Y				Y	Benkelman beam, Dynaflect	Y	
Ontario					Y		Y	limit time subgrade is exposed
Quebec	Y		Y			Y	Y	
Saskatchewan	Y				Y	Y	Y	

Y = Yes

TABLE A-4**Part 3 Highway Reconstruction Subgrade Design Philosophy**

Respondent	3. Comment on incumbent practitioner protocols
Arizona	Mainly. Generally a consensus effort by Geotech, pavement design & district.
Arkansas	Partly
California	Partly. Non-standard strategies may be developed for special problem areas.
Connecticut	Mainly. Very few subgrades problem. CT Valley varved clays may be problematic.
Florida	Mainly. Contractor's responsibility to maintain the finished subgrade.
Hawaii	Mainly. Pavement designer reviews the original soils report of subgrade conditions
Illinois	Mainly
Indiana	Partly
Louisiana	Partly
Massachusetts	Partly
Michigan	Mainly. Responsibility of district soils engineers
Nevada	Partly. Depending on the engineer. Number and type of tests vary on different projects.
New Mexico	Partly. Reconstruction surfacing by pavement design unit
New York	Mainly. See memo
North Carolina	Question cannot be answered
North Dakota	Mainly. Engineer researches the project and analyzes the soil and other related items and makes a recommendation.
Oklahoma	A combination of protocols. Standardized test (ASTM), not tests developed here
Pennsylvania	Partly
Rhode Island	Partly. Engineers review and approve construction techniques input from contractors/consultants that are considered beneficial.
Texas	Partly
Vermont	Mainly. See above.
Virginia	Partly. Subgrade evaluation methodology varies from project to project.
Washington	Partly. Not many poor subgrades. Subgrade improvement is contractor's responsibility.
West Virginia	Partly
Wisconsin	Mainly. Assessment and improvements of subgrades are the responsibility of district soil engineers
Alberta	Partly. Proto-types in vicinity of the project based on performance
Manitoba	Partly
Newfoundland	Partly. Severity of problem and/or geographical area play a role in evaluation method.
Nova Scotia	Mainly. Project engineer provides on site assessment
Ontario	Partly
Quebec	Partly. Agency protocols but engineers must evaluate the situation and modify the method if necessary.
Saskatchewan	Partly

TABLE A-5
Part 3 Highway Reconstruction Subgrade Design Philosophy

Respondent	4: End product	
Arizona	No	
Arkansas	No	
California	Yes	Require 95% relative compaction of subgrade material.
Connecticut	No	
Florida	Yes	
Hawaii	No	
Idaho	No	
Illinois	No	
Indiana	Yes	
Kansas	No	
Louisiana	Yes & No	
Maine	No	
Maryland	Yes	
Massachusetts	No	
Michigan	Yes	
Minnesota	Yes	Specified Density (AASHTO T 99)
Missouri	Partially	Ultimate product is evaluated by profilometer which provides end product quality control.
Nebraska	No	
Nevada	No	
New Mexico	Yes	Subgrade has to meet design R value, moisture & density requirement.
New York	Yes & No	Proof rolling for uniform subgrade support. Embankments at contractor's expense. Cut subgrades at state's expense.
North Carolina	No	Would like to have
North Dakota	No	
Oklahoma	No	
Oregon	Yes	In areas which cannot be dried out, the agency bears the cost of stabilizing.
Pennsylvania		Contractor's responsibility for 0.15m (6 in) within subgrade.
Rhode Island	Yes	
Texas	No	
Vermont	Not yet	
Virginia	No	
Washington	Yes	
West Virginia	No	
Wisconsin	Yes	
Wyoming	No	
Alberta	No	
Manitoba	No	
Newfoundland	No	
Nova Scotia	No	
Ontario	No	
Quebec	No	
Saskatchewan	Yes	

TABLE A-6

Part 3 Highway Reconstruction Subgrade Design Philosophy

Respondent a. integrity testing b. inspection & cleaning c. complete replacement d. edge drain e. open-graded base course f. geosynthetic All

Respondent	a. integrity testing	b. inspection & cleaning	c. complete replacement	d. edge drain	e. open-graded base course	f. geosynthetic	All
Arizona							
Arkansas							
California*							
Connecticut							
Florida							
Hawaii							
Idaho							
Illinois							
Indiana							
Louisiana							
Maine							
Maryland							
Massachusetts							
Michigan							
Minnesota							
Missouri							
Nebraska							
Nevada							
New Mexico							
New York St							
North Carolina							
North Dakota							
Oklahoma							
Pennsylvania							
Texas							
Vermont							
Virginia							
Washington St							
West Virginia							
Wisconsin							
Wyoming							
Alberta							
Manitoba							
Newfoundland							
Nova Scotia							
Ontario							
Quebec							
Saskatchewan							

* only West Virginia and California use all six categories
Y = Yes

TABLE A-7**Part 3 Highway Reconstruction Subgrade Design Philosophy**

Respondent	6. Comments on cost effectiveness
Arizona	Geotextiles (geogrid, membranes & fabrics) because less costly than overexcavation or stabilization.
Arkansas	Various alternatives are considered. Pavement selection committee chooses project pavement section.
California	Strategies are compared based on construction costs with probable equivalent pavement service life.
Connecticut	Few soils problem. Subgrades improvement involves removal and replacement.
Florida	No comparative analysis .
Hawaii	Subgrade improvement not necessary. Reconstruction is removing the surface and all or portions of the base and installing a full depth pavement (generally)
Illinois *	Unless problems with excessive settlement or poor subgrade stability is anticipated, subgrade improvement is primarily related to construction expedience and not to the long term pavement performance.
Indiana	Recommend most economical alternative.
Kansas	Alternates must be cost effective. Some improvements are weighed against constructibility and returning roadway to traffic. Cost effective is difficult to determine in these cases.
Michigan	Fix what is obvious. No cost analysis.
Minnesota	Various pavement designs (concrete and bituminous) are evaluated relative to cost. Evaluations include open-graded base courses and granular lifts in upper portion of the subgrade.
Missouri	Cost evaluation on alternatives is incorporated into policies & design stds, not on project basis. Economical analysis on 2 ft rock base.
Nebraska	Past service and existing condition of grade.
Nevada	Not when subgrade problems are very small.
New Mexico	Life cost analysis for rehabilitation and reconstruction projects.
New York	Improve subgrades for construction equipment operation to give support for subbase & pavement in its design life.B89
North Carolina	Design based on 1972 AASHTO. Effect of subgrade stabilization (either lime or cement) given SN=1.0 toward total design SN. Use LCC to select between design alternates.
Oregon	Subgrade improvement is done generally only if required to support construction traffic.
Rhode Island	Subgrade improvement not necessary. If required, the cost of subgrade modification would be balanced against removal of existing subgrade and replacement with satisfactory material.
Texas	Lime in subgrade and base stabilization, not as a pavement layer.
Vermont	Subgrade improvement is rare except for drainage. Geotextiles in new construction to improve subgrade.

TABLE A-7**Part 3 Highway Reconstruction Subgrade Design Philosophy**

Respondent	6. Comments on cost effectiveness
Virginia	Requirements for subgrade improvement are reflected in life cycle cost analysis for each alternative. Benefits of improvements are estimated by designer in terms of reduced maintenance costs.
Washington	Drainage beneath concrete pavements is necessary. Usually remove or place geotextile and granular material on poor subgrades.
West Virginia	AASHTO Pavement Design (DARWIN software) for truck traffic loads 20 year life cycle. Cost evaluation on different types of pavement.
Wisconsin	Consider cost of alternatives. Major problems occur during the construction phase. Few subgrade problem.
Wyoming	Life cycle cost analysis-compare surfacing section required for existing subgrade and replacing top 2 ft of subgrade, includes haul & material costs.
Newfoundland	Excavate/replace is a required std improvement method. Std "off-the-shelf" pavement designs are used. Life-cycle costs are not examined.
Nova Scotia	No, except site specific assessments and designs .
Ontario	Life cycle costing, past performance.
Quebec	Lime stabilization to dry clay for reuse. Thick pavement (0.6 to 1.1 m) (including subbase, base and cement or bituminous course) on top of subgrade because of heaves (cold and wet climate). Improvement of subgrade is less cost effective with such thickness.
Saskatchewan	Subgrade improvement seldom an issue ; reconstruction is resurfacing. Intensive maintenance limit the need for major reconstruction.

