A Simple Empirical Guide to Low-Volume Road Pavement Design in Indiana

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ABSTRACT

Low-volume roads constitute the vast majority of the United States road network. From an economic standpoint, low-volume road preservation accounts for more than eighty billion dollars per year, or more than half of the annual investment in roads. Although low-volume roads carry a small percentage of the overall traffic, their associated crash rates are considerably higher than those for higher volume roads. Clearly, low-volume roads are an important part of the nation's transportation infrastructure. Thus, there is a need to design low-volume roads using engineering principles to ensure an economic design and avoid premature road failures. Many agencies have proposed low volume design methods, yet most of them require input that may not be available to local agencies. To that end, this paper develops an empirical low-volume road design guide that requires minimal input that is readily available to local agencies, and is simple to use, while at the same time is customizable in order to account for specific weather and sub-grade conditions.

INTRODUCTION

Low volume roads constitute 86 percent of the developing world's road network (*1*). In the United States (US), approximately 70 percent of federal-aid road miles are considered low-volume roads, with low-volume road maintenance and rehabilitation accounting for $82 billion per year, or about 54 percent of the annual road related investment (*2*). Of these low-volume roads, more than 2.6 million miles are under the control of local government agencies (*3*). Although eventually low-volume roads carry only 15 percent of the traffic in the US, their corresponding accident rates are considerably higher as compared to higher-volume roads. An example of this disparity shows an average of 2.41 accidents per million vehicle miles traveled on low-volume roads versus an average of 1.56 for higher-volume roads (*4*). For more information on low-volume roads and their impacts the reader is referred to Faiz, 2012(*5*).

Clearly, low-volume roads are an important part of the nation's transportation infrastructure. To that end, the need to design low-volume roads using engineering principles to ensure an economic design and avoid premature road failures is exigent.

The objective of the work outlined in this paper is the development of an empirical low-volume road design guide that requires minimal input that is readily available to local agencies, and is simple to use, while at the same time is customizable to account for specific weather and sub-grade conditions.

REVIEW OF PAST WORK

The Federal Highway Administration (FHWA) classifies low-volume roads as roads servicing an average daily traffic (ADT) of less than 500 vehicles per day (*3*, *5*). Apart from the FHWA's generic definition that uses traffic volume as the main categorization criterion, low-volume roads have been defined differently for various organizations. A typical alternative criterion is the relative pavement structure damage caused by various axle loads, using the Equivalent Single Axle Load (ESAL). This mixed traffic causes various magnitudes and repetitions of wheel loads, and can be readily converted to an equivalent standardized "loads" number, with the most common being the 18,000 lbs (80 kN) ESAL (note that 1 pound = 0.454 kilograms). There are two standard US ESAL equations derived from the AASHTO Road Test, both dependent on the pavement type (rigid or flexible) and on the pavement structure (slab thickness for rigid pavements, and structural number for flexible pavements). It should be noted that the ESAL take into account mixed traffic loads. This allows for heavier and lighter vehicles and their associated loads to be properly considered, along with the number of lanes, traffic growth, traffic distribution and design period. Therefore, ESAL require more effort to obtain, but have the potential to provide more accurate road function classifications. Hall and Bettis (*3*) summarize that: (a) the American Association of State Highway and Transportation Officials (AASHTO) 1993 Design Guide considers a road to be low-volume when 50,000 < ESAL < 1,000,000; (b) the Asphalt Institute (*6*) considers a road to be low-volume when ESAL < 10,000; and (c) the Washington State Department of Transportation considers a road to be low-volume when ESAL < 100,000. Note that the AASHTO Guidelines for Geometric Design of Very Low-Volume Local Roads classifies low-volume roads as roads with ADT < 401 vehicles; however, this design guide is primarily relevant to roadway geometrics, and does not fall within the scope of this investigation (*7*).

Low-volume design methods have been widely developed and successfully used by federal and state agencies across the US (*8-23*). In Indiana, possibly the first such guide was developed in 1974 (*24*). While these methods are well adjusted for the particular agency's needs and capabilities, most of them require input that is typically not available to local agencies. For example, the AASHTO has developed a procedure broadly utilized by 37 of the 48 continental United States (*3*). Interestingly, the low-volume road design procedure is a simplified version of the high-volume road design procedure (similar design charts and input requirements are used). Specifically, the required inputs involve the subgrade resilient modulus (MR), design reliability (set to 50%), traffic (ESAL), and material properties for each layer (i.e., the structural layer coefficients, a_i). However, the number of variables and relative complexity of this procedure can make it cumbersome for low-volume road designs, given the limited resources available to local agency engineers. The problem is further compounded by the lack of information as well as time and budget constraints.

The United States Army Corps of Engineers (USACE) also developed a low-volume road design procedure that is widely used and is a simplified version of USACE's airport pavement design method. The relatively simple procedure has two major design input components: traffic load (ESAL) and soil strength (California Bearing Ratio, CBR). Even though the overall procedure is simple, complex equations are needed to estimate the structural thickness required for a material to be placed on top of another material of a given CBR strength, provided that the CBR of the added material is greater than the CBR of the underlying material.

The National Crushed Stone Association (NCSA) adapted parts of the USACE method, added several elements, and applied it to bituminous surfaces overlaying a crushed stone base (*25-26*). The expected soil support as determined from CBR values is separated into four categories: excellent, good, fair and poor. A Design Index (DI) is assigned based on the expected traffic conditions, and a total thickness of crushed stone or bituminous surface is selected from design tables. This design thickness is modified if severe conditions are applicable, such as frost damage or drainage issues.

Relatively recently, several states (California, Illinois, Kentucky, Mississippi, New York, Pennsylvania, Texas, Vermont, Virginia, and Minnesota) have developed their own non-AASHTO low-volume road design protocols with varying levels of complexity, incorporating environmental, soil, and traffic factors specific for their region. A representative example is Minnesota, which has two design procedures: the Gravel Equivalency (GE) method found in the State Aid Manual, and the R-value method (i.e., a measure of the response of a compacted sample of soil or aggregate to a vertically applied pressure under specific conditions) (*3*, *27*). The GE method is more commonly implemented throughout the state due to its simplicity and less conservative values. Nonetheless, both procedures are more conservative than the

AASHTO method. The GE method has two input variables: traffic load (ADT) and soil strength. The classification of soil, a Soil Factor, and an assumed R-Value are obtained for the soil strength. Using these inputs, a Minimum Bituminous GE and a total GE for design are obtained; or, in words, the amount of bituminous base and surface in inches is acquired (from a chart). The R-value procedure uses two additional input components: load and strength. However, for this method, load is in terms of a Sigma N-18 value (a standard 18-kip single axle load, serving to identify the cumulative deterioration effect of heavy vehicles for the design life of flexible pavements) and strength is the R-value as determined from a stabilometer (*28*). The important part in this detail-oriented design procedure is computing the R-value, as pavement structure requirements are influenced by small changes in this value.

