Preliminary Guidelines for Material Requirements of Low-Volume Roads

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The major findings of the study "Development of Preliminary Guidelines for Material Requirements of Low-Volume Roads" are summarized in this paper. The diminishing aggregate supply has forced many highway engineers to be more conservative in their use of conventional aggregates. As a result, the use of marginal aggregates for low-volume road construction is seriously considered to be a possible alternative. This study was undertaken to investigate the relationship between aggregate properties and roadway performance to determine whether traditional requirements for these properties could be revised. The performance of low-volume roads is considered to be influenced by three major elements: environmental conditions, material properties, and service levels. Moisture and temperature were identified as the main environmental factors, and plasticity, gradation, and degradation were selected as the most significant material properties. The more common failure types (indicators of performance) for low-volume roads and factors that affect performance are also presented. Preliminary guidelines were developed for relaxing the standard specification requirements of aggregates for low-volume roads. To demonstrate their applicability, 12 reportedly marginal materials from the Globetrotter study were evaluated. Throughout the report, the need for a monitoring system to collect performance data for nationwide use is strongly emphasized.

Guidelines have been developed from a final project report entitled "Development of Preliminary Guidelines for Material Requirements of Low-Volume Roads." The final report describes the research association with the Federal Highway Administration (FHWA) Research Project entitled, "Establish Requirements of Materials for Low-Volume Roads." The results presented in this report are based on the knowledge and experience of the project staff supplemented by numerous interviews with field engineers intimately involved with low-volume road problems. A review of the available literature, design manuals, existing specifications, and related materials is also presented.

The purpose of these guidelines is to illustrate how material specifications could be relaxed for use in certain low-volume road (LVR) construction as a function of the environmental region. These relaxed materials specifications could allow the use of what are now termed lower-quality or marginal quality materials for the construction of LVR. The user should refer to the final project report for a more detailed discussion on the development of the tables and figures used in these guidelines and for case studies of the use of marginal materials in LVR.

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DEFINITION OF LOW-VOLUME ROADS

A classification on the basis of traffic volumes is needed for the selection of materials for LVR. For the purposes of these guidelines, LVR are divided into two classes as follows:

Class I

Class I refers to those LVR with an average daily traffic (ADT) of less than 50. Class I roads are generally unsurfaced (graded in situ) or have a selected granular soil or soil aggregate surface and rarely have a treated surface.

Class II

Class II refers to those LVR with an ADT between 50 and 400. Class II roads generally have selected granular or stabilized soil aggregate surfaces. At higher traffic volumes, the surface may be a single or double course penetration type surface and rarely will have an asphaltic or other concrete surface layer (*1*).

OBJECTIVES

One objective of this research is to investigate the relationship between material properties and performance and to determine whether or not the traditional requirements of these properties can be relaxed for low-volume roads.

The other objective is to determine the minimum quality of aggregates that is acceptable for low-volume roads when considering aggregate type, environmental conditions, and road importance depending on whether the road is paved or unpaved.

RESEARCH APPROACH

A literature search was performed to meet the objectives of the project, and interviews with selected managers of LVR were conducted. Environmental factors important to the performance of LVR were identified. In order to evaluate the effect of these environmental factors on road performance, four different environmental regions were selected. These environmental regions were selected on the basis of temperature and moisture. The relationships between material requirements and roadway performance in these regions were investigated.

A detailed list of material properties and their importance to the performance of such roads was gathered from the literature review. Specifications currently used by the states and various other public works agencies were assimilated and summarized. For the purposes of this research, the extensive list of material properties was reduced to those properties that were considered relevant by the agencies, namely, plasticity, gradation, resistance to wear, durability, and resistance to freeze-thaw and wet-dry cycles.

Various agencies and certain managers of low-volume roads were contacted to identify the failure types encountered in low-volume roads, and information regarding the failure criteria used was obtained. These criteria were examined to evaluate how they varied with road importance, environmental region, and terrain. Performance prediction models were also reviewed in an attempt to assess the economic consequences of using low-quality aggregates.

The important material properties and limiting conditions were formulated as a function of road importance and environmental restraints. Using these data, tables were developed to assist the designer of LVR to evaluate the suitability of materials that did not meet current specifications. A suggested procedure was provided to classify and evaluate a material for use in LVR.

ENVIRONMENTAL REGIONS

Environmental factors, particularly those related to climate, can have a significant effect on the performance of a pavement and should therefore influence material requirements for LVR. Two environmental factors, moisture and temperature, were used to establish four environmental regions to be used in the selection of material requirements for LVR.