* Documents attached

TABLE A-8

Part 3 Highway Reconstruction Subgrade Design Philosophy

Respondent	7. Comments on design philosophy
Arizona	Attempt uniformly good subgrade (top 0.90m or 3 ft) support throughout project.
Arkansas	Materials Division evaluates subgrade soil and recommends any necessary stabilization measures.
California	Minimize disturbance to existing pavement structural sections during rehab. Subgrade improvements only occur with widenings, new construction and realignment of roadway which are considered same as new construction.
Connecticut	Trying to follow '93 AASHTO Pavement Design Guide.
Hawaii	Original design was to establish conservative subgrade strengths. Future pavement strengthening limited to the surface layers.
Louisiana	Soil survey includes 1.5 m (5 ft) subgrade sampling and testing. If subgrade is too wet, cut lime or provide drainage. If material is not suitable, remove and replace.
Minnesota*	Refer to part 2. Recently modified pavement design because of past pavement performance problems in reworking the subgrade soils in a short construction season for ease of the next reconstruction. Modifications included using a granular lift under the pavement structure.
Missouri	No payment for soil stabilizers. Contractors are allowed to incorporate stabilizers during construction at their expense (construction enhancement); improvement in the final product not provided.
Nevada	Use industry standards.
New Mexico	Destructive testing on rehabilitation/ reconstruction. Gradation, atterberg limits, r-value and in place moistures are performed on subgrades. Optimum moisture for samples are compared to a data base for type of soil-moistures are also looked at in place untreated base course to check if not over optimum.
North Carolina	Total reconstruction is rare. If so, subgrade improvement is done.
Oklahoma	Design depends on construction funding.
Pennsylvania	Subgrade evaluation for all reconstruction.
Rhode Island	Laboratory and field testing to determine acceptability, followed by subgrade crowning to design specs and paving.
Texas	Texas triaxial PI, swelling potential and lime content ASTM 977. FWD.
Virginia	FWD routinely to evaluate subgrades.
West Virginia	Mostly overlays. Removing the pavement is the same as removing a layer of base course.
Wyoming	If surfacing is removed on Interstate, some subexcavation of subgrade is done depending on condition & type. Prediction of subex in preliminary phase is difficult since it depends on moisture condition at time of construction. Often, if soil type indicate potential, additional MDC (Moisture-density control) will be included in plans.
Alberta	Subgrade evaluation based on soil test classification and proto-types.
Manitoba*	Use approved materials (borrow), ensure grade line higher than adjacent land, wide ditches and appropriate differential between grade line and ditch bottom.
Nova Scotia	Sampling protocol guideline for CBR.
Ontario	Frost susceptibility performance and bearing capacity of subgrade are used in design; subgrade soils are divided into six categories.
Quebec	Subgrade preparation: well drained (cross slope of 3%), stable and well compacted. Addition of drains if required. Control of loads and traffic to prevent deformation during construction.

*documents attached

TABLE A-9
Part 4 Subgrade Evaluation Methods For Highway Reconstruction
I. Subgrade Soil Sampling Methods

Documentation on subgrade sampling protocol							standard					
Respondent	coring	borings	undisturbed tube	split spoon	test pits	other	coring	borings	undisturbed tube	split spoon	test pits	other(specify)
Arizona	Y	Y	Y	Y	Y							
Arkansas	Y	Y						T203-82				
California	Y	Y			Y	Undisturbed R value						California test 301
Connecticut	Y	Y		Y								
Florida	see 5											
Idaho	Y				Y		IDA T-28					
Illinois	Y	Auger		Y				AASHTO		IDOT Push tubes (not the SPT)		
Indiana	Y	Y	Y	Y			Indiana DOT	Indiana DOT	AASHTO T207	ASTM D1586		
Kansas	Y		Y									
Louisiana	Y	Y	Y		Y		DOTD TR 225	AASHTO T 203				
Maine	Y	Y	Y	Y	Y		AASHTO	on subsurface	Investigations 1988			
Maryland	Y	Y					MD SHA Soil Survey Manual	MD SHA Soil Survey Manual				
Massachusetts	Y	Y	Y	Y	Y		AASHTO, ASTM	AASHTO, ASTM	AASHTO, ASTM	AASHTO, ASTM	AASHTO, ASTM	
Michigan	Y	Y					as needed by Soils Engineer	as needed by Soils Engineer				
Minnesota	Y	Y			Y	DCP						
Missouri	Y	Y					--	--				
Nebraska							Varies depends on problem					
Nevada		Y	Y	Y				ASTM D 1586 ASTM D 1452	ASTM D 1587	ASTM D 1586		
New Mexico	Y					Road Rater	--					--
New York St	Y	Y	Y	Y	Y	FWD (experimental)						
North Carolina	Y	Y					AASHTO T24-88	AASHTO T203-82				
North Dakota		Y						--				
Oklahoma	Y	Y	Y	Y	Y	DCP, FWD, CBR	AASHTO/ASTM	AASHTO/ASTM	AASHTO/ASTM	AASHTO/ASTM	AASHTO/ASTM	AASHTO/ASTM
Oregon					Y							
Pennsylvania	Y	Y	Y	Y	Y	Y	Penn DOT Pub 222	Penn DOT Pub 222 ASTM D 1452	ASTM D 1587	Penn DOT Pub 222 ASTM D 1586	Penn DOT Pub 222	
Rhode Island	Y	Y	Y	Y	Y	Y	performed by contractors under the direction of RIDOT inspection					
Virginia		Y		Y				ASTM		ASTM		
Vermont	Y	Y	Y	Y	Y	FWD	ASTM D 5381	T 251, T 203, T 206	AASHTO T 207	AASHTO T 206	in-house	ASTM D 4694
Washington St	Y						--					
West Virginia	Y	Y	Y	Y		Disturbed bag	State specs	AASHTO T 225	AASHTO T 207	AASHTO T 206		
Wisconsin	Y	Y		Y								
Wyoming	Y	Y	Y	Y		Continuous Sampling			ASTM	ASTM		
Alberta					Y							
Manitoba		Y						MRB 6-01				
Newfoundland	Y	Y		Y	Y		ASTM D 2113	ASTM D 2113		ASTM D 1586		
Nova Scotia	Y	Y	Y	Y	Y	CBR	ASTM D 5381	ASTM Guide line	ASTM D 1452	ASTM D 1586	--	ASTM D 1883
Ontario	Y	Auger	Y	Y	Y		MTO Directive C145	ASTM	ASTM	ASTM	N/A	
Quebec	Y	Y		Y	Y							
Saskatchewan	Y	Y										

FWD = Falling Weight Deflectometer
ME = Modulus of Elasticity

TABLE A-10
Part 4 Subgrade Evaluation Methods For Highway Reconstruction
I. Subgrade Soil Sampling Methods