Another example is Virginia's low-volume road design procedure, which appears to be applicable to any state in the US as long as certain assumptions for local conditions are made. This procedure basically uses traffic and soil inputs. The design ADT is calculated by multiplying the current ADT by a growth factor, and a soil support value is used to represent soil strength. Mississippi similarly uses a soil support value (SSV) for soil strength; it is estimated using a design CBR (two-thirds of the average CBR) and a resiliency factor (extracted from a table using soil classification) representing the soils elastic deformation characteristics and its ability to withstand repeated loading. Multiplying the design CBR by the growth factor gives the soil support value. Each county has average values posted in design tables, and the required thickness index (DR) is determined using the soil support value and the design ADT, which then gives the appropriate pavement structure design. This design procedure is not as conservative as AASHTO's, but gives similar design values.

Table 1(a) presents how traffic is handled by each low-volume road design procedure. Each design procedure requires the subgrade strength as an input; however, each procedure uses different parameters to represent it. Table 1(b) summarizes the parameters needed to reflect subgrade strength in each procedure. Table 2 presents the level of complexity of the reviewed design procedures. Only the USACE and the NCSA design procedures offer a simple alternative in which all the design inputs are readily available to local agencies. Therefore, these two methods provide the basis for the design procedure proposed herein.

GENERAL CONSIDERATIONS IN PAVEMENT DESIGN

There are three main factors to consider in pavement design: materials (subgrade, subbase, base, surface), physical loading of the pavement represented by traffic (ESAL, ADT, percent of heavy commercial vehicles), and the environment (temperature, precipitation, frost) (*29*). The subgrade is the in-situ (natural) soil prepared to be the foundation of the pavement structure. Treatments should be applied to the soil if the bearing capacity is insufficient. Desirable properties include high compressive and shear strength, ease and permanency of compaction, drainage ability, and low susceptibility to volume changes due to moisture and freezing. Overlying pavement layers should increase in quality as the surface layer is approached. A compacted subbase may not be needed if the subgrade is of sufficient quality. The subbase can either be a treated or untreated granular layer or a treated layer of soil. The base course, generally consisting of good quality aggregate, lies directly below the surface course and provides structural support.

Environmental conditions also play an important role in pavement design. Sudden temperature changes accompanied with moisture changes can cause cracking and raveling of asphalt layers. Soil shrinkage results from low temperatures, especially for cohesive soils, leading to cracking. Temperature changes on the soil will cause soil moisture to migrate from warmer to colder zones. Freezing conditions can lead to frost heave as ice lenses form in the subgrade. The depth of frozen soil can be estimated using the Freezing Index (cumulative days below 32°F, or 0°C). High losses of pavement strength occur in the spring as the soils thaw. It is therefore important to establish a load restriction if freezing is an issue. Precipitation also influences the strength and stability of the underlying soil layers as they approach saturated conditions. The water table elevation, the intensity of frost action, erosion, pumping and infiltration are all affected by rainfall. Moisture within the pavement affects the contraction and expansion of the material constituents.

LOW-VOLUME ROAD DESIGN

The objective of this paper is to demonstrate an empirical low-volume road design procedure that requires minimal input (readily available to local agencies), and is simple to use. The design should also be customizable to different weather and subgrade conditions. To that end, the design basis is first determined, followed by the development of the design guide.

From the procedures reviewed earlier, some provide low-volume road design procedures by simplifying general design guidelines, whereas others are specifically intended for low-volume road design. Based on the most promising of these design procedures, key features are identified and used in the development of a low-volume road design guide. The proposed design guide is intended to be customizable for low-volume roads, and as a case-state Indiana is selected. In particular, the design guide allows for two design options that are cost effective, aggregate roads and asphalt pavements. Other options include Portland Concrete Cement (PCC) pavement and Roller Compacted Concrete (RCC) pavement, which require a bigger commitment from the local agencies as they can frequently be more costly; even though the RCC option may be an economically feasible alternative, as the material costs fluctuate over time. For specifics on PCC see Packard (*30*) and PCA (*31-32*); and on RCC see Shin and Carboneau (*33*). However, these approaches do not simultaneously satisfy the criteria with respect to simplicity, input availability and cost effectiveness.

Low-Volume Road Design Basis

The USACE and the NCSA pavement design guides were earlier determined to be compatible with the objectives of this study, and the proposed design guide is therefore based on them.

The USACE design method is a simplified design guide based on the USACE procedure developed for airport pavements. It accounts for three main pavement categories, unsurfaced roads (the in-place natural soil is used as the road surface), aggregate surfaced roads, and bituminous pavements, and provides a pavement design using six main surface types (*3*): (a) Earth road; (b) treated surface (earth roads may be treated with bituminous materials to control dust and to waterproof the surface); (c) stabilized soil; (d) gravel roads; (e) processed materials (prepared by crushing and screening rock, gravel, or slag); and (f) spray applications and surface treatments (sprayed treatments and sprayed bitumen with an aggregate surface). The design procedure involves three basic steps. The first is to assign a class designation to the road based upon the daily traffic. A design category is then assigned to the traffic based upon the composition of the traffic, which is classified into groups (*34-35*). A design index is finally determined from the design category and road class, which is used to determine the thickness of the aggregate surface or flexible pavement system required above a soil with a given California Bearing Ratio (CBR) strength (charts are used to obtain the values). The procedure is relatively simple to use, but has a few limitations. With only two input factors, varying environmental effects and other uncertainties may not be adequately addressed. This procedure is based on equations that give required thicknesses for material that is to be placed over underlying material of a given strength (in terms of CBR), provided that the placed material has greater CBR strength than the underlying material.

The NCSA method requires the CBR value and the design index to be known or estimated. CBR (determined either by field testing, laboratory testing or by estimating it from the soil classification) is used to evaluate the subgrade soil, and traffic counts on secondary roads should be made separately for each of the (three) vehicle type groups used. The design index is based on the traffic parameter, which in turn is based on ranges of the average equivalent 18,000-lb single-axle loads per lane per day over a life expectancy of 20 years. Once the CBR and the traffic design index have been determined, the total design thickness is obtained using a design chart.

Design Guide

The proposed design guide is presented as a flow chart, and is based on the NCSA design guide and the USACE recommendations for pavement design. The design guide requires three basic inputs; traffic count and truck percentage, subgrade strength, and whether the road is located in a frost zone.

In order to produce the design guide, a number of assumptions are made:

(a) Different agencies have different traffic ranges corresponding to low volume traffic, with the assumed range for low volume traffic of less than 1,000 vehicles per day (vpd) being widely accepted.