Moisture

Most pavement engineers agree that the presence of excessive moisture in a pavement system is usually detrimental to overall performance (*2*). The moisture available is influenced by the amount of rainfall and the amount of evaporation that occurs locally. Thornthwaite related the two by introducing the concept of potential evapotranspiration (*3*). This value represents the amount of water that would return to the atmosphere if the supply of water to the plants and ground was unlimited.

When a surplus exists, moisture is stored in the subsoil. Moisture is removed from the subsoil during deficit periods. These periods are seasonal. However, a general index for the area over time can be computed. The Thornthwaite Moisture Index distribution in the United States is illustrated in Figure 1 (*3*). A negative value indicates a moisture deficit region (dry), and a positive value represents a moisture surplus region (wet).

It can be seen in Figure 1 that the eastern half of the United States generally has a moisture surplus (wet) and the western half generally has a moisture deficiency (dry). In other words, pavement problems related to excess moisture are generally more prevalent in the eastern portion of the United States.

Temperature

Researchers generally agree that many temperature-related pavement problems result from low temperatures, in particular freezing temperatures. High temperatures are usually not

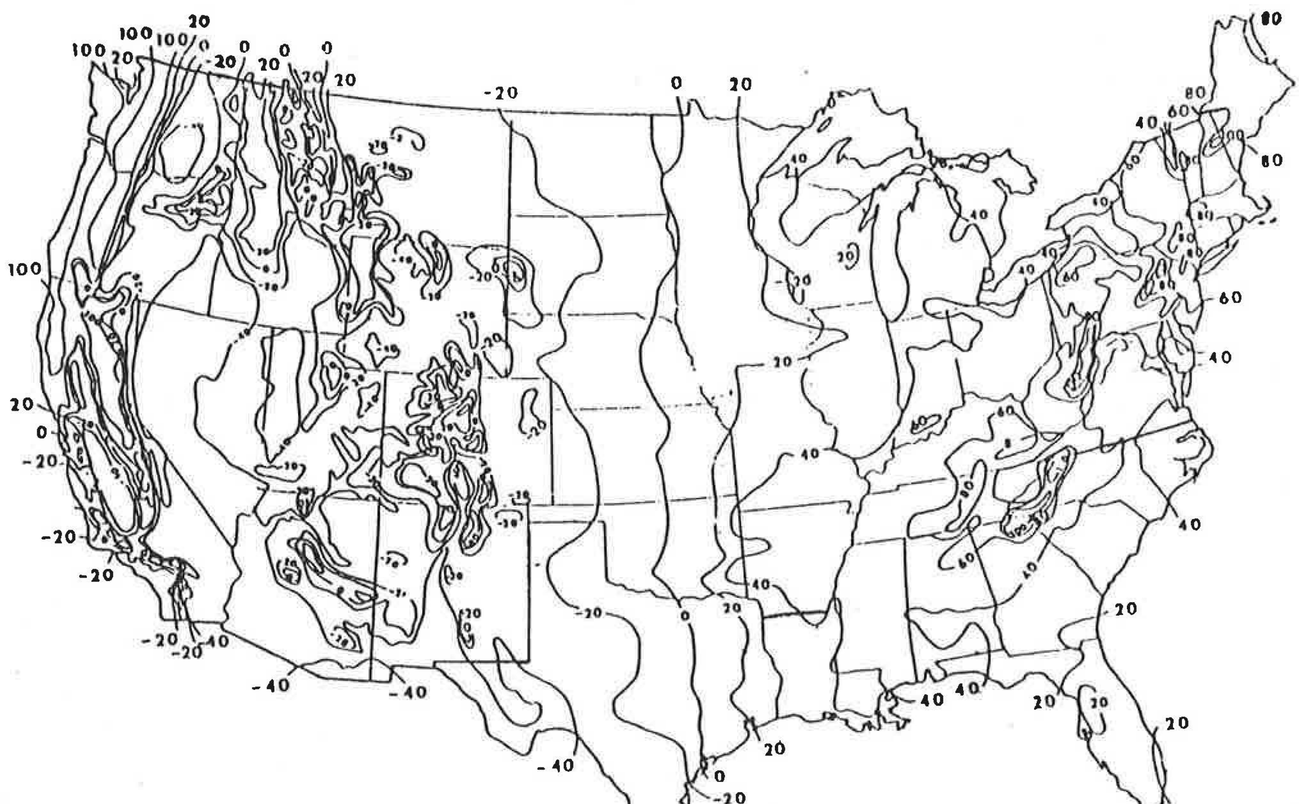

FIGURE 1 Thornthwaite Moisture Index distribution in the United States.

detrimental to aggregate-surfaced roads. Sourwine was among the first to recognize that temperature had to be related to duration in order to evaluate its effects (*4*). His work led to the freezing index, which is used by several agencies as a design consideration. The freezing index is the difference between the maximum and minimum points on a curve of cumulative degree days of below freezing temperature. A degree day is defined as the algebraic difference between the mean daily temperature and 32° F (10° C) multiplied by the duration of the temperature in days. The distribution of mean freezing indices for the continental United States is shown in Figure 2. Researchers have recommended that the 100 freezing index contour be used as a threshold value (*5-7*). In other words, if the road in question is above the index of 100, then frost-heave may be a consideration in the design of the road and in the materials selection process.