(2) frequency of sampling along highway alignment						
(3) depth of sampling						
Respondent	coring	borings	undisturbed	split spoon	test pits	other
Arizona	(2) about 2500 ft (3) Top of subgrade to 5 ft below					
Arkansas	(2) Only when requested by Roadway Design Division. Every 800 ft; alternating between lanes and in the vicinity of the center lane of each lane. (3) Disturbed auger samples from top of subgrade to 5 ft. below.					
California	(2) Three or more disturbed samples per centerline mile if required for widening, reconstruction or realignment. Pavement deflection measurements are always taken routinely on existing roadways to be rehabilitated. (3) in excavations withing 0.6 m to 1.5 m of profile grade.					
Connecticut	(2) New construction, 300 ft for overlays. Intervals vary. (3) One split spoon sample at the proposed top of subgrade elevation.					
Idaho	(2) 200 to 500 LF complete sample each mile.					
Illinois	(2) No standard & written sampling protocol. Representative soils are tested. Frequency depends on soil uniformity. (3) Disturbed samples to 2 ft depth					
Kansas	(2) 4 undisturbed sample per project. FWD @ 10 samples per mile for backcalculation of M. (3) Undisturbed 18-in depth					
Louisiana	(2) 500 to 1000 ft of roadway along centerline. Additional sampling at geologic changes in the terrain. (3) 5 ft. from top of subgrade. Auger sampling is 3 to 10 ft. below subgrade elevation shown on plans. Continuously to a minimum of 2 ft below construction.					
Maine	Field Manager judgement					
Massachusetts	(2) 1500 ft, 1/2 mi or 1 mi interval depending on size of project. Engineering judgement on spacing. (3) 4ft below finish profile grade					
Michigan	(2) 1 per 1000ft to 1 per 500ft (3) penetrates subgrade to identify soil types and moisture levels	1 per 1000ft to 1 per 500ft				
Minnesota	(2) 100 ft randomly. However the spacing or frequency may be adjusted. See attached. (3) 5 ft below the top of subgrade. However, may be adjusted depending on site condition.					
Missouri	(2) A minimum of 1 sample per mile with a minimum of 3 samples per project. (3) Aggregate base is sampled, composite from the bottom of the pavement to the top of the subgrade. Subgrade soil is sampled to one foot below the base.					
Nebraska	(2) 3 ft to 5 ft					
Nevada	(2) sample only the specific area where there is problem (3) 5 to 10 ft					
New Mexico	(2) 1 per 0.25 mile on mainline for length of project. Shoulder is cored at 1 per 0.25 mile or 1 per 0.5 mile. (3) 2ft into subgrade. If there is a vertical grade changes the sampling is adjusted accordingly. 2ft of the new subgrade is sampled.					
New York St	(2) All cuts are explored with borings, cores are taken to confirm the thicknesses noted in the highway's maintenance history (3) core the pavement, sample to 5 ft. usually continuously. Split spoon soil samples are taken unless drilling for a substantial cut (deeper than 10 ft.) and soft, plastic soils are encountered. Then undisturbed samples would be taken					
North Carolina	(2) for both tests, 1 per 0.5 mile but may change depending on specific local conditions (3) from top of subgrades to 1 ft below					
North Dakota	(2) 1 per 1000ft to 1 per 500ft (3) 5ft below top of existing pavement					
Oklahoma	Coring, borings, undisturbed tube variable; random sampling plans, DCP random sampling (2) FWD is 250 ft (3) 0 to 3 ft					
Oregon	(2) 2 locations per centerline mile, additional tests at known problem areas (3) Disturbed samples are within the top 3 ft. of subgrade					
Pennsylvania	(2) Boring spacing 200 to 500 ft. Depend on project size. Average on large projects is 2000 ft per each two lanes. (3) Varies approx 15 ft. Split spoon sampling is done continuous from 6 to 10 ft. below subgrade.					
Rhode Island	(2) Dependent on existing soil conditions and types of structures involved (3) 18 to 24 in. of subgrade (3) highway - 10 to 15 ft (3) bridge - varies, usually to bedrock			(3) 5 ft. intervals		
Vermont	(2) 100 ft. intervals in cuts and 200 ft. in fills (3) 10 ft. below grade in cut, 1 to 2 times the fill height					
Virginia	(2) No sampling protocol. Sampling varies based on designers' judgement (3) 4 ft			(3) 4 ft		

TABLE A-10

Part 4 Subgrade Evaluation Methods For Highway Reconstruction

I. Subgrade Soil Sampling Methods

(2) frequency of sampling along highway alignment (3) depth of sampling						
Respondent	coring	borings	undisturbed	split spoon	test pits	other
Washington St	(2) every 1/4 to 1/2 mile to verify pavement (AC) thickness and level of distress (3) run FWD and backcalculate layer moduli					
West Virginia	(3) Shelby tubes 3 ft. Pavement cores to the bottom of the existing base. R modulus to a depth of 3 ft. Split Spoon continuous of 3 ft.					
Wisconsin	(2) 4 to 5 per mile (3) Testing is confined to the upper 5 ft. unless some specific problem can be identified.					
Wyoming	(2) every 200-400 m (2) 1 every 3 holes (2) 1 every 4 holes ------(3) From below base to 1.5m ----- (3) Continue sampling from below base to 2.5m					
Alberta	(2) one sample every 200 m (3) Disturbed samples taken to at least 1 m below below the anticipated ditch elevation or 1m below the base of top soil horizon whichever is greater					
Manitoba*	Std MRB 6-01 for hole spacings and drilling depths. Profile depths measured. Increase hole depth by when unsuitable material encountered.					
Newfoundland	(2) periodic / as required					
Nova Scotia	(2) Guideline Feb 28/94 (3) All from top to 1.5m below					
Ontario	(2) 3 per km, min of one for each patch 25 m in fills & 50 m in cuts -----At the discretion of the Engineer----- (3) A minimum of 1.2m below subgrade. Depends on site conditions and work to be carried out.					
Quebec	(2) 300 m for reconstruction. Disturbed sample closer intervals if earthworks are major. (3) Generally 1.5 to 2 m below subgrade level. Minimum depth of sampling is 3 m if there is a sewage system to be built.					
Saskatchewan	(2) Varies depending on project length and problem to be addressed. See attached. (3) See attached					

*documents attached

The units are given in the form the respondents provided. To convert use : 1 in. = 2.54 cm = 25.4mm , 1 ft. = 30.54 cm = 0.3054 m

TABLE A-11
Part 4 Subgrade Evaluation Methods For Highway Reconstruction
I. Subgrade Soil Sampling Methods

Respondent	4. Time of Year
Arizona	No special time
Arkansas	No preference
California*	Anytime since R-value testing is conducted on disturbed samples at saturated moisture content
Connecticut	The timing of the soil sampling is more project schedule driven than climate related.
Florida	Good weather all year
Idaho	Throughout year. Design for worst condition
Illinois	Spring due to high moisture
Indiana	No preferred period
Kansas	Non freezing weather, to prevent water from freezing during coring
Louisiana	Winter - lack of personnel in the summer
Maine	April - Nov to avoid frozen subgrade
Massachusetts	Normally before frost
Minnesota	Summer-moisture conditions have stabilized. Sampling all seasons depending on availability of field crew, letting dates, etc
Missouri	Spring / fall (wet seasons) to identify pumping. Weather conditions are recorded.
Nebraska	Not in winter - frozen conditions
Nevada	Dictated by project schedule. Inadequate time to sample at proper time of year
New Mexico	All year round. In winter, the core crews are in the southern part of the state.
North Carolina	All year round
North Dakota	Late spring through early fall to avoid frozen samples
Oklahoma	Dictated by project schedule. Materials Division prefers late springtime.
Oregon	No real preference but most work occurs in summer
Pennsylvania	None
Rhode Island	Prefer dry and warm but may take place in variable field conditions
Vermont	Spring or fall as soil is saturated based on project scheduling
Virginia	Dictated by construction advertisement date.
Washington	Based on project scheduling
Wisconsin	Coring anytime of year but not winter. Subgrade assessments when ground is not frozen (April - Dec)
Wyoming	Spring time when construction usually gets started.
Alberta*	Late spring to fall - ground not frozen
Manitoba	May to Oct. No frost.
Nova Scotia	Spring the worst case scenario
Ontario	Spring / early summer for in-situ MC
Quebec	Anytime except during winter when the pavement structure or soils are frozen.
Saskatchewan	Summer and Fall - unfrozen & post spring thaw (drained) conditions

*documents attached

* Preliminary Survey Guidelines 5.0

TABLE A-12**Part 4 Subgrade Evaluation Methods For Highway Reconstruction*****1. Subgrade Soil Sampling Methods***

Respondent	5. Comments on protocols for sampling and evaluation
Florida	No sampling or testing on subgrades for stabilizing for construction traffic. Subgrades are stabilized to LBR40 which is adequate for construction traffic. Contractor is required to maintain subgrade.
Indiana	Test most critical and most predominant soil for design
Minnesota	Extensive FWD and backcalculate Mr. 120,000 data points compiled into a statistical computerized soil atlas of the states entire flexible pavement system.
Nebraska	Original soil survey info is used, plus condition info on present highway
New Mexico	Sampling using 12 in. cores. In-place base course is tested for gradation, Atterberg, MC, r-value. Stabilize subgrade with lime if high PI. Lime stabilization test AASHTO T 220, Eades & Grim for pH test.
Pennsylvania	Also look at moisture content, maximum density optimum moisture and classification
Rhode Island	Initial sampling and testing are according to design considerations but may be modified according to field and laboratory inspection.
Wisconsin	Coring to determine thickness, materials and conditions. Base course material measured for thickness and observed for quality. Subgrades are sampled for strata, textures, moisture, relative density. Lab test new for LL, PI, natural moisture and unconfined compression.
Alberta ^a	Soil classification, identification and in-situ moisture content
Manitoba	Details in Std MRB 6-01. Organic matter very crucial.
Quebec	Equipment used: vehicle mounted power auger, manual auger, backhoes, organic samplers, geophysics (seismic method - refraction)