(b) The lifetime expectancy of low-volume roads ranges from 15 to 20 years, with regular maintenance needed to ensure such service life.

(c) To simplify the input process for the users, all trucks considered in the analysis are assumed to have three or more axles (all axles are expected to be tandem axles, except the steering axle), with pickup trucks and light duty vehicles not considered as trucks (they are considered part of the general traffic).

(d) Freeze depth in various locations in Indiana (the case-state) was approximated using the USACE frost zone map (*29*), with Indiana being divided into 4 frost zones as illustrated in Figure 1 (zone A has no frost depth, zones B, C and D have frost depths of 5, 10 and 20 inches, respectively).

(e) Soil subgrade strength is listed in both California Bearing Ratio (CBR) and Dynamic Cone Penetrometer (DCP) values, with the relationship used to convert DCP to CBR being adopted from ASTM D6951, "Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications" (*36*). The equations utilized for DCP in in./blow or mm/blow (Table 3 illustrates the relationship between DCP and CBR), are as follows (*37*-*38*):

- For all soils except CL soils (inorganic clays of low to medium plasticity, gravelly clays, sandy clays, lean clays (backfilled using native soil)) with CBR < 10 and CH soils (inorganic clays of high plasticity, backfilled with granular material):

$$CBR = 292/(DCP \times 25.4)^{1.12} \quad (1)$$

- For CL soils with CBR < 10:

$$CBR = 1/(0.432283 \times DCP)^2 \quad (2)$$

- For CH soils:

$$CBR = 1/(0.072923 \times DCP). \quad (3)$$

The inputs needed consist of three basic components: traffic, geographic location (used to estimate frost depth), and subgrade strength.

Even though the design guide addresses low-volume roads, the traffic range of such roads remains broad to be handled using a single category. For this reason the traffic is subdivided into three categories: low (less than 70 vehicles per day, medium (70-200 vehicles per day), and heavy (201-1,000 vehicles per day). While being less broad than one category of up to 1,000 VPD, the traffic categories remain large enough to allow local agencies that do not have readily available traffic data to use an educated estimate in order to produce a reasonable design. This approach is very different from the approaches employed by AASHTO, Asphalt Institute or the Mechanistic-Empirical Pavement Design Guide (MEPDG), which require an extensive amount of information on the number of vehicles and their axle configurations.

The second traffic component needed for the design is an approximation of the percentage of trucks in the traffic stream (the exact truck percentage is not needed). It is only required to know whether the truck percentage is less than 1 percent, between 1 and 10 percent or greater than 10 percent.

Turning to the geographic location component, different locations in a state experience different weather conditions due to latitude and elevation. Since pavements are continuously subjected to variable weather conditions, it is important to consider the weather when designing a pavement. Design methods employed by the MEPDG involve rigorous analysis of a number of weather elements, such as temperature, precipitation, cloud cover and wind speed. Although this information may be available, it requires a significant amount of time and effort to collect and extract, and a high level of expertise and experience in the field to process and utilize. Simplified design methods proposed by the USACE design guide and the NCSA, only require knowledge of the frost depth in the area in which the roadway is to be located. Due to its simplicity, limited time-requirements and robustness, the second approach has been adopted herein. The case-state, Indiana, is a moderately sized state that does not have a homogenous climate, and was therefore divided into four frost zones (see Kim and Newcomb, *28*), as illustrated in Figure 1. Note that the four zones should not be treated as having fixed boundaries (a conservative estimate should be used in the vicinity of the boundaries); for example, if a road is to be built near the boundaries between zones A and B, the frost depth could have a value of 2.5 in. (i.e., the average of the frost depth of the two zones, 0 in. and 5 in.).

The subgrade soil type and strength component is directly related to the location and the frost zone. For example, roads built in zone A (no frost) are required by the design guide to detail subgrade strength in terms of DCP or CBR. Roads built in zones B, C or D (frost zones) only require the soil type. Soil types behave differently in freezing conditions, providing the background for the differentiation. Although, some adjustments are needed depending on moisture content, soil strength gives a adequate description of the soil in non-freezing conditions. It is important to note that soil strength could be misleading when observed under freezing conditions. The subgrade soil type is needed if the road is to be built in a frost zone. The soil type can be classified in four categories, shown in Figure 2. The subgrade strength is required if the road is to be built in a non-frost zone, and is also divided into four categories, also shown in Figure 2. To produce a reliable design, there is no need for definite CBR or DCP values, as a rough approximation of the soil strength will suffice. Also, if there is uncertainty with respect to the soil strength (e.g., weak versus medium soil), the proposed guide allows for the timely design of each case, so that an informed decision can be made as to whether the extra thickness is cost-effective.

Design Process

The design process involves the following steps: (a) acquiring the design index; (b) determining the frost zone in which the road is located; (c) selecting the proper subgrade strength/quality category; and (d) choosing the desired design from the available design options.

The pavement design index is based on the traffic volume and related truck percentage of the road, and it is assigned a value from 1 to 4, as shown in Table 4. Table 4 summarizes the combinations of traffic volumes and truck percentages that correspond to each design index, illustrating that higher traffic and higher truck percentages correspond to higher design indices.

The following step in the design process is to identify the location of the road, and in turn the corresponding frost zone for the selected road by using the map in Figure 1. Next, the proper subgrade strength/quality category (i.e., weak, medium, or strong) of the soil needs to be identified, in terms of CBR, DCP, or soil type (see Figure 2).

The proposed design guide offers two pavement designs for any given set of inputs, an aggregate road option and a flexible pavement option. The complete design process is depicted in Figure 3. Figure 3a provides the general specifications that result in a specific design index (given traffic and truck characteristics, a design index is obtained which in turn directs to an appropriate chart), and Figures 3b through 3e present the proposed sections for aggregate and flexible pavements with corresponding design indices 1 through 4, respectively. In some cases, surface treatments such as double chip seals can be used as an alternative to a 1-inch asphalt surface, depending on local circumstances, available funding, and future plans. However, for steep grades (6% or greater) the AC surface layer is recommended.

It is important for the designer to understand that aggregates used for surface courses and base courses can vary significantly, as the two courses serve different purposes in the pavement. Aggregate gradation, plasticity and permeability requirements for the two are different. For example, aggregate materials used for a surface course are typically more finely graded than base course aggregates and contain higher amounts of fines (material passing the #200 (0.075-mm) sieve). Additionally, when deciding between aggregate and flexible pavements, the costs of maintaining both should be properly accounted for over the life of the pavement. For example, an aggregate road will need additional aggregate placed over time, and in some localities, it may be necessary to apply dust palliatives on a consistent basis. For flexible pavements, periodic crack sealing may be needed. For cases that conditions in their area support the use of Clay or silt, the reader is referred to 'Mix Design With Low Bearing Capacity Materials' (*39*).