As shown in Figure 2, the 100 freezing index contour divides the continental United States into two temperature zones. The southern half is a no-freeze or hot zone, and the northern half is a freeze or cold zone. Pavement problems related to freezing temperatures are therefore more prevalent in the northern portion of the United States.

Selection of Environmental Regions

For the purposes of these guidelines, four environmental regions were selected. These regions are cold/dry, cold/wet, hot/dry, and hot/wet, as shown in Figure 3. These regional divisions have been used by others as environmental inputs for pavement studies (*8-10*). These regions are provided for general selection only and should not be construed to represent local conditions completely. If the moisture index and freezing index are known for a particular location, those values should be used to determine environmental inputs. It should be noted that in terms of moisture index and temperature index every local situation can generally be placed into one of the four environmental regions. If the local area is on the borderline, for example, has a moisture index of zero, then the designer will have to consider two environmental inputs and choose the more conservative values for materials selection.

Hot/Dry Region

This region generally describes an area with less than 100 degree days annually and a negative moisture index. These areas are typified by a low annual rainfall of less than 35 in (889 mm), high mean annual temperatures greater than 50° F (10° C), and sparse vegetation.

Hot/Wet Region

This region describes an area with fewer than 100 degree days annually and a positive moisture index. These areas are typified by a high annual rainfall greater than 35 in (889 mm), high mean annual temperatures greater than 50° F (10° C), and heavy vegetation.