*documents attached

^a Preliminary Survey Guidelines 5.0

TABLE A-13

Part 4 Subgrade Evaluation Methods For Highway Reconstruction

II. 1. Laboratory Testing of Subgrade Soils

Respondent	test type	usage	standard
Arizona	PI	Always	AASHTO T 90 - 92
	Passing #200	Always	AASHTO T 27 - 93 & T 11 - 91
	R value	Sometimes	AASHTO T 190 - 93
Arkansas	Dry preparation of disturbed soils	Always	AASHTO T 87 - 86
	Gradation (+#200, -#200 and #200wash, no hydrometer)	Always	AASHTO T 88 - 93
	Atterberg	Always	AASHTO T 89, T 90
	R value (on selected samples)	Always	AASHTO T 90 - 83
California	Gradation	Always	California test 202, 203
	Atterberg	Always	California test 204
	Soil Classification	Always	ASTM D 2487
	Moisture content	Always	California test 226
	Sand Equivalent (SE)	Always	California test 217
	Maximum density	Always	California test 216
	R-value	Always	California test 301
	Unconfined compression strength of lime treated soils and aggregate	Sometimes when assessing lime treatment	California test 373
Connecticut	Gradation	Always	---
	Water content	Always	---
	Atterberg	Sometimes	---
Florida	LBR during construction	Always	FM 5-515
	Proctor during construction	Always	FM 5-521
Hawaii	R-value	Sometimes	AASHTO T 190
Illinois	Moisture	Always	AASHTO
	Strength (IDOT's modified)	Sometimes	Field unconfined strength
	Rimac Spring Tester)		
	Gradation	Sometimes	AASHTO
Indiana	Organics	Sometimes	AASHTO
	Gradation	Always	AASHTO
	Moisture content	Always	AASHTO
	Unconfined compression	Sometimes	AASHTO
	Loss on Ignition	Sometimes	AASHTO
	pH	Always	ASTM
	Calcium & Magnesium	Sometimes	Indiana DOT
	Natural Density	Always	AASHTO
	Std Proctor	Always	AASHTO
	CBR	Always	AASHTO
Kansas	Atterberg	Always	AASHTO
	Gradation	Always	Kansas / AASHTO
	Modulus	Always	AASHTO
Louisiana	Gradation (Mech)	Always	DOTD TR 407
	Atterberg	Always	DOTD TR 428
	Soil Classification	Always	DOTD TR 423
	Minimum cement content	If required	DOTD TR 432
	Proctor (for density control)	Always	DOTD TR 418
	Minimum Lime content	Sometimes	DOTD TR 416
	Resistivity & pH	If metal pipe conduit is required	DOTD TR 429 & 430
	Natural moisture content	Sometimes	DOTD TR 403
	Organic matter	Sometimes	DOTD TR 413
Maryland	Sample preparation	Always	MSMT 301
	Gradation (Mech)	Always	MSMT 302
	Moisture content	Always	MSMT 303
	Atterberg	Always	AASHTO T 89, T 90
	Shrinkage limit	Sometimes	AASHTO T 92
	Resilient modulus	Sometimes	AASHTO T 292

TABLE A-13

Part 4 Subgrade Evaluation Methods For Highway Reconstruction

II. 1. Laboratory Testing of Subgrade Soils

Respondent	test type	usage	standard
Massachusetts	Gradation	Always	AASHTO
	Unit Weight	Always	AASHTO
	Proctor	Always	AASHTO
	Atterberg	Sometimes	AASHTO
Michigan	Gradation	Sometimes	MTM * 108 & 109
Minnesota	Gradation	Always	AASHTO T 88
	Atterberg Limits	Always	AASHTO T 89, T 90
	Proctor	Always	AASHTO T 99
	R-value	Sometimes	AASHTO T 190
	Mr	Sometimes	AASHTO T 294
	% organic	Sometimes	
	Specific Gravity	Sometimes	
Missouri	Gradation < #200 content of base	Always	---
	Gradation < #200 content of subgrade	Always	---
	Moisture	Always	AASHTO T265
	Soil classification	Always	AASHTO M145, ASTM D 2487
Nevada	R value	Sometimes (if needed)	California 305
	Atterberg	Sometimes (if needed)	AASHTO T 89
	Shrinkage limit	Sometimes (if needed)	AASHTO T 89
	Gradation	Sometimes (if needed)	AASHTO T 88
	Sand equivalent	Sometimes (if needed)	AASHTO T 227
	Chem	Sometimes (if needed)	---
	Swell	Sometimes (if needed)	AASHTO T 216
	Triaxial		AASHTO T 296
	Direct Shear		AASHTO T 236
	Unconfined		AASHTO T 208
	Collapse		
	X-ray		
New Mexico	Wash Gradation	Always	AASHTO T 11 / T 27
	Moisture determination	Always	AASHTO T 265
	Atterberg	Always	AASHTO T 90 / T 90
	Proctor	Always	AASHTO T 99 / T 180
	Unit weight	Always	AASHTO T 19
	R value	Always	AASHTO T 190
	Lime stabilization	Sometimes	AASHTO T 220
	Soil Cement Design	Sometimes	AASHTO T 134 / T 135
	Moisture Density relations of soil-cement mixture		
New York	Moisture content	Always	---
	Visual Description	Always	---
	Atterberg	Rarely	---
	Triaxial Testing	Very rarely	---
North Carolina	Gradation	Always	AASHTO T 87, 88
	Atterberg	Always	AASHTO T 89, 90
	Proctor (if CBR is used)	Sometimes	AASHTO T 99 - 90
	CBR (on major soil types)	Sometimes	AASHTO T 193
	Soil cement mixtures (on granular PI < 15)	Sometimes	ASTM D 1632 modified ny NCDOT
	Lime soil mixtures (on fine PI > 15)	Sometimes	NCDOT
North Dakota	Proctor (depends on soil classification)	Always	AASHTO T 99, T 180
	Atterberg	Always	AASHTO T 89(B), T 90
	Gradation	Always	AASHTO T 27, T88
	Soil classification	Always	AASHTO M 145
Oklahoma	Soil Classification	Always	AASHTO
	Atterberg	Always	AASHTO T 89, T 90
	Moisture Content	Always	AASHTO T 265
	Proctor	Always	AASHTO T 180
	CBR	Always	AASHTO T 193