Design examples are presented in Figure 4.

If the frost depth is equal to 0 in. (zone A), the aggregate road design is a 3-layer pavement design. The 3 layers are as follows (top to bottom): (a) aggregate surface course (the top layer of the aggregate design); (b) subbase layer (the second layer in the aggregate design, typically with a coarser gradation than the top layer); and (c) compacted soil layer (optional layer used in the case of weak soils). Figure 4a-i shows a typical aggregate layer pavement in a non-frost zone.

In the case of a frost zone (i.e., frost depth is greater than 0 in.) the aggregate road is a 4-layer pavement design. The 4 layers are (top to bottom): (a) aggregate surface course (using crushed stone); (b) subbase layer (second layer, typically with a coarser gradation than the top layer); (c) clean soil filter (typically sand); and (d) compacted soil (optional layer used in the case of weak soils or higher levels of traffic). Figure 4a-ii shows a typical aggregate layer pavement in a frost zone.

Turning to the flexible design option, for the case of frost depth equal to 0 in. (zone A), the flexible road design is a 3-layer pavement design (top to bottom): (a) asphalt surface course (hot or warm mix asphalt); (b) aggregate base layer (second layer in the flexible design, typically with a coarser gradation than the surface course); and (c) crushed stone (optional layer used in the case of weak soils). Figure 4b-i shows a typical flexible pavement in a non-frost zone.

In the case of a frost zone (i.e., frost depth is greater than 0 in.) the flexible road is a 3-layer pavement design (top to bottom): (a) asphalt surface course (hot or warm mix asphalt); (b) aggregate base layer (second layer in the aggregate design, typically with a coarser gradation than the surface); and (c) stabilized soil (typically cement stabilized; the depth of this layer is equal to the frost depth in the design location). Figure 4b-ii shows a typical flexible pavement in a frost zone.

SUMMARY AND CONCLUSION

This paper developed an empirical low-volume road design guide, based on the USACE and the NCSA pavement design methods. From a comparison among various low-volume road design approaches applied by several states in the US, these two design guides were found to be the least complex and require easily attainable input.

The proposed guide is developed based on the same principles, that is, requires minimal input that is readily available to local agencies, and is simple to use. As inputs, approximations of the daily traffic and truck percentage are used, along with the subgrade soil type and strength. Given these factors and the location of the road (identifying weather characteristics affecting the pavement structure), specific aggregate and flexible road design options are given.

The state of Indiana is presented as a case study and the specified low-volume road design options are presented. The flexibility of the proposed guide allows its use by most local agencies, and provides for the design of low-volume roads in a timely fashion.

Future direction for work in low-volume road design should involve the development of a similar guide for tropical climates or cold regions, as the presented guide is anticipated to be well suited for regions characterized by moderate climate.

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LIST OF FIGURES

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TABLE 1 Summary of (a) traffic input criteria, and (b) subgrade strength criteria by low-volume road design procedure

Procedure	(a) Traffic Input Criteria				
	ESAL	ADT	Index	Design Period	GF
AASHTO	•				
USACE	•				
NCSA	•		•		
AI	•				
California	•		•		
Minnesota (GE)		•			
Minnesota (R-Value)	•				
Mississippi	•			•	
New York	•				
Pennsylvania	•				
Vermont	•				
Virginia		•			•

Procedure	(b) Subgrade Strength Criteria					
	MR	CBR	Soil Type	R-Value	Frost	Drainage
AASHTO	•					
USACE		•				
NCSA		•	•		•	•
AI	•					
California				•		
Minnesota (GE)			•			
Minnesota (R-Value)				•	•	
Mississippi		•				
New York	•				•	•
Pennsylvania		•			•	
Vermont	•				•	
Virginia		•				

ADT: Average daily traffic; CBR: California bearing ratio; ESALs: Equivalent single axle loads; GF: Growth factor; MR: Subgrade resilient modulus.

TABLE 2 Complexity of low-volume road design procedures

Procedure	Availability of Design Inputs		Complexity of Procedure
	Traffic	Subgrade strength	
AASHTO	Not readily available	Not readily available	Complex
USACE	Available	Available	Simple
NCSA	Available	Available	Simple
AI	Not readily available	Not readily available	Simple
California	Available	Not readily available	Moderate
Minnesota (GE)	Not readily available	Not readily available	Simple
Minnesota (R-Value)	Not readily available	Not readily available	Moderate
Mississippi	Not readily available	Available	Simple
New York	Not readily available	Not readily available	Complex
Pennsylvania	Not readily available	Available	Moderate
Vermont	Not readily available	Not readily available	Complex
Virginia	Not readily available	Available	Moderate

TABLE 3 Tabulated correlation of CBR versus DCP index

DCP (mm/blow)	DCP (in./blow)	CBR%
3	0.118	100.0
5	0.197	50.0
9	0.354	25.0
11	0.433	20.0
14	0.551	15.0
16	0.630	13.0
23	0.748	11.0
19	0.906	9.0
29	1.142	7.0
38	1.496	5.0
42	1.654	4.5
46	1.811	4.0
52	2.047	3.5
60	2.362	3.0

Note: 1 inch = 25.4 millimeters.

TABLE 4 Design index

Traffic Volume (vehicles per day)	Truck%		
	<1%	1-10%	10%<
<70	1	1	1
70-200	1	2	3
201-1,000	2	3	4