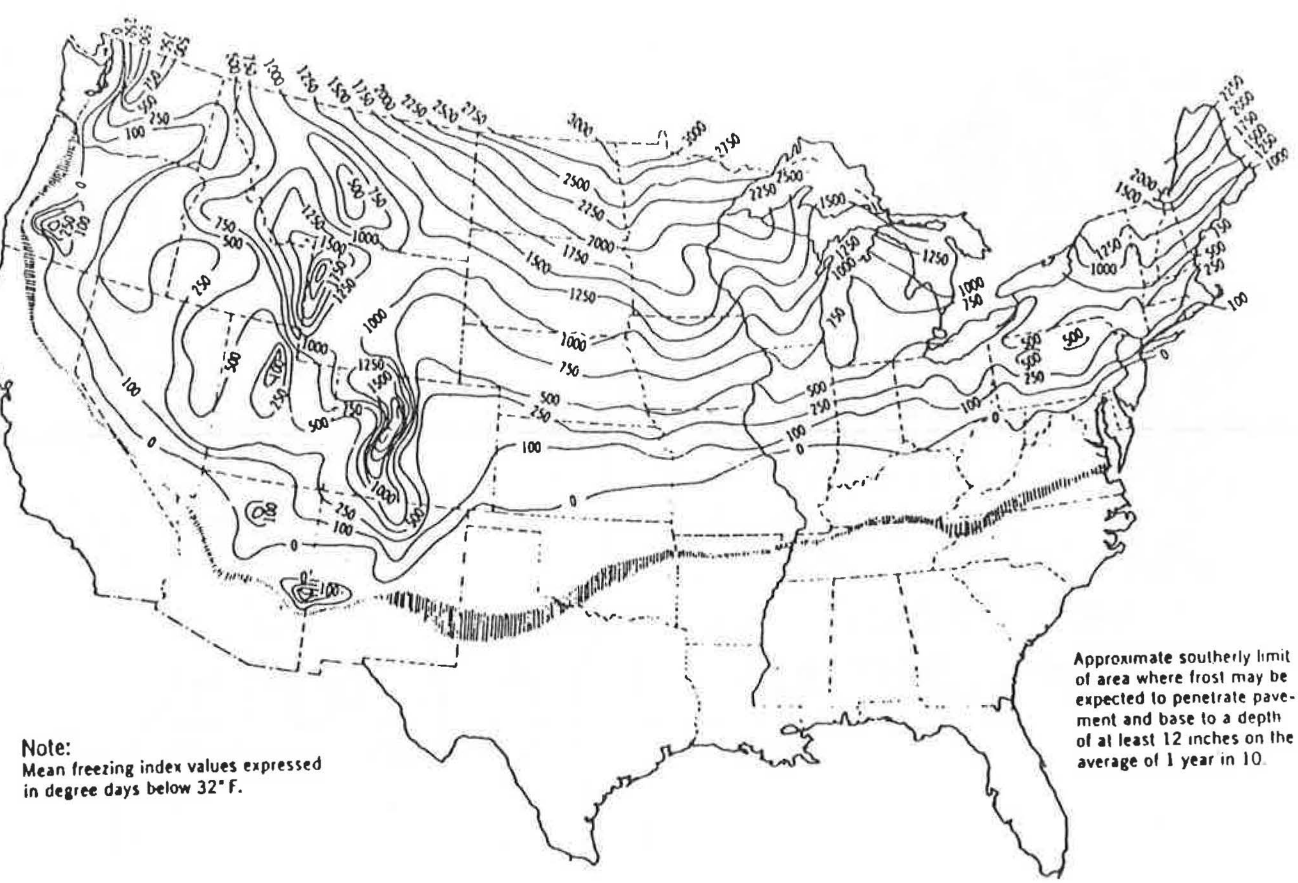

FIGURE 2 Freezing index map.

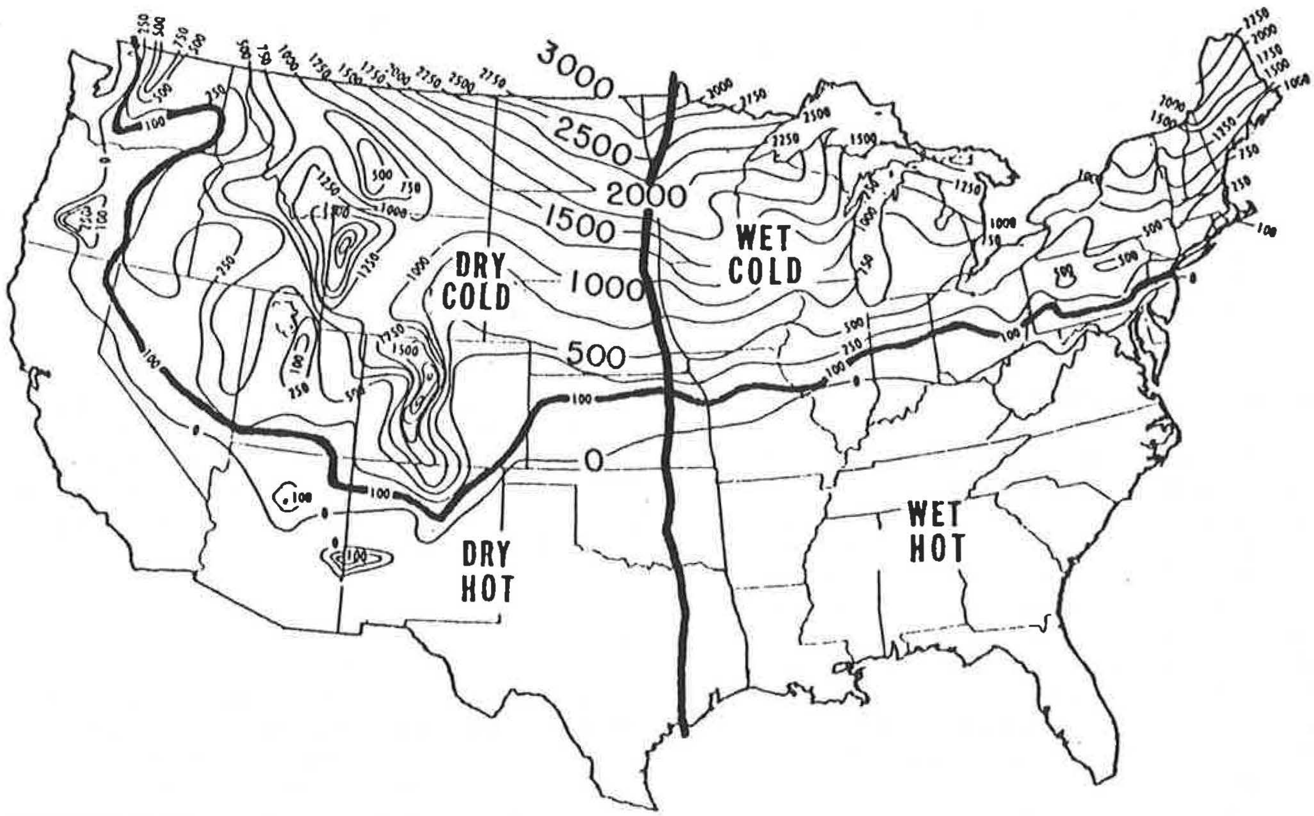

FIGURE 3 Environmental regions.