TABLE A-13

Part 4 Subgrade Evaluation Methods For Highway Reconstruction

II. 1. Laboratory Testing of Subgrade Soils

Respondent	test type	usage	standard
Oregon	Moisture Content	Always	
	Resilient Modulus	Sometimes	
	Soil Classification	Always	
Pennsylvania	CBR	Always	AASHTO T 193
	Gradation	Always	AASHTO T 88
	Atterberg	Always	AASHTO T 89, T 90
	Proctor	Always	AASHTO T 99
	Standard Penetration	Always	Penn DOT Pub 222
	Moisture content	Always	
	Pocket Penetrometer	Always	
Rhode Island	Gradation	Sometimes	AASHTO T 88
	Atterberg	Sometimes	AASHTO T 89, T 90
	Proctor	Always	AASHTO T 180
	CBR	Sometimes	AASHTO T 193
	Permeability	Generally	AASHTO T 215
	Moisture Content	Always	AASHTO T 265
	Organic content	Sometimes	AASHTO T 267
Vermont	Gradation	Always	AASHTO T 87, T 88
	Atterberg	Sometimes	AASHTO T 89, T 90
	CBR	Sometimes	AASHTO T 193
	Unconfined Compression	Sometimes	AASHTO T 208
	Moisture Content	Always	AASHTO T 265
Virginia		Sometimes	AASHTO T 297
	CBR	Sometimes	VTM 8
	Atterberg	Sometimes	ASTM D 423 / 424
	Soil classification	Sometimes	AASHTO M 145
	Optimum moisture	Sometimes	AASHTO T 99
Washington	Resilient Modulus	New alignment, new construction, rare	AASHTO T 292
	Atterberg	do	AASHTO T 89
	R - value	do	WSDOT modified AASHTO T 190
	Max density	do	AASHTO T 99
West Virginia	Classification	Always	AASHTO M 145 & T 88
	Max density & moist content	Always	AASHTO T 99
	Spec gravity	Always	AASHTO T 100
	Atterberg	Always	AASHTO T 89 & T 90
	Direct Shear	Sometimes	AASHTO T 236
	Resilient Modulus	Always	AASHTO T 294
	Field Moisture	Always	AASHTO T 93
Wisconsin	Atterberg	Sometimes	AASHTO T 89, T 90
	Unconfined Compression	Sometimes	AASHTO T 208
	Moisture content	Sometimes	AASHTO T 265
	Gradation	Sometimes	AASHTO T 88
Wyoming	Unconfined Compression	Sometimes	
	Consolidated Undrained Direct Shear	Sometimes	
	Consolidation	Sometimes	
	Falling Head Permeability	Sometimes	
	Atterberg	Always	AASHTO T 89, T 90
	Proctor	Sometimes	AASHTO T 99, T 180
	Plastic Fines (Sand Equivalent Test)	Sometimes	AASHTO T 176
	R - value	Always	AASHTO T 190
	Soil Cement	Sometimes	AASHTO T 134, T 136
	Gradation	Always	AASHTO T 88
Alberta	Atterberg	Always	AASHTO T 89, T 90
	Gradation	Always	AASHTO T 88
	Soil Classification	Always	Unified System, ASTM D 2487

TABLE A-13

Part 4 Subgrade Evaluation Methods For Highway Reconstruction

II. 1. Laboratory Testing of Subgrade Soils

Respondent	test type	usage	standard
Manitoba	Dry preparation of soil samples		ASTM D 421
	Gradation		ASTM D 422
	Moisture content		ASTM D 2216
	Gradation < #200 by Washing		ASTM C 117
	Gradation		ASTM C 136
	Atterberg		ASTM D 4318
	Organic matter by Wet combustion		AASHTO T 194
Newfoundland	CBR	Occasional	ASTM D 1883
	Gradation	Always	ASTM D 422
	Moisture content	Always	ASTM D 2216
Nova Scotia	Moisture content	Always	ASTM D 2216
	Gradation	Sometimes	ASTM C 136 / C 177 / D 422
	Atterberg	Sometimes	ASTM D 4318
	CBR	Usually	ASTM D 1883
Ontario	Atterberg		ASTM
	Field Vane	Sometimes	ASTM
	Gradation		ASTM D421, T 87, D 422, T 88
	Moisture content		ASTM D 2216
	Proctor		ASTM
	Lab Vane	Sometimes	
	Density		ASTM (LS 705)
Quebec	Gradation	Always (every sample tested)	BNQ*
	Moisture content (on fine soils)	Always (1 sample tested out of 3)	BNQ*
	Atterberg (on fine soils)	Always (1 sample tested out of 3)	BNQ*
	Silt and clay proportion	Sometimes	BNQ*
Saskatchewan	Nw	Always	
	Pw	Always	
	Lw	Sometimes	
	Dry density	Sometimes	
	Gradation	Sometimes	

MTM* = Michigan Test Method

BNQ* = Bureau de Normalisation du Quebec - Standard derived from ASTM in general and adapted for Quebec)

TABLE A-14
Part 4 Subgrade Evaluation Methods For Highway Reconstruction
II. Laboratory Testing of Subgrade Soils

Respondent: 2. Addressing seasonal variations through laboratory testing	
Arizona	Generally not applied to tests
Arkansas	Not addressed
California	R value at saturated soil conditions
Connecticut	Not quantified
Florida	No seasonal variations
Hawaii	Not a factor
Illinois	Grain size analysis for checking soil frost susceptibility. Field observation of ground water.
Indiana	Not addressed
Louisiana	Lime to condition moisture sensitive silts and high PI clay in areas of seasonal change in water table elevation. No stabilization until water table gets low e.g. Mississippi River area
Michigan	No
Minnesota	Pavement structural design is based on R-value which is based on saturated condition (spring type condition)
Missouri	Not laboratory tested
Nevada	Swell test / collapsible test
New Mexico	Not addressed
New York	Strength changes are addressed in pavement designs, not in laboratory testing
North Carolina	CBR samples are soaked for 96 hours prior to strength testing
North Dakota	Frozen samples are noted and allowed during subgrade evaluation
Oklahoma	Not addressed.
Pennsylvania	None
Rhode Island	Water table variations are monitored along with frozen subgrade.
Texas	Triaxial procedure uses saturation to test for worst condition.
Vermont	Moisture contents are adjusted, seasonal corrections are used in pavement design
Virginia	Not addressed.
Washington	Used in conjunction with FWD testing and backcalculation / mechanistic - empirical overlay design procedure
West Virginia	Not addressed yet.
Wisconsin	Not addressed through laboratory testing.
Wyoming	Samples saturated to simulate a wet condition if considered a problem area. R-value curve to determine moisture sensitivity.
Nova Scotia	Soaked CBR
Quebec	Subgrade variation; measured in the field with bearing capacity equipment correlations with CBR testing and soil classification. Once this was done, soil classification is used as indicator
Saskatchewan	Design is based on spring thaw weakened state.

TABLE A-15**Part 4 Subgrade Evaluation Methods For Highway Reconstruction****II. Laboratory Testing of Subgrade Soils**

Respondent 3. minimum acceptance criteria	
Arizona	R value > 15
California	With an expansive basement (subgrade) soil (PI>12) or R value < 10, a flexible (AC) structural section should be specified unless treated with lime or other stabilization agents which would increase R value above 10 for a minimum depth of 200 mm.
Connecticut	No formalized criteria
Florida	LBR>40
Idaho	R value
Illinois	Immediate IBR (CBR) > 6%, PI>12 (or silt content < 65%), density > 14.2 kN/m ³ (90 pcf), compaction > 95% (AASHTO T 99), organic content < 10 %.
Indiana	Refer to the dry density of 100 lb/cu ft.
Louisiana	Soil hauled in by the contractor: LL< 35 ; PI < 12 ; organic < 2% ; sand content < 79% ; silt < 60%
Massachusetts	Designer should consider the economics of replacing poor material.
Nebraska	Use some selective placement to provide uniformity of base materials
Nevada	Usually R value > 45. PI & LL < 10
New Mexico	Once a design r-value is set for a project, if the r-value during construction falls 6 points below design r-value, samples must be submitted to the central laboratory and remedied as necessary.
New York	No, design for $M_r < 27,600 \text{ kN/m}^2$ (4000psi). If native soils are weaker than that, undercut to improve to this minimum
North Carolina	No, but require stabilization with aggregate for poor soils in order to provide a stable working platform for construction equipment. Require subgrade compacted to 100% of AASHTO T 99
North Dakota	Specified by % of compaction and % of optimum moisture
Oklahoma	CBR tabulated guides
Pennsylvania	Varies. Non movement under a 10 ton roller.
Rhode Island	Generally based on minimum criteria, i.e., 95% relative compaction.
Virginia	Minimum CBR 30 for construction platform.
Wyoming	Shear strength, moisture content, type of material & previous history to set criteria for construction phase.
Manitoba	Only the organic content
Nova Scotia	No, except in localized areas severely deteriorated subbase materials (high clay or silt content) would be replaced.
Quebec	No, design is modified to take subgrade properties into account. Construction methods are also modified.

No minimum criteria for: Hawaii, Kansas, Maryland, Michigan, Minnesota, Texas, Vermont, Washington, West Virginia, Wisconsin, Newfoundland, Ontario, Saskatchewan.