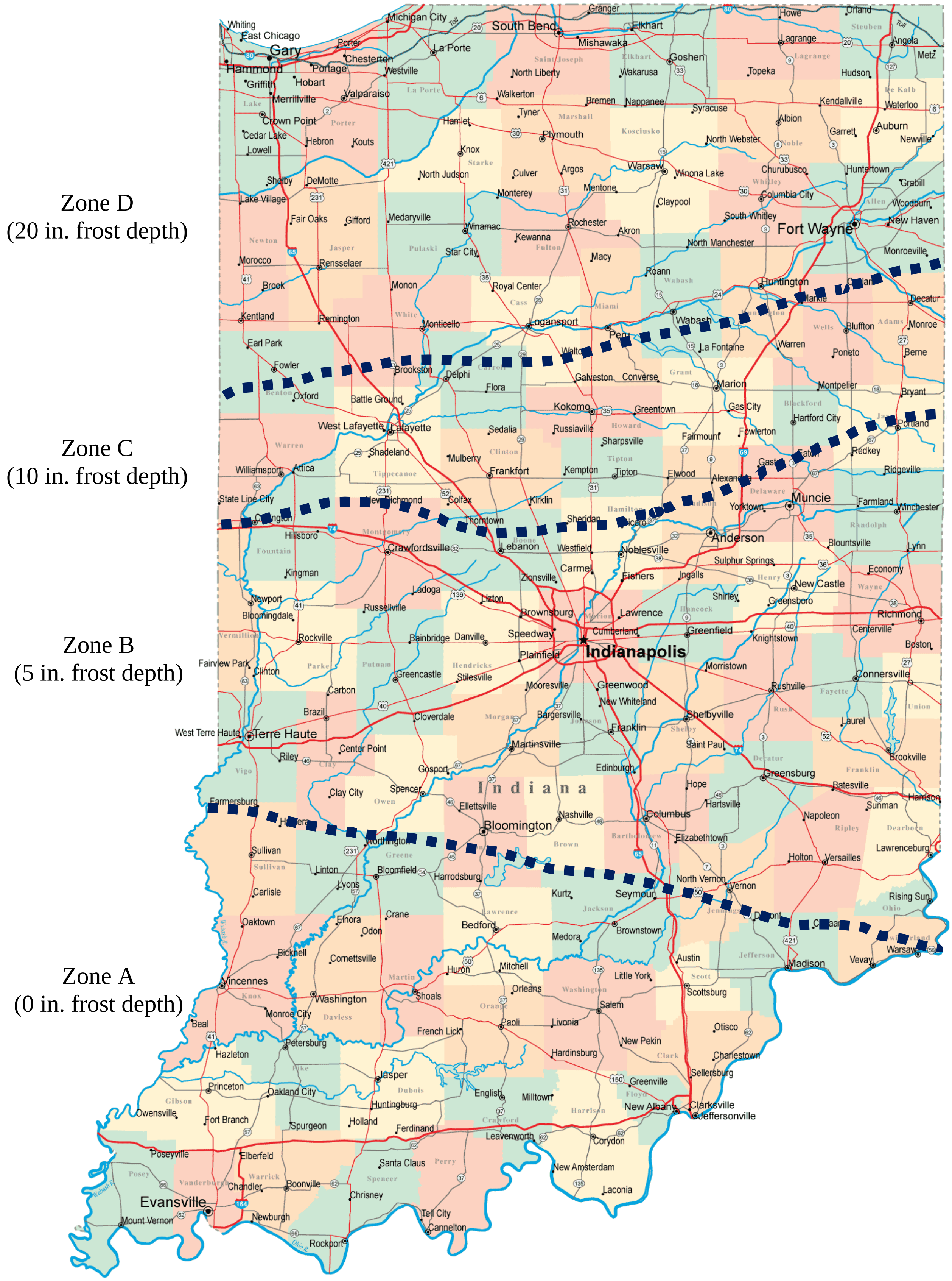


FIGURE 1 Frost zone map for Indiana [Adopted from: Kim and Newcomb (*29*)].

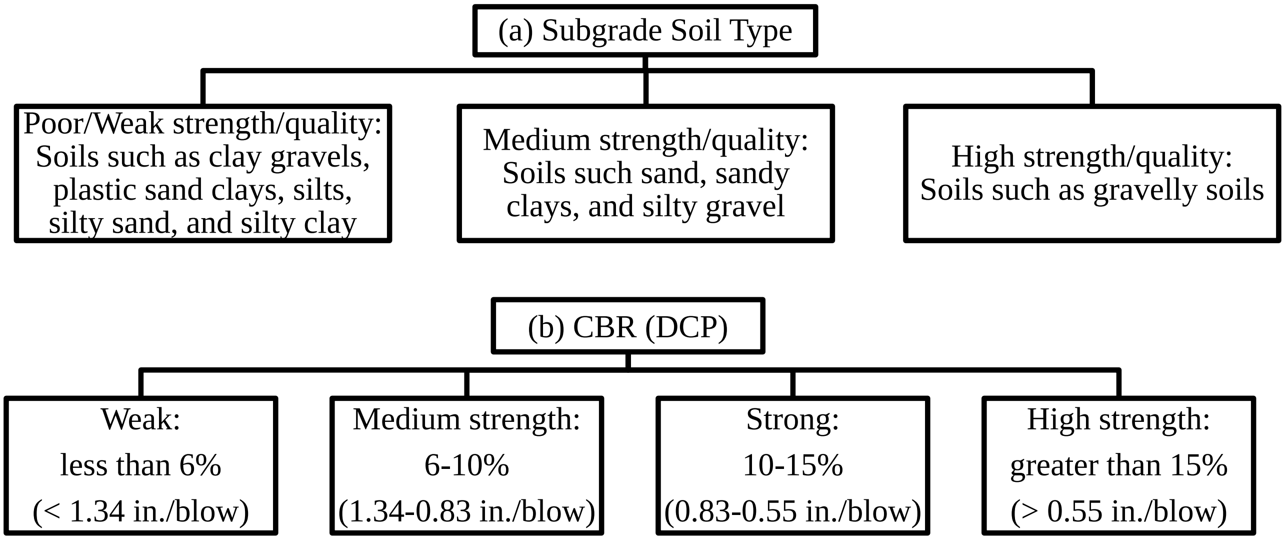
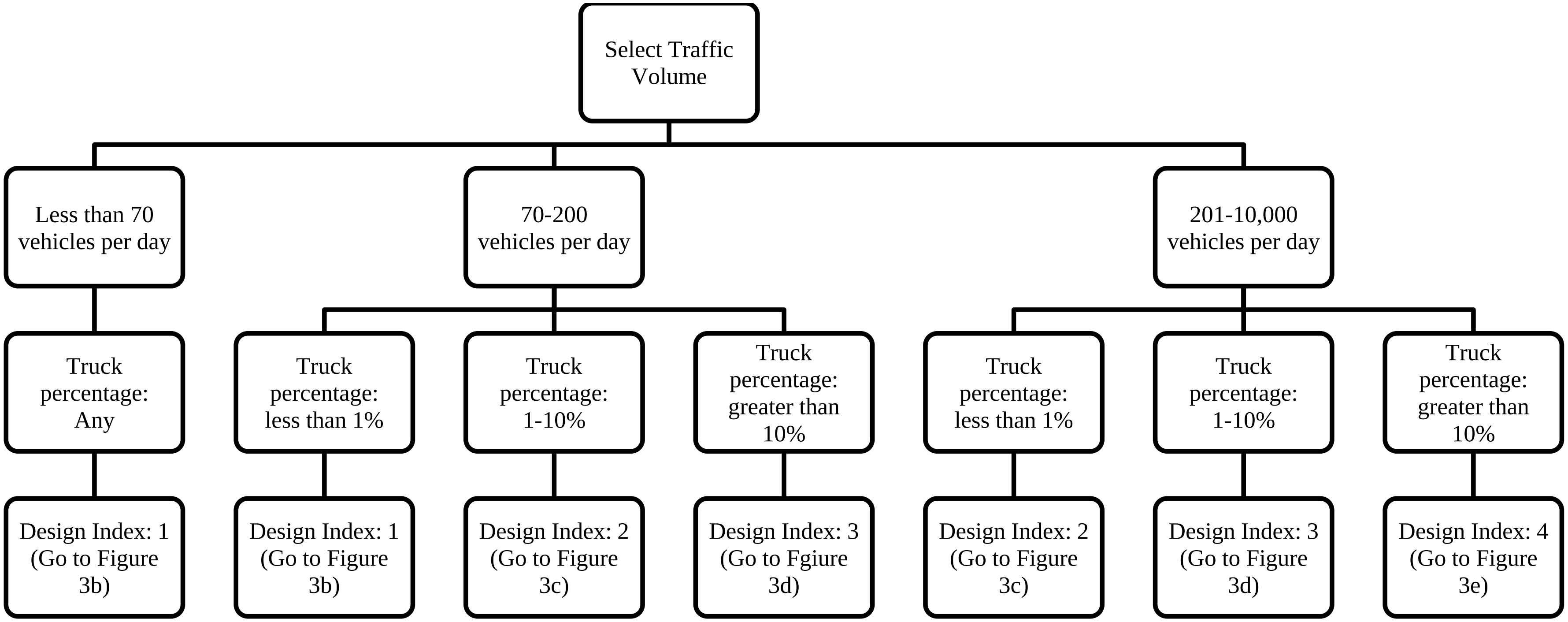