Cold/Dry Region

This region describes an area with more than 100 degree days annually and a negative moisture index. These areas are typified by a low annual rainfall of less than 35 in (899 mm) and low mean annual temperatures less than 50° F (10° C).

Cold/Wet Region

This region describes an area with more than 100 degree days annually and a positive moisture index. These areas are typified by a high annual rainfall greater than 35 in (889 mm) and a low mean annual temperature of less than 50° F (10° C).

Relationships Between Environmental Regions and Performance

The relationship between environmental region and performance can be discussed in qualitative terms only because quantitative values of performance for LVR are extremely limited. Although there is sufficient experience and interest in the performance of LVR, no systematic approach exists among LVR managers for measuring, recording, and reporting performance data.

Hot/Dry Weather Deterioration

In this environmental region, deterioration most likely involves the surface layer because of the typically dry nature of the subsurface layers. The following are the most prominent deterioration mechanisms in unpaved roads in dry weather:

- Wear and abrasion of the surface, which generates loose material and develops ruts;
- Loss of the surfacing material by whip-off and dust;
- The movement of loose material to form corrugations under traffic action; and
- Raveling of the surface in cases in which the binding power of the material is insufficient to keep the surface intact (*11*).

The sustained higher temperatures in this region result in softening of the asphalt cement of paved roads for longer periods of time than occur in colder regions. This softening of the asphalt cement results in an increased incidence of raveling, bleeding, shoving, slippage, and weathering.

Hot/Wet Weather Deterioration

In this environmental region, deterioration may occur in both the surface and subsurface. Soils in this region typically have high moisture contents, which cause the subsurface layers to have lower strengths. Weaker subsurface layers result in an increased incidence of rutting, surface erosion, and potholes in unpaved roads, and corrugation, alligator cracking, depressions, and rutting in paved roads.

Cold/Dry Weather Deterioration

In the cold/dry region, as in the hot/dry region, deterioration predominantly occurs on the surface. The potential exists for freezing-thawing deterioration, but the low moisture contents of the subsurface layers cause other forms of deterioration to be more frequent and extensive.

Deterioration of unpaved roads will generally be the same as that of hot/dry regions. The prevailing forms of deterioration in paved roads are weathering, transverse cracking, longitudinal cracking, and alligator cracking.

Cold/Wet Weather Deterioration

Deterioration in cold/wet regions is similar to that of hot/wet regions, except for the additional detrimental effects of frost heave and freeze-thaw cycles.

MATERIAL REQUIREMENTS

The standard specification requirements of those aggregate properties that are considered pertinent to low-volume roads were evaluated to determine whether these specifications could be relaxed as a function of environmental conditions. The AASHTO, ASTM, and FHWA specifications were used as a basis and, where applicable, the U.S. Forest Service specifications were included. The test methods most widely used by these agencies and state highway departments were reviewed in addition to those proposed and used by other agencies.

Given the selected aggregate properties and standard test methods, the consequences of relaxing these standard specification requirements in various environmental regions were summarized and evaluated based on the literature review and interviews with consulting engineers. Preliminary guidelines are suggested for relaxing currently used aggregate requirements.

Methods of Testing Aggregates

Several test methods are available to determine the quality of aggregates. Because the majority of state highway agencies specify aggregate requirements based on AASHTO procedures, the quality of the aggregates for LVR will also be based on the AASHTO test methods for consistency. The materials tests to be used with these guidelines are summarized in Table 1.

Plasticity

Most public agencies determine the plasticity of an aggregate by its liquid limit (LL) and plasticity index (PI). The AASHTO T-89 test is a standard test method for determining the liquid limit of soils, and the AASHTO T-90 test contains a standard procedure for determining the plastic limit of soils. The plasticity index is the numerical difference between the liquid limit and plastic limit of the soil.

Gradation

The AASHTO T-27 or T-88 tests are the usual methods public agencies use to determine the gradation of aggregates. The AASHTO T-27 test covers a procedure for the determination of the particle size distribution of fine and coarse aggregates by use of sieves with square openings. The AASHTO T-88 test describes a procedure for the quantitative determination of the distribution of particle sizes in soils.

