North Carolina Department of Transportation

Design Guide for Concrete Local Roads & Streets

Version 1.0

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EXECUTIVE SUMMARY

The Design Guide and Standard Specifications for Concrete Streets and Roads, hereafter referred to as "the Guide," is based on Version 12 of the StreetPave software developed by the American Concrete Pavement Association and specifications representative of best practices for constructing these types of roadways.

StreetPave is a mechanistic-empirical based procedure that incorporates numerous design elements that are under the control of the pavement designer and various site condition variables, including traffic and soil type that are "fixed" for a specific project. The specifications were derived from a number of agency and industry specifications and guidelines.

The overall purpose of this document is to standardize the design and specifications for concrete pavements over a wide range of conditions from lightly trafficked residential streets to more heavily travelled minor arterial routes. The design process has been greatly simplified compared with performing multiple computer iterations and analyzing the results to determine a feasible design.

The simplified process presented in the Guide will provide the required slab thickness, transverse joint spacing and load transfer requirements. A number of variables, including design life, concrete strength properties and recommended levels of reliability, have been fixed based on current or recommended Agency practices. Site variables including traffic characterization and soil conditions must be determined (or estimated) for each project. The need for sound engineering judgment is still a crucial aspect in generating a pavement design with reasonable initial cost and good long-term performance.

The information is presented in both graphical and tabular format with specific guidance regarding selection of the most appropriate data to use for a specific project. It must be recognized that long-lasting and relatively maintenance free concrete pavements are a combination of a suitable design, reasonable specifications, high quality materials and good construction practices. The information presented in this Guide pertains only to the design and specifications.

OVERVIEW OF THE GUIDE

The Guide is comprised of two sections pertaining to pavement design and standard specifications. These sections may be considered independently and will be treated as such in the following chapters. Note that the first portion of the Guide is devoted entirely to pavement design.

The design procedure used in the development of the Guide is based on both scientific principles (mechanistic) and observed pavement performance (empirical). This methodology is referred to as mechanistic-empirical pavement design and represents one of the most up-to-date approaches in designing reliable and long-lasting concrete pavements.

The Guide is intended to standardize the way in which concrete pavements are designed for a wide range of traffic and site conditions. There is still a need to exercise sound engineering judgment in the selection of realistic and representative input values and in determining the overall suitability of the design.

The StreetPave design methodology is one of three widely used concrete pavement design procedures and was selected based on its applicability to the roadway types and traffic volumes managed by the Agency. The other methods; The AASHTO 1993 Guide and the AASHTO Mechanistic-Empirical Design Procedure (Pavement ME), are primarily for high traffic volume roadways and not well suited to lower-volume streets and roads. Therefore, for highly trafficked roadways (heavily trafficked minor arterial and above), it is recommended that the user consult one of these alternate design methods with appropriate calibrations for local conditions.

The Guide uses a stepwise approach in which key design variables are determined and then used in the appropriate graphs and tables to arrive at a feasible design. A complete listing of the design variables included in StreetPave software include the following:

- Failure criteria.
  - Percent cracked slabs at end of design life.
  - Terminal serviceability.
- Design life.
- Design reliability.

- Traffic characterization (in terms of traffic load spectra).
    - Traffic category.
        - Residential.
        - Collector.
        - Minor arterial.
    - Number of traffic lanes.
    - Directional distribution of traffic.
    - Percent of traffic in design lane (the most heavily trafficked lane).
    - Average daily truck traffic (ADTT) <u>or</u>
    - Average daily traffic (ADT) and percent trucks.
    - Traffic growth.
- Pavement support conditions.
    - Subgrade properties.
    - Base properties (if applicable).
- Concrete properties.
    - Modulus of rupture (MR).
    - Elastic modulus (E).
- Load transfer type (dowels or aggregate interlock).
- Edge support (tied concrete shoulder or curb and gutter, widened lane or no edge support.

The program output, based on the listed input parameters, includes the following:

- Concrete slab thickness.
    - Calculated thickness.
    - Rounded thickness.
- Recommended joint spacing.
- Recommended load transfer type
    - Dowels.
        - Size.
    - No dowels (aggregate interlock).

Complete details regarding each of these parameters are discussed in the following section.

DEVELOPMENT OF INPUT VALUES

The variables required by the StreetPave analysis procedure are, for the most part, common to other design methodologies and may be broadly categorized as site-related inputs and design-related inputs. The variables used in developing the design tables and graphs contained in the Guide are explained in detail in this section.