FIGURE 2 Subgrade soil types (a) and strength categories (b).



1

2 **FIGURE 3a General specifications.**

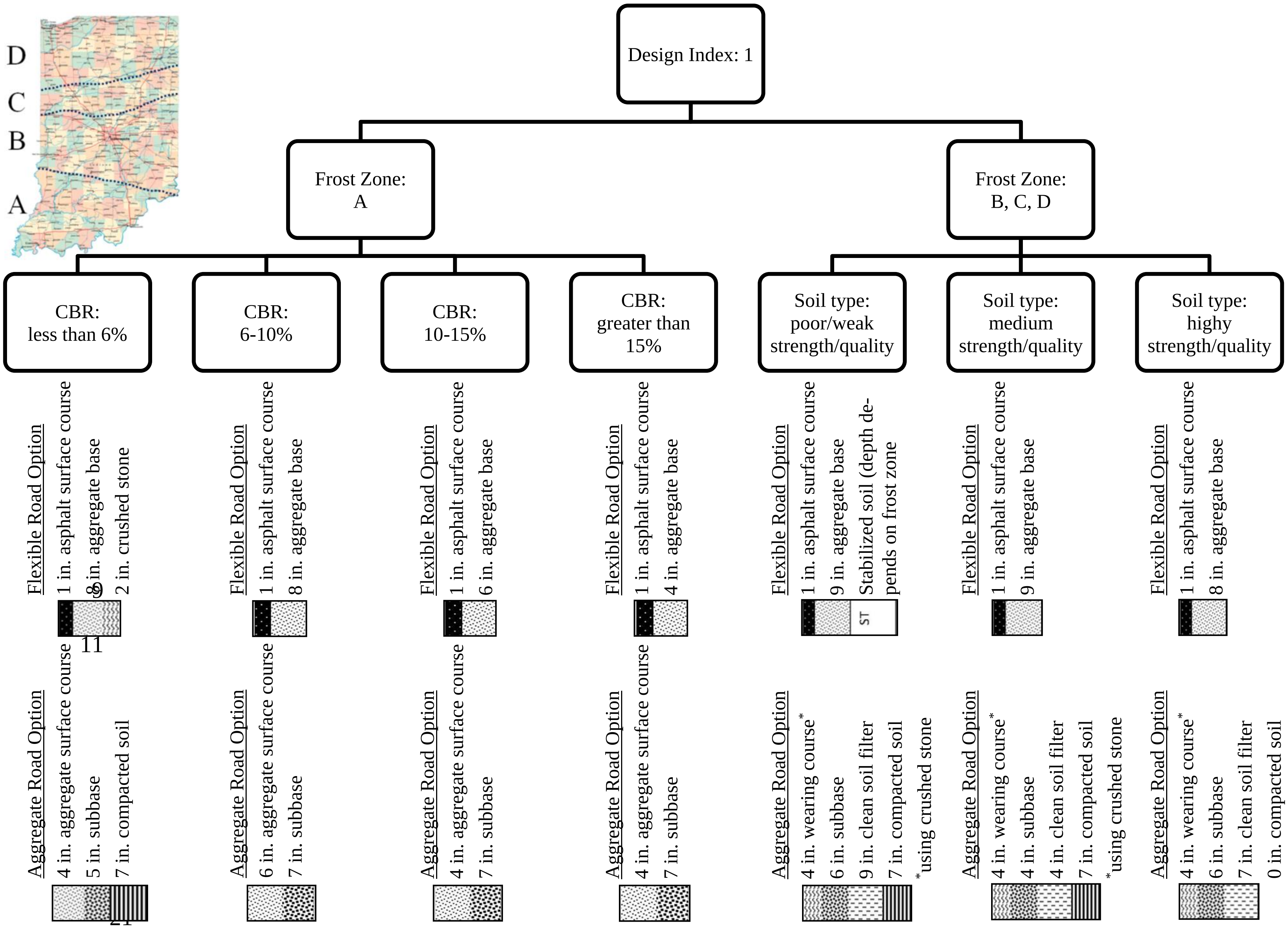


FIGURE 3b Proposed sections for pavements with design index 1.