TABLE 1 TYPICAL TESTS USED TO SPECIFY QUALITY OF AGGREGATE MATERIALS

AASHTO Designation	Title	Purpose
T-89	Determining the Liquid Limit of Soils	To determine the amount of soil binder material present for classification and specification check.
T-90	Determining the Plastic Limit and Plasticity Index of Soils	To determine the range of moisture in which a soil remains in a plastic state and to determine the effect of moisture on the soil material and specification.
T-27 or T-88	Sieve Analysis of Fine and Coarse Aggregates or Particle Size Analysis of Soils	To determine the partial distribution of fine and coarse aggregates using the mechanical analysis.
T-96	Resistance to Abrasion of Small Size Coarse Aggregate by use of the Los Angeles Machine	To test sizes of coarse aggregate smaller than 1.5 in. (37.5 mm) for resistance to abrasion.
T-210	Production of Plastic Fines in Aggregates	To determine the durability of aggregates by indicating the relative resistance of an aggregate to produced detrimental clay-like fines when subject to degradation.

Resistance to Wear

The standard method of test for resistance to abrasion of coarse aggregates smaller than 1.5 in (38 mm) is covered in the AASHTO T-96 test using the Los Angeles testing machine. It is a mechanical degradation test that is used to measure the ability of an aggregate to resist being worn away by the rubbing and friction produced by externally applied forces such as tires. Because untreated or surface-treated roads are designed to carry low traffic volumes, base-course aggregates are not significantly affected by these loads. As a result, the Los Angeles abrasion specifications are not required for untreated bases in these guidelines.

Durability

The AASHTO T-210 test describes the procedure for determining the durability of aggregates. The durability index is a value that indicates the relative resistance of an aggregate to producing detrimental clay-like fines when subjected to the prescribed mechanical methods of degradation.

Recommended Limiting Values of Aggregate Properties

The limiting values presented in Tables 2, 3, and 4 are recommended as guidelines to evaluate the suitability of local materials for road construction. The use of these tables should assist the designer of low-volume roads to consider materials that provide adequate performance but do not currently meet the standard specifications. The user only needs to identify the intended use (location of the aggregate in the pavement structure) and the local environment to use the tables. If staged construction is to be performed, then Table 2 should be used for base courses under either untreated or treated surfaces.

Twelve reportedly marginal aggregates from another study were selected to demonstrate the use of these tables. A

TABLE 2 RECOMMENDED LIMITING VALUES OF AGGREGATE PROPERTIES FOR UNTREATED SURFACE COURSES

Material Property	Current Practice	Limiting Values per Environmental Region			
		Cold/Dry	Cold/Wet	Hot/Wet	Hot/Dry
Gradation					
%-200 (.075 mm) sieve	8 Min	6 Min	6 Min	6 Min	6 Min
Max. Part. Size, in. (mm)	1 (25)	1.5 (38)	1.5 (38)	1.5 (38)	1.5 (38)
Plasticity					
Liquid Limit, %	35 Max	55 Max	40 Max	35 Max	55
Plasticity Index, %	4-9	2-15	2-9	2-9	2-15
Degradation					
Los Angeles Abrasion, %	40 Max	50 Max	50 Max	50 Max	50 Max
Durability Index	35 Min	35 Min	35 Min	35 Min	35 Min

TABLE 3 RECOMMENDED LIMITING VALUES OF AGGREGATE PROPERTIES FOR UNTREATED BASE COURSES UNDER UNTREATED SURFACE COURSES

Material Property	Current Practice	Limiting Values per Environmental Region			
		Cold/Dry	Cold/Wet	Hot/Wet	Hot/Dry
Gradation					
%-200 (.075 mm) sieve	8 Max	10 Max	9 Max	9 Max	12 Max
Max. Part. Size, in. (mm)	1 (25)	2 (50)	2 (50)	2 (50)	2 (50)
Plasticity					
Liquid Limit, %	25 Max	30 Max	25 Max	25 Max	30 Max
Plasticity Index, %	6 Max	8 Max	8 Max	8 Max	10 Max
Degradation					
Durability Index	35 Min	35 Min	35 Min	35 Min	35 Min

TABLE 4 RECOMMENDED LIMITING VALUES OF AGGREGATE PROPETIES FOR UNTREATED BASES UNDER UNTREATED SURFACE COURSES

Material Property	Current Practice	Limiting Values per Environmental Region Cold/Dry	Cold/Wet	Hot/Wet	Hot/Dry
Gradation					
%-200 (.075 mm) sieve	8 Max	10 Max	9 Max	9 Max	15 Max
Max. Part. Size, in. (mm)	1 (25)	2 (50)	2 (50)	2 (50)	2 (50)
Plasticity					
Liquid Limit, %	25 Max	30 Max	25 Max	25 Max	30 Max
Plasticity Index, %	6 Max	8 Max	8 Max	8 Max	12 Max
Degradation					
Durability Index	35 Min	35 Min	35 Min	35 Min	35 Min

description of these materials and their classification based on the AASHTO Soil Classification System are presented in the final report. To verify the effectiveness of the tables, each sample was evaluated based on its in situ properties and past performance in a given region.