Site-Related Variables

Site-related variables include traffic and subgrade support conditions. These values are project specific and can't be altered significantly by the pavement designer. The exception to this would be removal and replacement of the existing subgrade soil, chemical stabilization of the soil to a substantial depth or mechanical stabilization.

Traffic Characterization

Traffic characterization is one of the most critical inputs in any pavement design. Reasonably accurate traffic counts, in terms of the number of vehicles (particularly trucks), vehicle weights, number of axles and so on, are necessary for all projects. This baseline value is increased by incorporating a traffic growth factor for the specified design period. Note that the design is based on the number and weights of heavy trucks and is relatively unaffected by car and light truck traffic.

StreetPave uses axle load spectra as the traffic characterization parameter for design rather than Equivalent Single Axle Loads (ESALs) as in the AASHTO 1993 Design method. Axle load spectra considers the number of vehicles, vehicle configuration and axle weights in determining the required pavement structure to resist slab cracking and erosion of the support layers. This approach is superior to the use of ESALs since the relative damage done by each vehicle type is calculated separately and then used to determine the accumulated damage in the pavement.

It has been shown that streets and roads within a particular traffic category have approximately the same relative proportion of vehicles. Therefore, a traffic count to determine the number of daily trucks will provide a reasonable traffic input for the Guide.

Traffic counts should focus only on the number of trucks larger than 2 axle, 4 tired vehicles (FHWA Class 4 and above). Although the distribution of axle weights will vary by the type of roadway (i.e. the axle weights for trucks travelling on minor arterials will exceed those on collector streets and so on), these differences have already been accounted for in the design tables.

The following traffic inputs were used in developing the design charts and tables.

Traffic Category

Two categories are used for traffic characterization, as shown in Table 1. The values shown in Table 1 are based on an extensive review of traffic data and are sufficiently accurate for the majority of street and road designs.

Traffic Category	**Description**	**Average Annual Daily Traffic (ADT)**	**Percent Trucks (Typical Range)**	**Average Annual Daily Truck Traffic (ADTT)**	**ADTT Values Used in Development of the Guide**
Residential	Residential streets and low volume secondary roads	200-800	1-3	<20	1, 5, 10 and 20
Collector	Collector streets, high volume secondary roads and low volume arterial roads	700-5000	5-18	20-500	50, 200, and 500

Table 1. Traffic Categories.

As the daily truck volumes increase, truck weights also typically increase. This has been accounted for in the design graphs and no further action is required. In cases where the ADTT values overlap, it is necessary for the designer to select the appropriate traffic category. As the classification increases, the design will be based on heavier trucks and will be more conservative. In this case, a more detailed traffic study may be warranted. The StreetPave traffic load spectra data was used for development of all design charts and is shown in Appendix A.

Number of Lanes

The number of lanes refers to all through travel lanes (both directions). The design tables and graphs assume the values shown in Table 2. In cases where the number of design lanes exceed the values shown, multiplying the ADTT by .90 for 4 lanes will provide a reasonable estimate of the design lane traffic to be used in the design charts (Refer to the *Design Lane Distribution*).

Directional Distribution

The directional distribution refers to the percent of traffic travelling in each direction. A directional distribution of 50% was used in development of the Guide and assumes an equal number of vehicles travelling in each direction.

Design Lane Distribution

When two or more lanes exist in each direction, the lane carrying the majority of traffic is termed the design lane. As the number of lanes increase, the percentage of traffic using the design lane typically is reduced. The design lane distribution refers to the percentage of traffic (trucks) that travel in the designated design lane. The values used in development of the Guide are shown in Table 2.

Traffic Growth Factor

The traffic growth factor anticipates the annual growth of traffic over the design life of the pavement. This value can vary greatly depending on the traffic category and economic conditions. The Guide is based on a 2 percent annual growth rate for all traffic categories as shown in Table 2.

Traffic Category	Total Number of Lanes	Directional Distribution (Percent)	Design Lane Distribution (Percent)	Traffic Growth Factor (Percent)	Baseline ADTT Values Used in Development of the Guide
Residential	2	50	100	2	1, 5, 10 and 20
Collector	2	50	100	2	50, 200, and 500

Table 2. Traffic Variables Used in Development of the Guide

Subgrade Characterization

The soil conditions on which the pavement is to be constructed should be thoroughly evaluated in terms of uniformity, and strength and deformation characteristics. The soil characteristics may be assessed by correlations to soil type, material sampling and laboratory testing, or by the use of non-destructive testing methods such as the dynamic cone penetrometer (DCP). The time and expenditure devoted to soil characterization is based on the scale and importance of the project. Residential streets typically rely on soil type correlations or DCP testing.