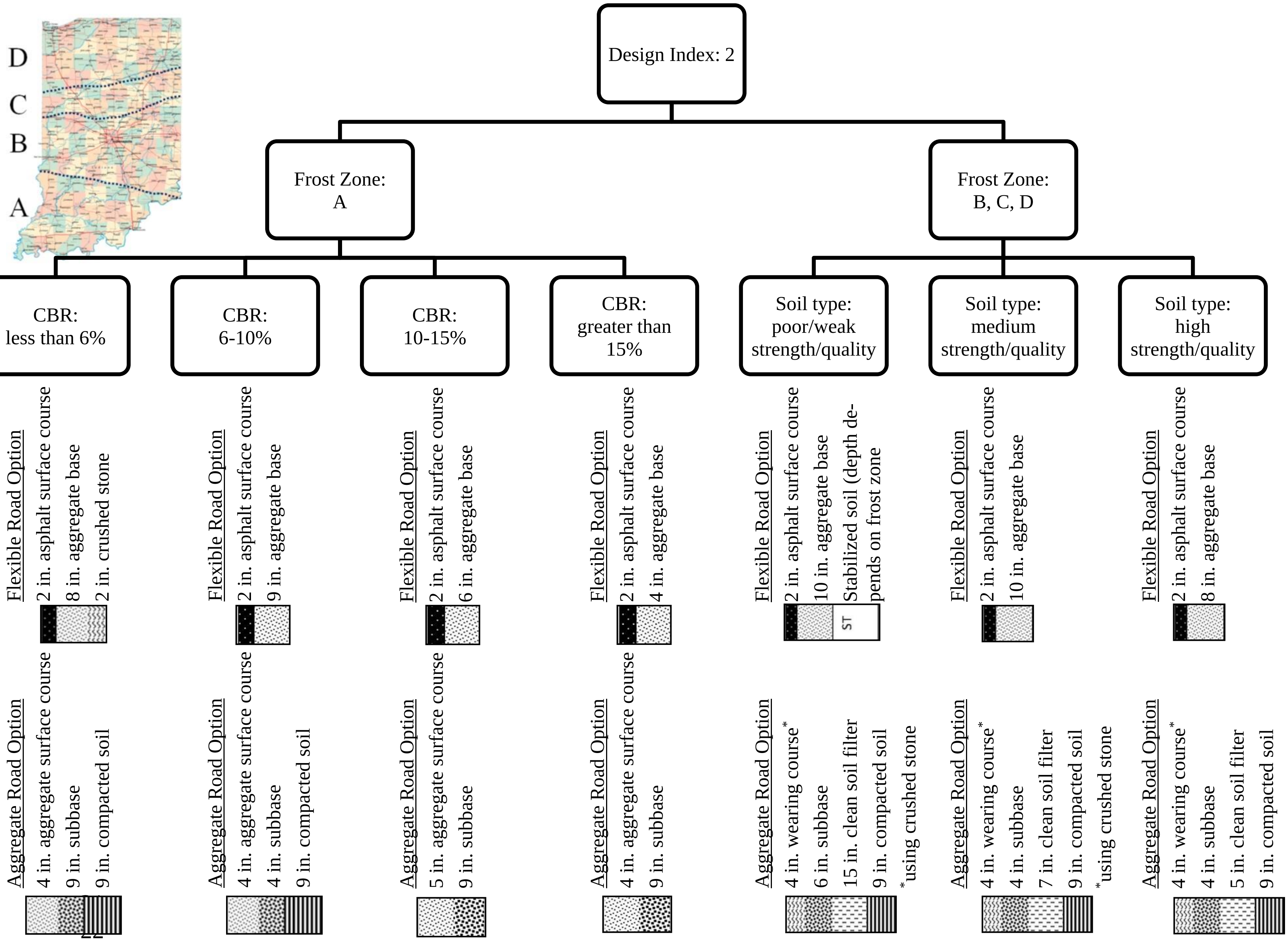


FIGURE 3c Proposed sections for pavements with design index 2.

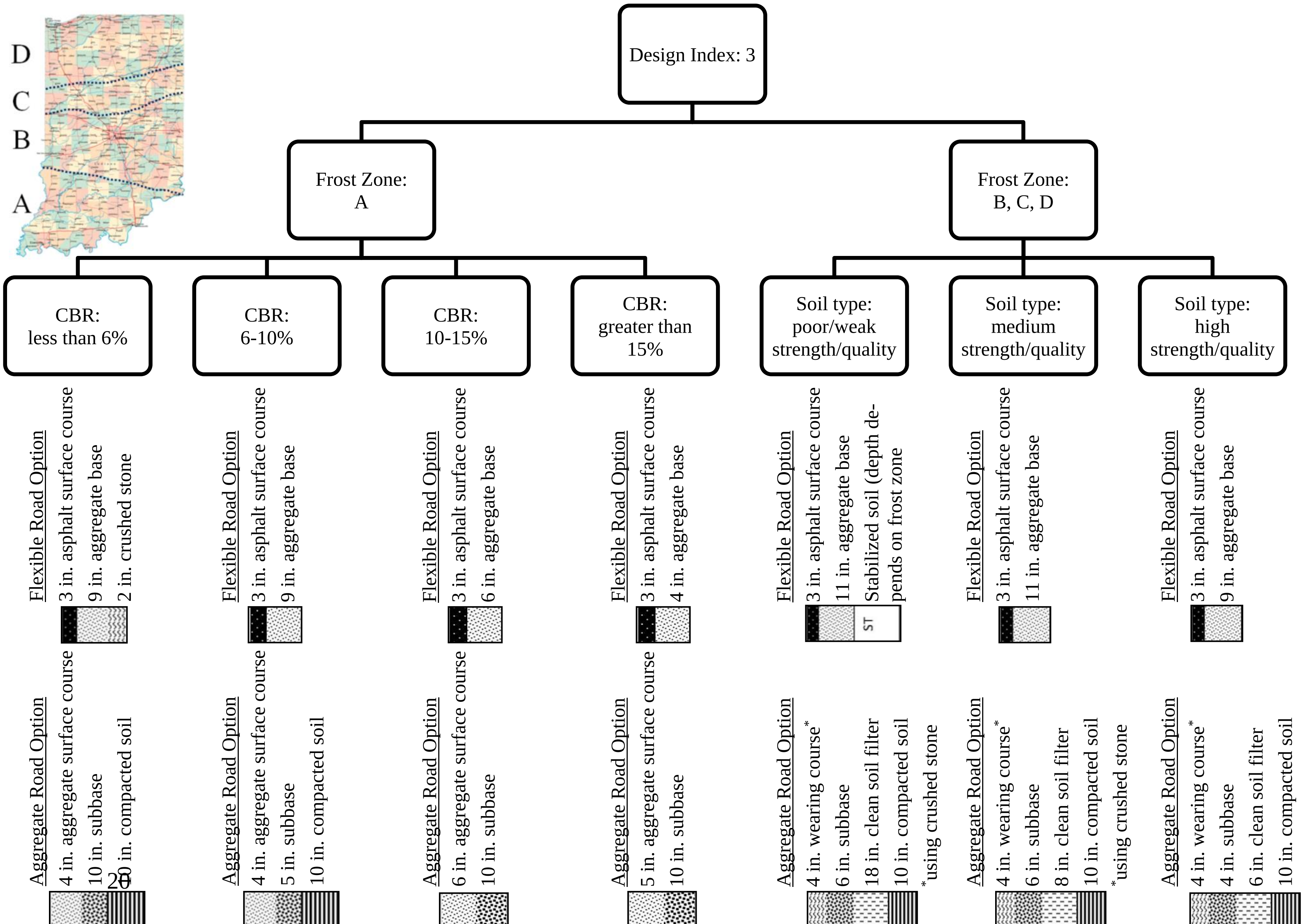


FIGURE 3d Proposed sections for pavements with design index 3.