TECHNICAL, ECONOMIC, AND ECOLOGICAL EFFECTS OF USING LOW-QUALITY AGGREGATES

No hard data could be identified that evaluated the performance of truly marginal or low-quality aggregates. As a result, no detailed or quantitative impacts can be presented. However, material property data available from other studies were used in models to illustrate the effects.

The approach taken is to examine the effect of relaxing aggregate requirements for base courses only in paved roads. In other words, when a chip seal or hot-mixed asphalt concrete surface layer is used, it will require high-quality aggregates. The aggregate requirements can be relaxed for all layers of aggregate-surfaced roads.

Technical Impact

Two limiting alternatives are generally accepted when consideration is given to the use of lower-quality or marginal aggregates for LVR. The first limiting alternative is to use the aggregate as available and accept the consequences or risks associated with poorer pavement performance. Most pavement engineers would agree that whether the road is paved or unpaved, the expected performance would be as shown in Figure 4. Although many variables affect pavement performance, it is generally expected that the use of lower-quality aggregates results in poorer performance. The second limiting alternative is to enhance the low-quality aggregate in such a way that its material properties or performance characteristics are equal to or better than available high-quality aggregates.

The first limiting alternative is not usually available in current practice because the aggregate does not satisfy certain specifications. However, the relaxation of current specifications would allow the use of lower-quality aggregates with perhaps shorter service lives. The second limiting alternative is sometimes more costly than purchasing high-quality aggregates.

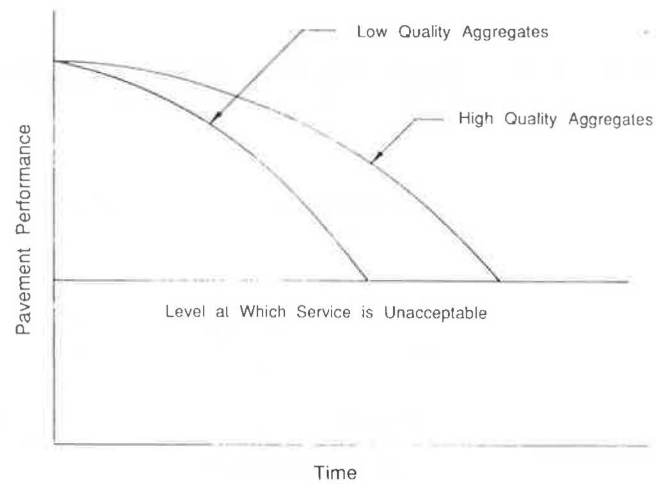

FIGURE 4 Pavement performance versus time.

In addition to these limiting alternatives, there are many other choices such as relaxing specifications or partial enhancement in the form of screening to improve gradation or washing to remove excess fines. Another choice is the use of an admixture for stabilization to an acceptable performance level but not necessarily to the level of a high-quality aggregate. The specifications for aggregates for LVR should be written in such a manner as to allow the selection of an alternative that can be economically justified.

Economic Impact

The economic consequences can only be suggested because no hard data exist and each set of circumstances may produce quite different results. Many factors influence economics, including everything from interest rates to local politics. However, in most instances, whatever savings are realized will generally accrue to local agencies. Consider the following benefits of using marginal aggregates.

- *Environmental.* In many areas, marginal aggregates are a waste product associated with high-quality aggregates. The use of marginal-quality aggregates would therefore reduce the impact of mining in these areas.

- *Efficiency*. The use of marginal-quality materials would preserve limited supplies of high-quality aggregates for high-type construction.
- *Construction*. Layman demonstrated that materials represented approximately 51 percent of the in-place cost of asphaltic concrete (*12*). A 10 percent reduction in the cost of materials would therefore result in a 5 percent reduction in the total construction cost of the pavement.

In a laboratory study, Schoen et al. showed that mix designs that use marginal aggregates could produce mixtures with properties consistent with conventional black base mixtures at a substantially lower cost (*13*). They also pointed out that mixture design and pavement design must be considered simultaneously to use marginal materials economically.

Burchfield and Hicks demonstrated that a cement-treated marginal aggregate would provide pavement equivalent to untreated high-quality aggregate at a lower cost if the haul distance for the high-quality aggregate exceeded the haul distance for the marginal material by at least 28 mi (47 km) (*14*).

Ecological Impact

As long as good engineering design practices for geometrics, drainage, and pavements are followed, the use of marginal materials should not increase the potential for ecological damage. The Environmental Protection Agency provides an adequate design procedure to reduce the environmental impact of unpaved roads. (*15*).