Concrete pavement design is based on the modulus of subgrade reaction or "k". The k value is determined directly by full-scale plate load tests. However, due to time and expense, plate load tests are rarely performed and the values used in design are based on correlations to other soil parameters. Note that the units for k are psi/in but are oftentimes abbreviated as pci, both terms are used in the Guide. General soil type, typical values for k, approximate correlation to resilient modulus and the values used in development of the Guide are shown in Table 3.

If CBR is the sole evaluation used to characterize the subgrade soil, a more defined relationship exists relating CBR to the k value as documented in the U.S. Department of Transportation, Federal Aviation Administration, Advisory Circular AC 150/5320-6E, dated September 30, 2009. This relationship is shown in the following equation and graphically in Figure 1.

$$K = [(1500*CBR)/26]^{0.7788}$$

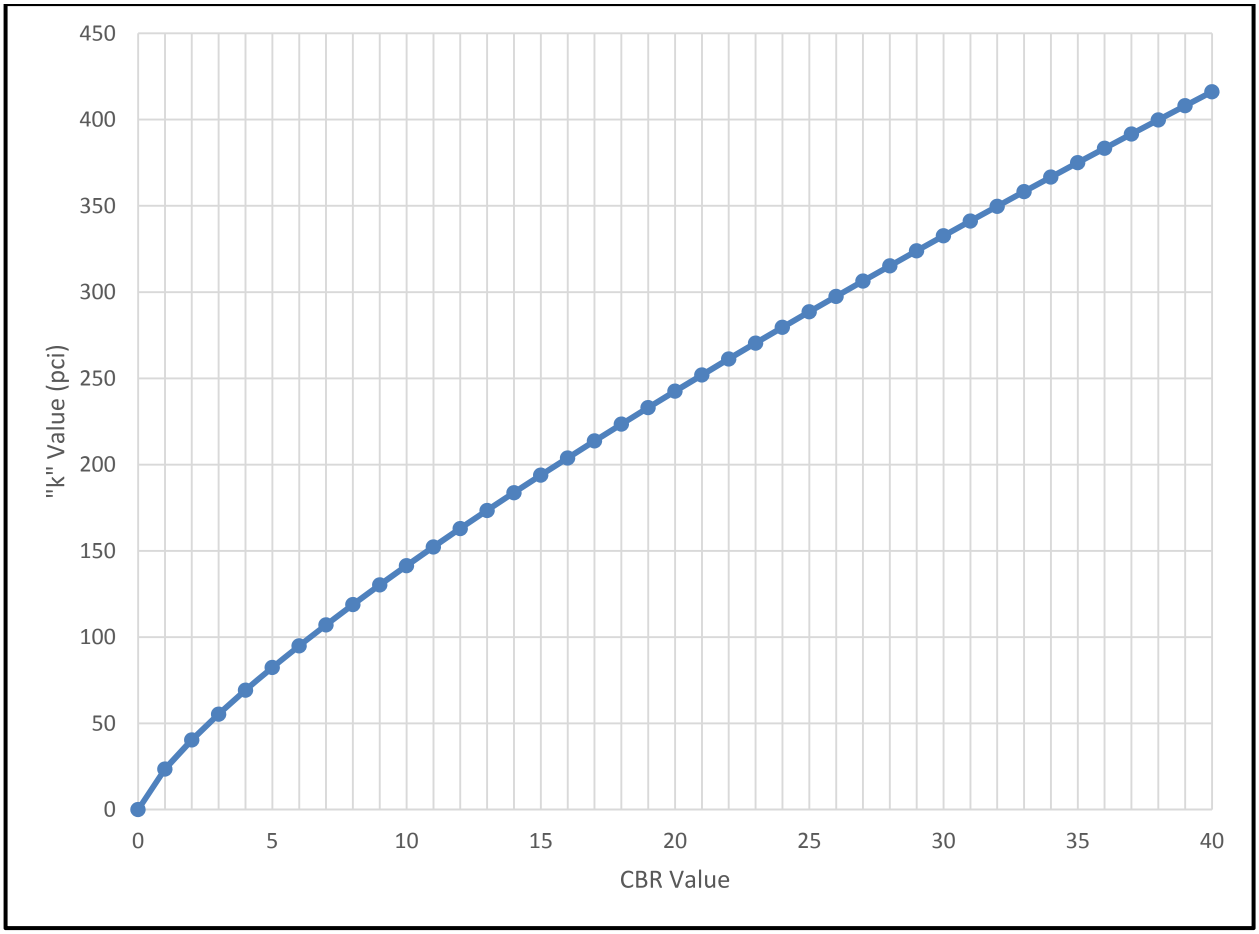


Figure 1. Relationship between CBR and k value.