TABLE A-16
Part 4 Subgrade Evaluation Methods For Highway Reconstruction
III. 1. Field Testing

Respondent	test type	usage	standard	comments
Arizona	FWD	Always		
Arkansas	FWD	Always	Rehab, Reconstruction	Per Roadway Design Division request
California	Pavement deflection			Where minimim disturbance will occur to existing pavement
Florida	Density in-place Depth check	Always Always	FM1-T238 ---	Nuclear density and check for uniform mix & depth during construction
Illinois	DCP Static Cone FWD	Always Sometimes Sometimes	IDOT & U of Illinois Corps of Engrs AASHTO	
Indiana	FWD	Sometimes	---	---
Kansas	FWD Cone penetration	Always Sometimes	ASTM ASTM	---
Maryland	FWD	Sometimes	Maryland	Not published
Massachusetts	FWD	Sometimes		
Michigan	Soil Auger Boring	Always	District preference	---
Minnesota	FWD DCP Moisture Proctor Sand Cone Test Rolling Subgrade	Always for bituminous Sometimes Sometimes Sometimes Sometimes Sometimes	MnDOT method --- AASHTO T 99 AASHTO T 191 MnDOT method	--- --- --- --- ---
Nevada	FWD SPT	Sometimes Sometimes	--- AASHTO T 206, ASTM D 1586	If needed If needed
New Mexico	NDT Roadrater Coring Destructive Test	Sometimes Always		Has not been reliable comfortable with results
New York	FWD	experimental	---	---
North Carolina	CPT FWD CLEGG impact hammer Dynamic CPT GPR	Sometimes Sometimes Sometimes ~ 60% Just beginning	NCDOT NCDOT NCDOT CBR conversion TTI info	--- --- --- Based on South African method ---
North Dakota	FWD CBR	Always Always	N/A AASHTO T 193	--- ---
Oklahoma	SPT DCP FWD		ASTM 1586 Mn technique ASTM D 4694-96, D 4695-96	

TABLE A-16
Part 4 Subgrade Evaluation Methods For Highway Reconstruction
III. 1. Field Testing

Respondent	test type	usage	standard	comments
Oregon	FWD	Always		9000 lbs drop
Pennsylvania	Test Borings	Always	ASTM D 1452	
	Sampling	Always	ASTM D 1587	
	Pits	Always	ASTM D 1586	
	SPT	Always	Penn DOT Pub 222	
Rhode Island	Nuclear testing	Always	AASHTO T 238	
	Gradation	Always	AASHTO T 27	
Texas	FWD	Almost Always		Moderate to high traffic
	Texas Triaxial	Rarely	Test Method in E	Low traffic roads
Vermont	FWD	Always	ASTM D 4694	---
	Vane shear	Sometimes	AASHTO T 223	---
	SPT	Sometimes	AASHTO T 206	---
Virginia	FWD	Always	ASTM D 4694	---
Washington	FWD	Maturity of overlay projects		---
Wisconsin	SPT	Nearly always	AASHTO T 206	Standard Method
	Hand Penetrometer	Sometimes		
Wyoming	R - value	On fill material	AASHTO T 99 or 180, T 190	Compare to design
	Proctor (MDC as required)	On all fill	AASHTO T 99 & T 180	As control, may indicate reworking
Nova Scotia	Benkleman beam	occasionally	CGRA	
	Dynalect	most often	NSDOTPW	
Ontario	Field Vane	Sometimes	ASTM	Only in extreme poor subgrade
	Cone Penetrometer	Sometimes	ASTM	Only in extreme poor subgrade
Quebec	FWD	Sometimes		Mainly used for research on rigid pavements or for monitoring
	Penetration Test	Sometimes	ASTM D 1586	On cohesive soils
	Field Vane Test	Sometimes	BNQ 2501-201(Quebec Std)	On cohesive soils or peat
	Dynalect	Sometimes		
Saskatchewan	Benkelman Beam	Usually		

TABLE A-17**Part 4 Subgrade Evaluation Methods For Highway Reconstruction****III. Field testing**

Respondent	2. Elaborations on nondestructive testing
California	GPR on limited basis for location of voids under PCC pavement. Results were questionable.
Connecticut	GPR to determine extend of voids below continuously reinforced concrete on I-84
Minnesota	On rare occasions have used seismic testing for locating and evaluating bedrock
Nebraska	Have not used this equipment
Nevada	Only use FWD
New Mexico	Limited use of Roadrater to identify saturated subgrade areas.
New York	GPR for identifying voids beneath the pavement
North Carolina	N/A but have used GPR in few occasions to locate buried pipes under subgrade when notice wet subgrade in a localized area or pavement failure. GPR for layer thickness, stripping & voids.
North Dakota	FWD only at present
Oklahoma	Only in the past two years started to emphasize on two field methods; FWD and DCP
Rhode Island	Evaluating a new method to determine subgrade moisture in the field, in addition to nuclear testing
Texas	FWD. The GPR, seismic and general L204 echo are evaluated for implementation techniques
Vermont	Had limited success with GPR
Virginia	Occasionally use GPR for layer thickness determination.
West Virginia	Planning on using FWD
Wisconsin	Limited use of GPR. Use Drilling and sampling more
Wyoming	FWD for subgrade condition for rehab strategies. Look at subgrade Mr and soft spots.
Alberta	Back calculation for subgrade resilient modulus is done with analysis of FWD testing using Elmod program.
Nova Scotia	Dynaflect & Benkelman
Ontario	GPR on experimental basis
Quebec	Seismic testing when earthworks are substantial or when access to the site is unfeasible and to validate rock or boulders level.
Saskatchewan	Beginning to use GPR. Benkelman was used for decades

TABLE A-18
Part 5 Stabilization of Weak Subgrades

Respondent	1. Recycled materials
Arizona	RAP
Arkansas	Fly ash and other by products have been utilized on an experimental basis.
California*	Reclaimed asphalt/PCC pavement for subbase and base materials over existing subgrades.
Connecticut	Exclusively remove and replace weak subgrade.
Hawaii	Subgrade stabilization is not necessary.
Idaho*	Full depth recycling with 2% cement on two interstate projects. Specials and typical attached.
Illinois	RAP (above groundwater), recycled concrete, lime kiln dust (primary). Hydrated lime, hydrated by-product lime and slag furnace.
Indiana	Recycled asphalt & concrete pavement, rubblization, fly ash & kiln dust.
Kansas	Fly ash to dry up wet subgrades. RAP to modify subgrade soil when available.
Louisiana	Rubblization PCC. Break and seat PCC. Calcium sulfate hemihydrate as working table/base. Recycled portland cement as working table/base/subgrade layer.
Massachusetts	RAP rubblization. Gradation of subgrade has to conform to the standard specs.
Michigan	Not for backfill.
Minnesota	Crushed concrete and salvaged bituminous pavement materials that meet a dense graded aggregate base gradation and are either incorporated into the upper portion of the unstable subgrade material or are placed as a layer (2-3 inches) on top of unstable subgrade.
Missouri	Lime kiln dust for stabilization.
Nebraska	Asphalt millings, crushed concrete, salvaged soil aggregate base or foundation course.
New Mexico	Considering a project using flyash to stabilize subgrade. Soil-lime stabilization used at a frequency of one project per one and half year.
New York St	Rubblized PCCP before overlay, recycled PCC/ACC for subbase, recycled beverage containers (glass) as granular materials. Fly ash for embankment.
North Carolina	RAP had skid problems in surface layer. Rubblization with substantial asphalt overlay provides good results. Do not have good estimates of undercut.
Oklahoma	Fly ash and by product lime for stabilization. RAP in base. Class C flyash for NP to sandy soils. "Carbide" lime for lime stabilization but no success. Lime or fly ash (if they are pay quantities) are used to dry up wet subgrades. Undercut and replace with suitable material Subsection 202.02(b). ODOT Std. Constr.Spec. Subgrade Method 'B' (reconstituting OMC and max gd).

TABLE A-18
Part 5 Stabilization of Weak Subgrades

Respondent 1. Recycled materials	
<hr/>	
Pennsylvania	Concrete crushed to AASHTO 2A coarse aggregate. Recycled 2A used a backfill between layers of class 4 geotextile.
Texas	Lime or Fly ash
Vermont	In-place recycling for base and subbase stabilization, not subgrade.
Virginia	Frequently portland cement. Occasionally lime. No recycled materials. Will experiment with full- depth reclamation on suitable low-volume roads.
West Virginia	Recycled concrete pavement
Wisconsin	Not for stabilization.
Wyoming	RAP on primary & secondary roads as temporary surfacing to carry traffic over soft soils. Rubbleization to break expansive cement treated base on one project. Cement stabilization on PCCP reconstruction to stabilize subgrade due to wet condition.
Alberta	On reconstruction, RAP is rare in subgrade preparation.
Nova Scotia	RAP with/without emulsion for binder.
Quebec	Lime treatment to reuse soft clays locally (use is scarce).
Saskatchewan	RAP in AC pavement recycling and occasionally as a substitute for granular base course and surface gravelling.