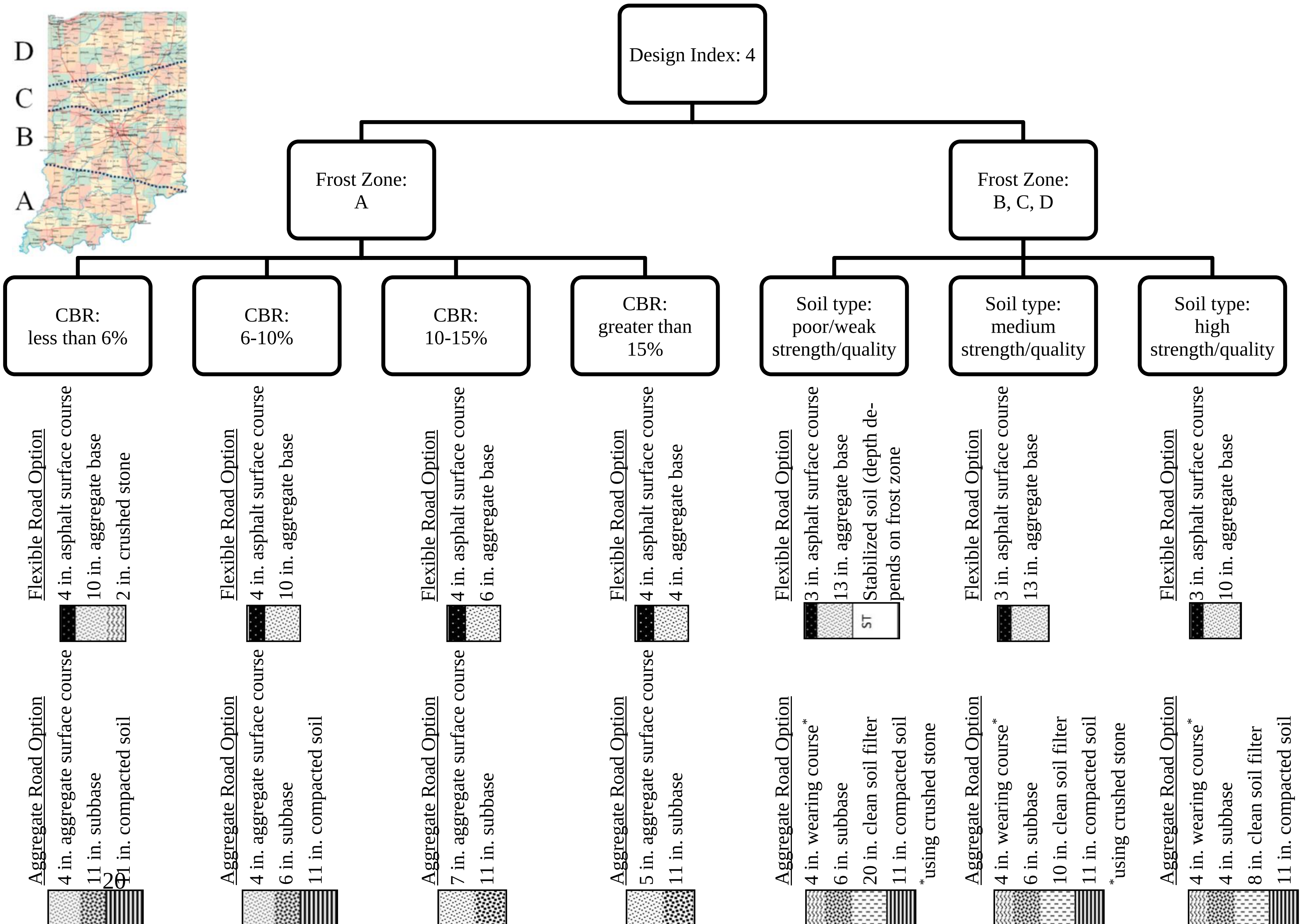
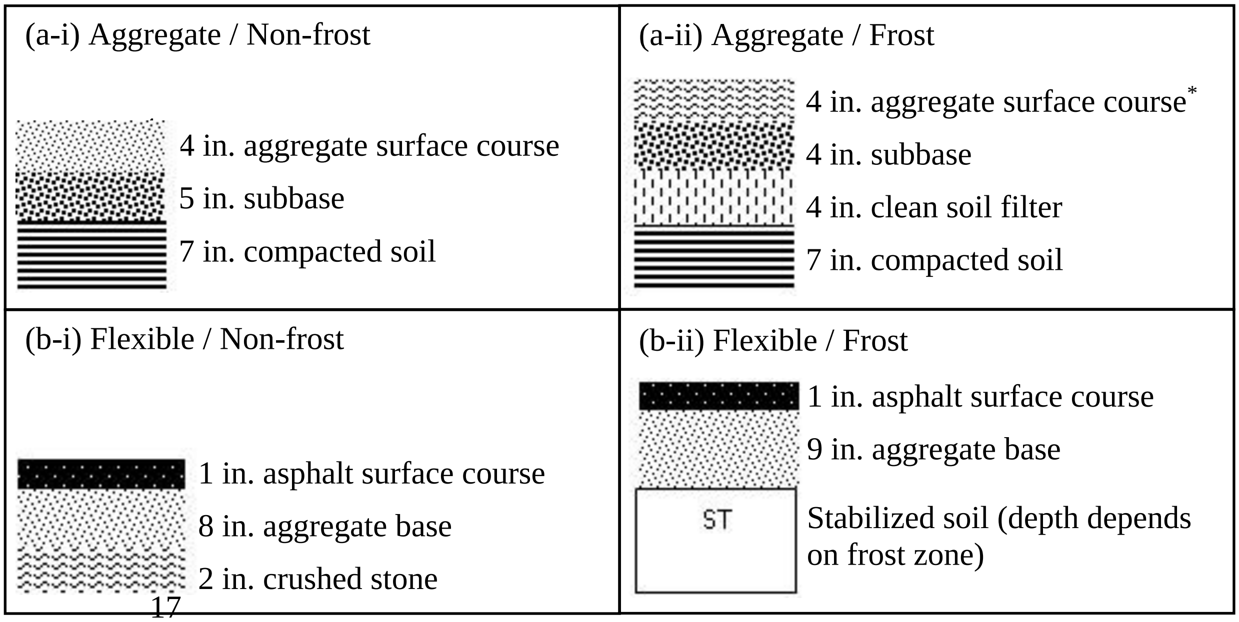


FIGURE 3e Proposed sections for pavements with design index 4.



*Using crushed stone.

FIGURE 4 Typical aggregate (a) and flexible (b) designs in non-frost (i) and frost (ii) conditions.