Soil Type Description	Relative Level of Soil Support	Typical Range for k (psi/in or pci)	Typical Range for CBR	Typical Range for Resilient Modulus (psi)	Average k Value used in Development of the Guide (pci)
Fine-grained soil with high silt and/or clay content	Low	75-120	1-3	1455 - 2325	100
Sand and sand-gravel with moderate silt and/or clay content	Medium	130 - 170	4-8	2500 - 3300	150
Sand and sand-gravel with low silt and/or clay content	High	180 - 220	9-13	3500 - 4275	200

Table 3. Typical Range of Soil Characteristics and Support Values for Subgrade Soils.

The subgrade k value has only a moderate influence the design thickness. However, uniformity and erosion resistance are very important and should be ensured for all pavement projects. Very poor support conditions (k less than 100) typically have high clay or silt content and are not satisfactory without modification. One of the most effective means to remedy poor soil conditions is through cement or lime stabilization.

It is important to note that the k value specified in the design charts is a composite k value consisting of both the subgrade soil and the subbase (recommended for all roads but optional for very low truck traffic volumes). In cases where the subgrade soil has been chemically stabilized, the subgrade k value must be increased by an appropriate amount prior to using Figures 2, 3 or 4. Guidance on adjusting subgrade k to account for stabilization is given in the section below titled “Composite k Value”.

Design-Related Variables

Design-related variables include those inputs that are selected by the pavement designer to meet the requirements of a specific project. Decisions regarding these variables have a significant impact on pavement performance, constructability, long-term maintenance and rehabilitation requirements, initial and long-term costs and numerous other related issues.

In order to partially standardize concrete pavement design for streets and roads, the design-related variables have been set at a specific value or range of values, as shown in Table 4. These values represent either current Agency policy or are representative of current industry trends.

Design-Related Variable	**Typical Range**	**Values Used in Development of the Guide**
Design life (years)	10 to 40	30
Cracked slabs (percent)	5 - 25	15
Reliability (percent)	50 - 99	85
Composite k value (psi/in)	100 – 400	100, 150, 250, 400
Concrete flexural strength (psi)	550 – 750	550 and 650
Concrete elastic modulus (psi)	Correlated to MR value	3,712,500 and 4,387,500 respectively
Load transfer	Dowels or no dowels	Dowels or no dowels (based on thickness)
Edge support	Yes or No	Yes or No

Table 4. Design-related Variables

Design Life

The design life represents the estimated time, in years, to reach the specified level of pavement distress (cracked slabs or erosion of the support layers). The design life is an important parameter since the accumulated damage in the pavement is a function of the initial traffic volume and the specified growth rate per year. Note that the design life does not equate to failure of the pavement, it relates only to the specified level of distress. All design charts in the Guide were developed for a 30 year design life.

Failure Criteria (Percent Cracked Slabs)

The percent cracked slabs (at the end of the design life) is a measure of pavement distress due to fatigue damage in the slabs. It should be noted that a cracked slab may or may not be impacting the serviceability of the pavement at the end of the design life. Depending on the base's susceptibility to erosion and the traffic level, a tight crack with good load transfer may not impact the pavement serviceability for many years after first appearance. Routing and sealing of tight mid-slab cracks in lightly trafficked pavements can retard spalling and erosion and extend the time until patching is required.

Reliability

The design reliability is a measure of the factor of safety against premature failure. Reliability has a significant effect on the design thickness, particularly at very high levels (greater than 95%). The specified reliability should consider the traffic volume and speed, availability of alternate routes, user costs related to roadway maintenance and rehabilitation and so on. Relatively higher levels of reliability are used for urban roadways but are always dependent on the roadway classification. The reliability level of 85% used in the Guide is typical for the residential and collector roadways covered herein.