One exception may be an increased potential for dust, particularly if the use of the marginal material is not designed to provide equivalent performance to high-quality materials. Becker has shown that roughness is a significant factor in increasing dust when an average increase in roughness is the result of the use of the marginal material (*16*). However, this is primarily true when silt-size particles are present. When silt-size particles are present in the surface materials, the use of a dust palliator, such as oil or chlorides, should therefore be considered.

CONCLUSIONS AND RECOMMENDATIONS

As was observed earlier in this report and repeated many times, little, if any, hard data relate aggregate properties to pavement performance for LVR in general, and for unpaved (aggregate-surfaced) roads in particular. The basic findings of this report therefore represent the best estimate of what will occur under certain circumstances based on experience, published laboratory studies, models, published data from other countries, and some published case studies.

Conclusions

The following represent the basic findings of the final project report, "Development of Preliminary Guidelines for Material Requirements of Low-Volume Roads":

- A need exists to conserve high-quality aggregates for more critical uses and to reduce construction costs of LVR.
- No state modifies its aggregate specifications for LVR to account for environmental or traffic factors.
- Based on current practices, aggregates for LVR are evaluated primarily on the basis of gradation, plasticity, and degradation.
- Environmental factors of moisture and temperature should influence aggregate specifications for LVR.
- Current aggregate specifications for LVR can be relaxed in certain areas without significantly affecting pavement performance.
- Many low-quality aggregates can be economically enhanced for adequate performance in LVR.
- Insufficient LVR pavement performance data are currently available.

Recommendations

The following recommendations are made:

- Laboratory studies should be conducted to include a minimum of four low-quality aggregates from each environmental region.
- Aggregate specifications for LVR for selected agencies should be relaxed in accordance with Tables 2, 3, and 4 until performance data support or refute the relaxation. These agencies should include city, county, and state agencies as well as federal agencies such as the U.S. Forest Service.
- Pavement performance data on LVR should be obtained in a uniform and rational manner from selected agencies. The U.S. Forest Service has conducted a study to evaluate which types of equipment and procedures should be used to obtain a data base for LVR. The project should provide an excellent approach for performance data collection.
- Simple aggregate tests should be developed to predict performance.

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Proposed Specifications of Soil Aggregates for Low-Volume Roads

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Lateritic soils are extensive in Thailand, and have been employed as highway materials for many decades. Test results on selected lateritic soils tend to reflect that lateritic gravel in Thailand is durable as a base course for low- and medium-volume roads. However, the results of an Atterberg limits test showed that both the LL and PI of most lateritic soils in Thailand are higher than the adopted criteria. In order to more efficiently employ local materials for low- to medium-volume road construction, modifications of the present specifications are necessary. On the basis of the results obtained in this investigation, values of LAA, LL, PI, and the percent passing a No. 200 sieve are proposed as changes to be able to use the soil aggregates in Thailand as a base and subbase for low- and medium-volume roads.

Northeast Thailand occupies about one-third of the total area of the kingdom, and this region is physiographically called the Khorat Plateau or the Northeast Plateau because of its relatively flat, elevated plain. A rather complex road system was built to link cities, districts, villages, and other populated areas to induce economic growth and to develop communities in this region. The most available local materials in this area are lateritic soils, gravel, and silty sand. Some rock sources are also available in the southernmost and westernmost parts of the Khorat Plateau, which border other physiographic regions. As a consequence, problems are encountered in road construction and maintenance in some parts of the Khorat Plateau, especially in the north, with rock deficiency for pavement construction. The hauling distance from the rock quarries to some projects could be as far as 150 to 200 kilometers. The probable rock sources in this region are shown in Figure 1.

The other factor to be considered in pavement design in Thailand is overloaded trucks. Most trucks that carry the construction materials, especially the rock products, are overloaded. It was found from random spot checks that most 10-wheel trucks (three axles) that carry the construction materials have a gross weight in the range of 300 to 400 kN, whereas the legal load limit is only 210 kN. These overloaded trucks tend to destroy the pavement structure along all the roads they pass. Therefore, once the Thailand Department of Highways constructs a new road, some sections of the existing ones will already be deteriorated as a result of overloaded trucks that haul the construction materials. Because the traffic volume on the roads in this region is generally low to medium, employing inferior local materials in road construction tends to solve this problem. However, the present material specifications adopted by the Thailand Department of Highways are similar to those recommended by AASHTO; in fact, AASHTO specifications are suitable for high-standard roads. In order to make more effective use to be made of local materials for the construction of low- and medium-volume roads, new specifications for local materials must first be established.

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