RAP = Recycled Asphalt Pavement, PCC = Portland Cement Concrete, ACC = Asphalt Cement Concrete
 *documents attached

Note: These states do not use recycled material - Nevada, North Dakota, Rhode Island, Washington St., Ontario.

TABLE A-19**Part 5 Stabilization of Weak Subgrades**

Respondent	2: Geosynthetics
Arizona	High survivability fabric and geogrids. See attached.
Arkansas	Geosynthetics and geogrids on experimental and limited job basis. Usually use high survivability AASHTO M288 separation fabric (woven or unwoven) with min. 0.2 to 0.31 m (8-12 in.) aggregate base on top.
California*	See attached
Connecticut	Limited
Illinois	Woven fabric for separation. Geogrid with granular material for stabilization.
Indiana	Geogrids. Attached specs for the type and properties.
Louisiana	Geotextiles for subgrade separation. Geogrids for subgrade (base) reinforcement. See attached.
Maine	Woven & nonwoven geotextiles for stabilization and drainage. No geogrids
Massachusetts	See attached.
Michigan	Very seldom-- see attached
Minnesota	Not for Interstate system. Other roadway use woven and non woven geotextile for separation and reinforcement.
Nevada	High survivability nonwoven needle punch geotextiles.
New Mexico	Biaxial geogrid to stabilize soils on three projects
New York St	Geotextiles as separators to prevent fine-grained material from contaminating select materials. Geogrids to add tensile strength to the bottom of undercuts
North Carolina	Geosynthetic to confine ABC in lieu of deeper undercut 0.30 m to 0.46 m (1' to 18"), place geosynthetic fabric and back fill with dense graded ABC.
North Dakota	Separation. Reinforcement
Oklahoma	Sparingly when recommended by LAB, minor experimental use. Geotextiles on a few projects. No Std used.
Oregon	Generally nonwoven. ASTM D 4632 - 180 lbs, ASTM D 3786 - 290 psi, ASTM D 4833 - 80 lbs, ASTM D 4751 - less than #30, ASTM D 2291 - 0.005 cm/sec.
Pennsylvania	Limited use. Includes separators, reinforcement or combination materials include woven and non-woven geotextile, geogrid and geocell. Class 4 in Penn DOT Pub 408 - woven grab strength 1.02 kN (230 lbs), best strength 2.98 kN/m ² (430 psi), elongation 15%, puncture 490 N (110 lbs).
Rhode Island	Not in soil stabilization but in other applications (Soil nail wall, etc.)
Texas	Experimenting geogrids. Geotextile as layer separator.

TABLE A-19
Part 5 Stabilization of Weak Subgrades

Respondent	2. Geosynthetics
Vermont	Woven/non woven geosynthetics with grab tensile strength 890 N, burst strength 2000 kPa, Puncture 445N, Trapezoidal tear strength 335N, apparent opening size 0.42mm max.
Virginia	Occasionally woven geotextiles and geogrids. Type and property requirements vary by project.
Washington St	Attached
West Virginia	See attached II
Wisconsin	Geotextile fabrics as separator. Geogrids for structural support and load distribution.
Wyoming	Woven (130 lb/in wide with tensile) slit film to separate soft subgrade and base or pitrun backfill after subexcavation of soft soils. Nonwoven (65 lb/in wide) needle punched to separate use and drainage. Biaxial stiff geogrids (Tensar BX1100) to separate and stabilize soft soils. Have used with nonwoven fabric. Woven (200 lb/in wide) to separate and stabilize soft soils
Alberta*	On rare occasions, woven geotextile is used when building on muskegs and light weight fill- saw dust.
Manitoba	Using woven and nonwoven geotextiles as separator and reinforcement on specific locations.
Nova Scotia	See attached, " guidelines for geotextiles"
Ontario	Geogrids for reinforcement. Geotextile to separate subgrade and granular bases.
Quebec	Geosynthetic on subgrade to prevent contamination of the base and subbase materials by the fines from the subgrade
Saskatchewan	Geosynthetics (non-woven) for separation and filters.

* documents attached

Note : These states do not use geosynthetics - Kansas, Missouri, Nebraska,

TABLE A-20
Part 5 Stabilization of Weak Subgrades

Respondent	3. Other approaches
Arizona	Lime stabilization
Arkansas	Hydrated and pebble quick lime, or portland cement as drying agent to provide a working platform.
California*	Use of select material or lime stabilization.
Illinois	See attached sheet. For lime modification, chemical analysis is done on the lime and lime soil mix design is performed to determine the lime content
Indiana	Air drying, lime & cement stabilization and undercutting & replacement with aggregate.
Kansas	Lime to control swell and modify high clay content soil
Louisiana	Lime for conditioning. Cement for stabilization
Maine	Stabilization - compaction, & CaCl ₂ or H ₂ O only. Use construction surcharge, and remove before the next lift.
Massachusetts	Lime & Calcium Chloride
Minnesota	Lime sparingly for drying clayey soils very late in the construction season when "fanning" is impossible.
Missouri	Remove "soft spots" and replacement with approved stable material, subgrade scarifying and compaction, lime stabilization and the use of two foot or greater rock base when available.
Nebraska	Lime stabilization
Nevada	Lime stabilization. Replace material.
New Mexico	Lime, cement and flyash stabilization are under consideration.
New York	No lime/cement since 1960's. Plentiful granular material is cheaper
North Dakota	Lime on extreme cases
Oklahoma	Lime treated subgrade -- spec sect 307
Oregon	Occasionally lime or cement treatment
Rhode Island	Soil stabilization is not necessary for the type of soils in this region.
Texas	0.15 to 0.30 m (6 to 12 in.) lime, ASTM 977 to assure stabilization
Vermont	Underdrain, sand cushion (subgrade removal)
Virginia	Lime fairly extensively for certain soil types.
Washington	Lime/cement/flyash rarely due to quality of subgrade.
West Virginia	Undercut unsuitable material and backfill with stone. Cement stabilization.
Wisconsin	Undercutting and soil replacement; add coarse crushed stone (breakerrun), discing and drying.
Wyoming	Lime to stabilize silty subgrade soils on I-80 but difficult to maintain quality control during construction. Some areas that were treated too heavily with lime slurry mixture expanded after surfacing was in place.
Alberta	Subgrade preparation - lime is added to modify soils and rarely added to stabilize heavy clay soils.
Manitoba	Granular materials (e.g. 0.15 m or 6 in. minus limestone) to bridge the soft spots
Ontario	Lime stabilization occasionally
Quebec	Lime stabilization (scarcely), replacement with borrow materials (sometimes)
Saskatchewan	Only lime modification but high cost and difficult field control.