Composite k Value

The composite k value is based on the subgrade soil and base material characteristics. In order to determine the appropriate composite k value for use in the design charts, the subgrade k must first be determined, as previously discussed. The use of a base layer is not mandatory under certain conditions, particularly for low trafficked roads. However, the benefit of using a base for constructability reasons and improved long-term pavement performance may justify the added expense. When the pavement is constructed directly on subgrade, the subgrade k value is used directly in the design charts.

The pavement may be constructed on the subgrade without a base layer if the following conditions are met:

- Subgrade soils have not more than 15 percent passing the Number 200 sieve, a plastic index of 6 or less, and a liquid limit of 25 or less.
- Subgrade soils are compacted to at least 95 percent of AASHTO T99 at the time of concrete placement.
- Design thickness is less than 7 inches.
- Average Annual Daily Truck Traffic (AADTT) is 20 or less.

If a base is to be used, the decision must then be made as to the most appropriate material type for the project. Unbound granular bases are widely used due to their relatively low cost, availability of suitable materials and ease of construction. This base type is generally preferred for low to moderate traffic volumes and is typically constructed in 4 to 6 inch thicknesses, although increased thicknesses are sometimes used for geometric or drainage considerations.. The composite k value using a granular base can be estimated in Figure 2 by choosing the appropriate subgrade k and the desired base thickness. Interpolation is permissible in Figures 2 through 4.

Poor subgrade soil conditions (k values less than 100 or high moisture sensitivity (erodible)) are often remedied through the use of cement or lime stabilization or removal and replacement of the subgrade soil to varying depths. An approximation of a chemically stabilized subgrade k value can be determined in Figure 2 by selecting the initial subgrade k value (prior to treatment) and then determining the appropriate depth of stabilization. This method is less precise than actually determining the stabilized k value since the type of stabilizer, content, placement technique and so on has a strong influence on strength and performance.

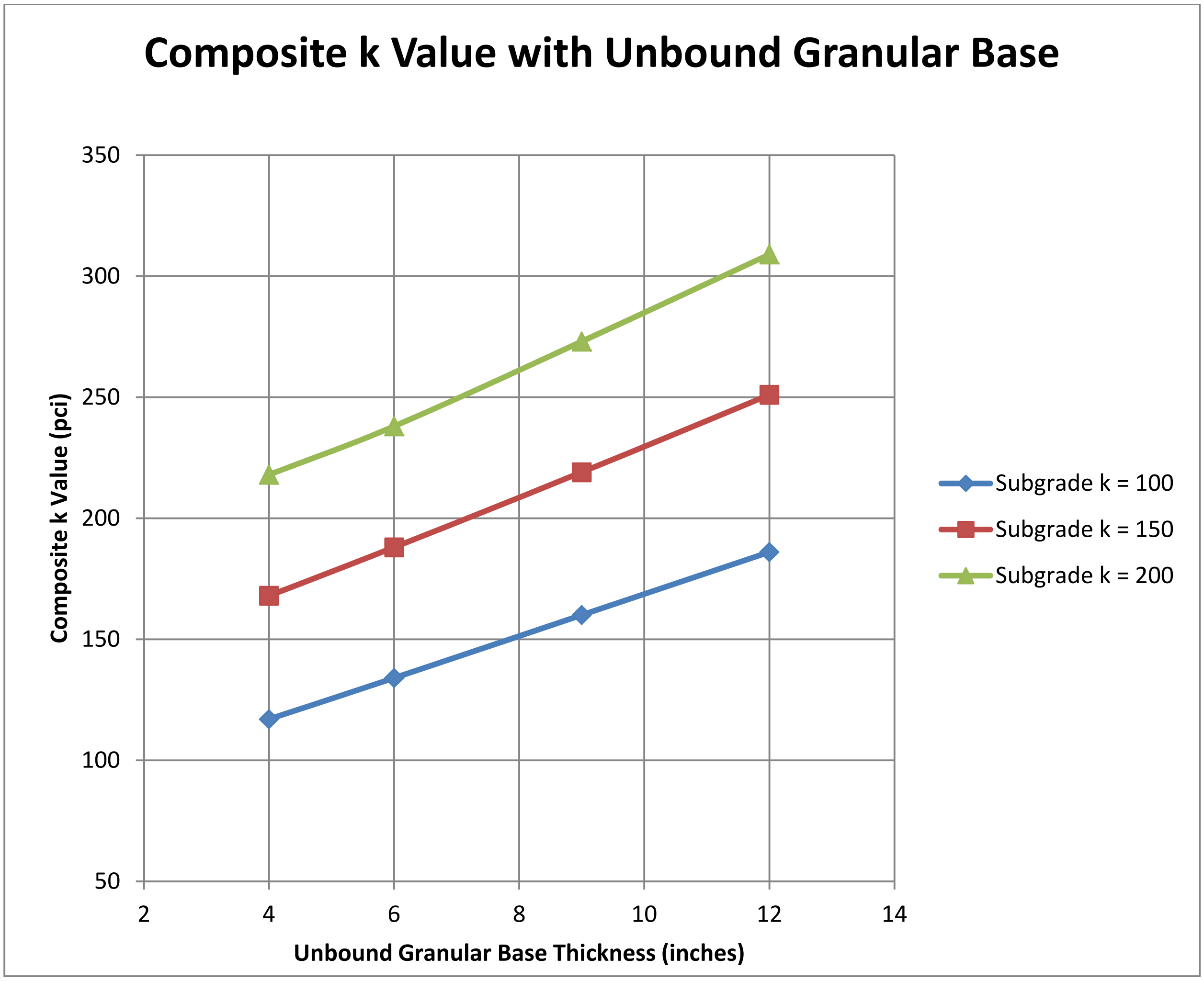


Figure 2. Composite k Value for Unbound Aggregate Base.

For highly trafficked roadways, the use of cement or asphalt treated bases is sometimes warranted to resolve constructability or performance issues. Either of these options will substantially increase the composite k value although at a greater cost than an unbound aggregate base.

The primary reasons for using a stabilized material are to provide a non-erodible base, improve pavement performance by limiting deflections, improve load transfer efficiency at the joints, and provide a more uniform level of support and a high quality construction platform. The use of a stabilized base will result in decreased slab thickness due to the increased composite k value. An optimized design would consider the cost of the stabilized base and its benefits relative to the cost savings realized with the thinner pavement.

An asphalt or cement treated base will result in very high composite k values, particularly for thicker sections. A practical upper bound for the composite k value has been set at 400 psi/in for development of the Guide. At levels exceeding this value, particularly for cement treated bases, the material may actually be too rigid and result in slab cracking due to curling, warping and load stresses. Figures 3 and 4 have been truncated to show only those thicknesses corresponding to a composite k of 400 psi/in or less.

Where a cement or asphalt treated base is specified by the designer, a laboratory-based mix design process is required. Mixing and placement should be closely monitored to ensure the specified level of support is achieved. The cement treated base used in the calculations in Figure 3 is assumed to have a modulus of elasticity of 750,000 psi, which is expected to correlate to a compressive strength of at least 550 psi at 28 days for typical materials.