RAP = Recycled Asphalt Pavement, PCC = Portland Cement Concrete, ACC = Asphalt Cement Concrete

TABLE A-21

Part 6 Pavement Drainage

Respondent:	1. Protocol for Determining the Viability of Existing Pavement Subdrainage System
Arizona	Low Rainfall, subdrains are rare
Arkansas	Edge drainage systems are inspected using the Department's video inspection system.
California*	Attempt to clean existing system, reestablish subsurface drainage or remove and replace or plug and abandon depending on past performance. Positive drainage must be provided when possible.
Hawaii	No Subdrainage system
Illinois*	Inspection of pipe outlets
Indiana	Visual
Kansas	Use on all pavement with ESAL > 650
Louisiana	Camera's run through edge drain system.
Michigan	No drainage system
Minnesota	No edge drains in original pavements. Other types of drains are located and examined as to condition and functionally
Missouri *	Determine moisture related damage and if the base is permeable enough to facilitate edge drains.
Nebraska	Replaced damaged drains
Nevada	Project specific
New Mexico *	Majority of reconstruction using PCCP contain asphalt treated open graded base with underdrains. Flexible pavement are usually built on top of untreated base course which acts as drainable layer.
New York	Pavement distress symptoms and evidence of water pumping from the pavement will indicate whether drainage is required.
North Carolina	Visual inspection for outlets. Video camera for internal. Visual inspection of 4" diameter pipe edge drain.
North Dakota	On all interstate projects
Oklahoma	Do not know of a protocol
Oregon	If specific problems are identified a drainage design will be developed.
Pennsylvania	No evaluation in most situation except use camera in state wide projects
Texas	Insufficient experience in reconstruction with existing subdrainage systems
Virginia	Edge drains are constructed during rehab. Existing edge drains are reconstructed due to damage during reconstruction
Washington	Determine if existing system is adequate. Based on past history.
West Virginia	All rehabilitation requires improved drainage system. New construction requires a free drainage base course.
Wisconsin	No standard method. No drainage system on older pavements.
Wyoming	Surface condition survey & FWD in preliminary stages.
Newfoundland	Assessment on degree of saturation of subgrade, effectiveness of existing ditching, subdrains, visually assessed.
Nova Scotia	Visual
Ontario	Evaluation of existing pavement distresses visual examination of existing drainage system. If problem exists, boreholes and/or excavation is used to determine existing conditions of drainage system.
Saskatchewan *	Subdrain systems in cut sections are flushed and inspected visually

* Documents attached

TABLE A-22
Part 6 Pavement Drainage

Respondent	2. Description of the major aspect of subdrainage design and design methods
Arkansas	Subdrainage is provided when necessary to provide positive drainage of permeable base materials.
California	TPB drainage layer with lateral slotted pipe to outlet; edgedrains.
Connecticut	Underdrains and pavement edge drains in areas of high ground water.
Hawaii	Introduce permeable base.
Illinois*	IDOT Standard Specs
Indiana	Underdrains if subgrade soils are less permeable. Filter fabric if subgrade soils have high silt content.
Kansas	Ensure layer has sufficient permeability, adequate slopes for drains, adequate free board above ditch for outlets
Minnesota	Permeable bases and a minimum edge drains. Subcut drains to prevent "bathtub" design.
Missouri *	Attached
Nebraska	Trench and pipe drains in water flow area. Sand blanket on wet zones.
Nevada	French drain and edge drain.
New Mexico *	On new PCCP, a minimum of 4 in. of asphalt treated open graded base as drainable layer which is collected in underdrain system.
New York St	New construction requires a drainage layer and edge drains. Rehabilitation requires retrofit edge drains.
North Carolina	Total reconstruction rare. Most rehabilitation includes shoulder drains to drain out water quickly. Drainage design per NCDOT.
North Dakota	Use standard design.
Oklahoma	AASHTO Pavement Design Guide, layer coef = 0.12, drainage coef = 1.25
Pennsylvania	Design manual and roadway construction standards.
Texas	Used FHWA Reconstruction Project 87 report guideline.
Vermont	Underdrain installed in all cut sections
Virginia	0.075 m (3 in.) stabilized open graded drainage layer beneath the base course; perforated edge-drains backfilled with open-graded stone wrapped in a nonwoven geotextile fabric connected to nonperforated PVC laterals terminated at concrete endwalls.
Washington St	Day lighted sections. Internal system in urban areas. Edge drains not used. Permeable bases beneath PCC pavements.
Wisconsin	Open graded base as standard item.
Wyoming	Edge drains (conventional 4 in. pipe w/ fabric and drain gravel in a trench) on interstate to drain base material. Prefabricated edge drains were used but currently prohibited due to clogging.
Newfoundland	Adequate ditching and perforated pipe subdrains.
Nova Scotia	Rely on open ditch drainage and free draining granulars under the pavement except where piped/unpipd french drain systems are employed.
Ontario	Drainage layers and collector systems for all rigid composite and freeway flexible pavements. Positive drainage on all pavements. Crossfalls of minimum 3% ; subgrade, granular bases daylighted.
Quebec	Standards in Quebec are used.
Saskatchewan *	Water table elevation, gradeline, frost penetration depth, granular backfill gradation and pipe intervals.

* Documents attached

TABLE A-23
Part 7 Construction Methods for Maintaining Subgrade Integrity

Respondent	1. Innovations	2. Use of lightweight equipment
Arizona	No. Dry climate	Not needed
Arkansas	*Generally only vehicles used to dump the concrete is permitted on the subgrade immediately ahead of the paver.	None
California	Edgedrains, grouting, crack and seat PCCP	---
Florida	Base material is placed by back-dumping in these areas where the subgrade might be damaged during placement operations.	None
Hawaii	Not necessary	None
Illinois	Close some lanes (for construction) and open others to traffic	None
Indiana	None	None
Kansas	None	None
Louisiana	None	None
Maine	Subgrades will not support traffic so granular subgrade (one or more lifts) is placed and open to traffic.	None
Michigan	None	No. Contractor's responsibility
Minnesota	None	None
Missouri	None. Contractor's responsibility.	---
Nebraska	Construction phasing	Do not restrict vehicle weights. Make special provision statement that contractor shall employ methods which minimize damage to subgrade during removal operations.
Nevada	None	Yes - Recommend
New Mexico	Utilizes detours to keep traffic off. Detour specs attached - section 405	No. Conventional construction equipment.
New York	See specs	Left to the contractor (see specs)
North Dakota	None	None. Lightweight if fabrics are used
Oklahoma	None	None
Pennsylvania	None. Contractor's responsibility.	None
Rhode Island	Road close to traffic during reconstruction	
Texas	During construction, traffic is diverted to frontage roads which have been retrofitted with adequate shoulders.	None
Vermont	None	None
Virginia	Occasionally place limits on haul road boundaries.	N/A
Washington	None	None

TABLE A-23**Part 7 Construction Methods for Maintaining Subgrade Integrity**

Respondent	1. Innovations	2. Use of lightweight equipment
West Virginia	---	Not part of specification
Wisconsin	Temporary haul road	None
Wyoming	On interstate, switch traffic off lane and require contractor to maintain subgrade.	
Newfoundland	None	None
Ontario	Limit time subgrade is exposed.	None
Saskatchewan	Contractor is responsible for maintenance of the existing surface. Construction traffic cannot be limited on the travelled lanes (a public highway) as long as legal loading is maintained.	None

ESAL = equivalent single axle load

*Documents attached

TABLE A-24**Part 7 Construction Methods for Maintaining Subgrade Integrity**

Respondent	3. Other maintenance practices
Arizona	Not needed
Arkansas*	None
California*	Contractor's responsibility to control erosion and divert surface water away from the work. The final grading plane shall conform to the profile and grade established by engineer.
Illinois*	Subgrade sealing and crowning. Cutting the source of surface water through diversion ditches. (IDOT Secs 302 & 310)
Indiana	Subgrade crowning reduces infiltration.
Kansas	Crown subgrade promotes drainage.
Maine	Geotextiles on occasion.
Michigan*	Part of normal construction practices - not mandated
Minnesota	Subgrade drainage - contractor's responsibility. Depression in the subgrade prior to placement of any base course are to be filled and compacted and shaped to grade.
Nebraska	Require contractor by specification to provide drainage at all times.
Nevada	Rubberized asphalt & moisture barrier.
New Mexico*	Crowning or cross-slopes of 0.015 to 0.02 ft/ft (Refer to pavement type selection & design policy (1993))
New York	Contractor's responsibility.
North Dakota	Crowned, sloped and/or primed with asphalt.
Oregon	On occasion , no construction equipment on subgrade.
Pennsylvania	Subgrade compacted to grade and sloped for drainage. Construction traffic - contractor's responsibility
Rhode Island	Subgrade crowning to provide adequate drainage
Texas	Lime treatment of subgrade
West Virginia	Positive drainage. Surface is sealed with smooth drum roller.
Wisconsin	Maintenance & draining subgrade - contractor's responsibility
Alberta*	Not specified. Contractor is specified to maintain subgrade to be firm and uniform and repair any damages at his own expense.
Nova Scotia	Subcrown crowning at 2 to 3%
Ontario*	Attached - Earth Excavation, Construction procedure.
Quebec	Subgrade crowning is systematically used. Static compaction for the first layer overlying the subgrade.
Saskatchewan	Contractor's responsibility

*Documents attached

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