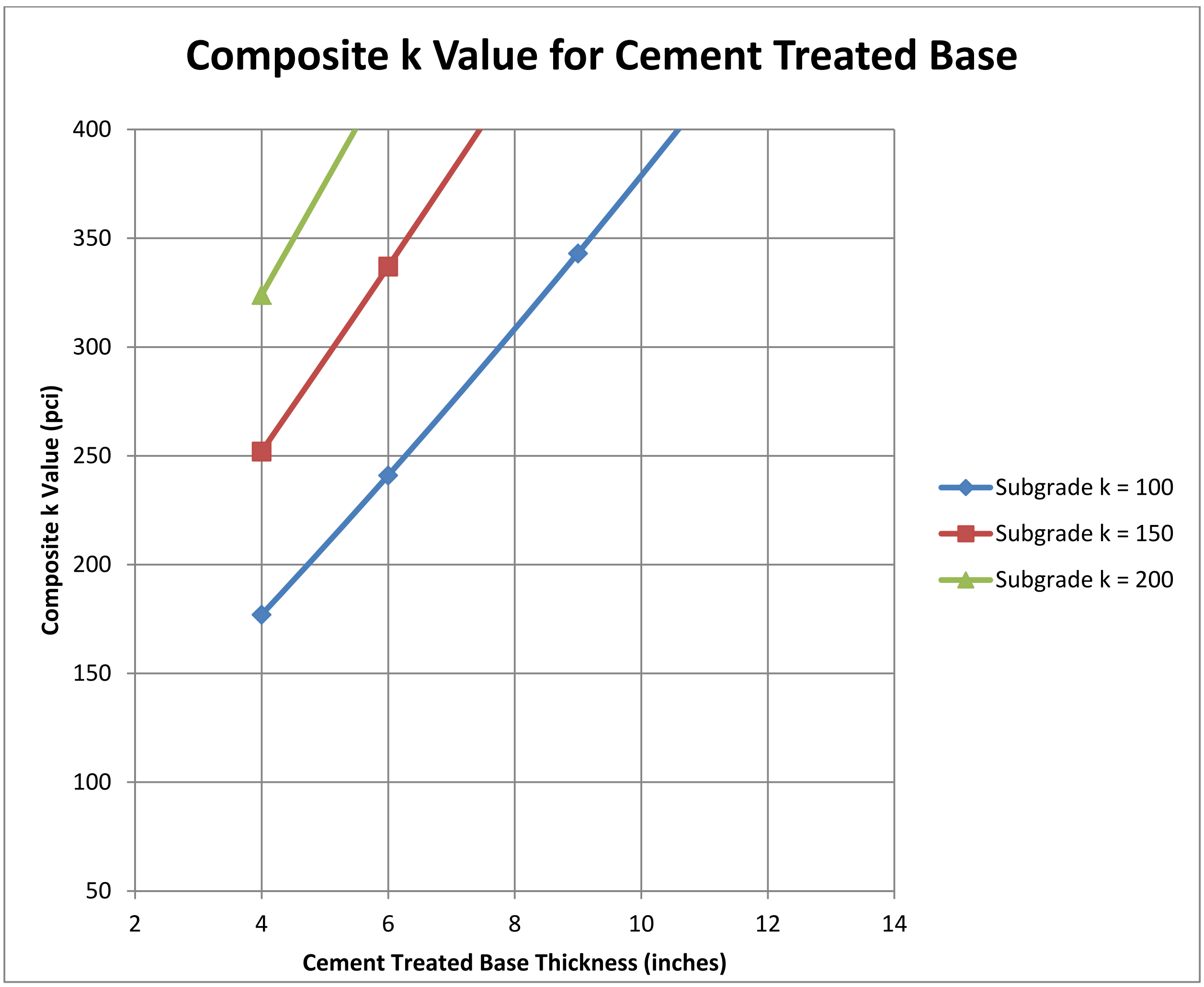


Figure 3. Composite k Value for Cement Treated Base.

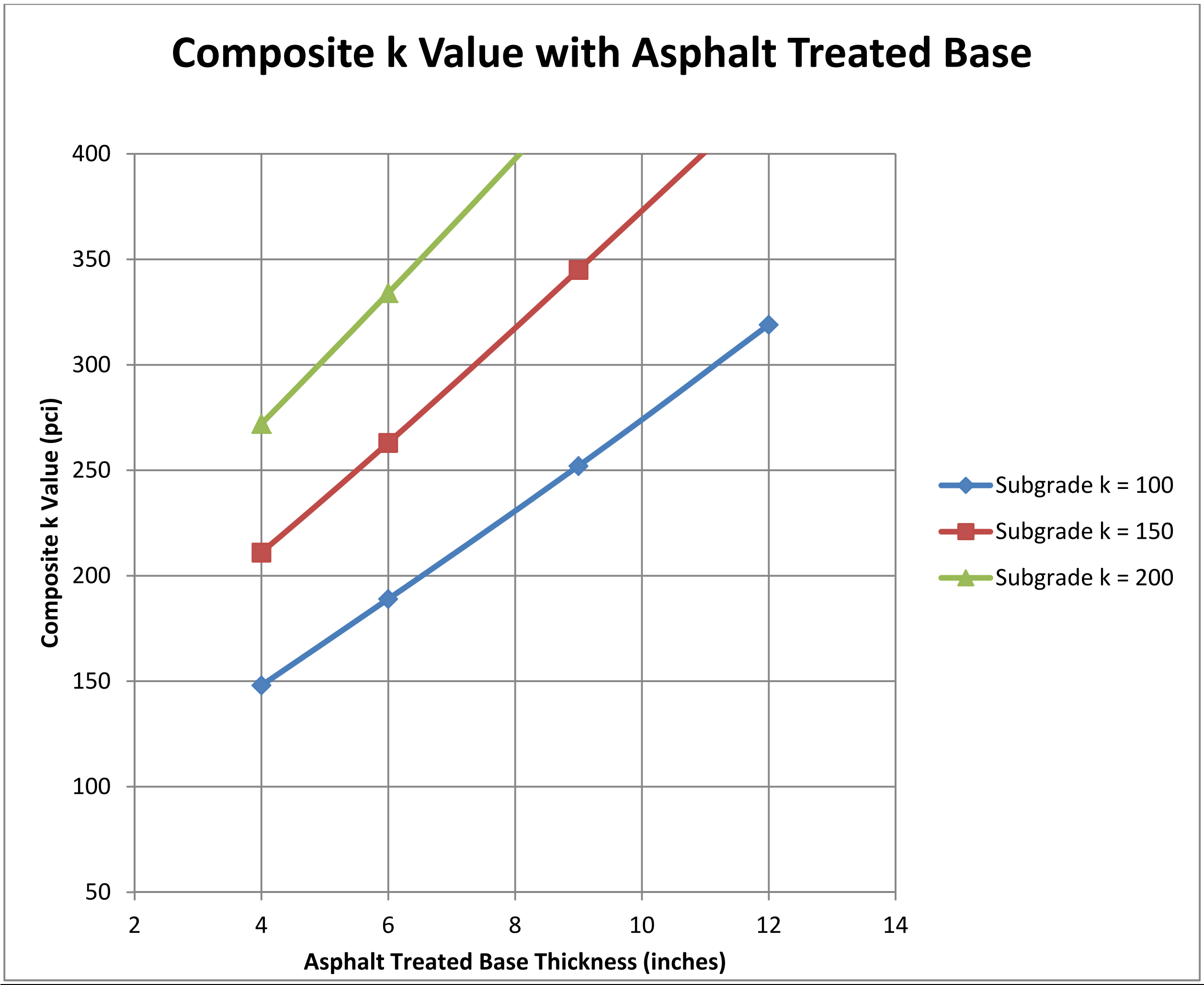


Figure 4. Composite k Value for Asphalt Treated Base.

Concrete Properties

The concrete properties specified by the pavement designer include the 28-day flexural strength or modulus of rupture (MR) and the corresponding elastic modulus value. Concrete strength has a significant impact on the required slab thickness with higher strengths resulting in decreased slab thickness. The elastic modulus value is rarely measured and is typically correlated to the flexural or compressive strength of the concrete.

It is critical that the flexural strength used by the designer be transmitted to the contractor and construction inspection personnel and be clearly noted prior to bidding. The use of a lower strength concrete than used in design will result in a shorter life than designed. Preferably, both the construction documents and the plans should clearly and

unambiguously indicate the required strength, either as flexural strength or as compressive strength or both.

The design charts in the Guide include two MR values that bracket the range of concrete strengths typically in use, 550 and 650 psi (approximately 3750 and 5000 psi compressive strength, respectively). The corresponding elastic modulus values of 3,712,500 psi and 4,387,500 were used. Compressive strength is sometimes specified rather than flexural strength, particularly if cylinder breaks are favored over beam breaks for quality control and quality assurance purposes

Load Transfer

Load transfer at the transverse contraction or construction joints in concrete pavements is important in reducing pavement deflections and edge stresses. High deflections, particularly at slab corners, can lead to erosion of the support layers unless these materials are highly non-erodible. The most effective means to reduce deflections and achieve load transfer is through the use of smooth dowel bars placed at mid-depth of the slab and distributed along the joint. Aggregate interlock can also be used where truck traffic is 20 per day or less and the calculated pavement thickness is less than 7 inches.

Table 6 indicates the conditions under which dowel bars are recommended along with the appropriate sizes for various slab thicknesses. Dowel bars should be 18 inches long and placed 12 inches center-to-center regardless of diameter.

Slab Thickness	Load Transfer
Less than 7.5 inches	Dowel bars are not required
7.5 inches or greater	1.00 inch dowel bars required

Table 5. Recommended Load Transfer Options

Edge Support

Edge support refers to the presence of a tied concrete curb and gutter, tied concrete shoulder or a widened lane (typically 13 feet but with the edge stripe placed at 12 feet). Tied support implies that the travel lane and the curb and gutter or shoulder are “tied” with deformed reinforcing bars to ensure a measure of load transfer across the longitudinal joint and prevent separation or integral with the mainline pavement. When new pavements are constructed with the existing curb and gutter in place, tie bars must be installed to be considered as edge support.

The intent of edge support is to reduce the edge stresses in the slab thereby increasing pavement life and enhancing performance for a given slab thickness. Alternately, adding edge support will reduce the required slab thickness for a fixed level of performance.

The design charts in the Guide were developed for pavements with and without edge support. If pavement geometric considerations allow, the use of tied edge support is encouraged.

Longitudinal Joint Spacing and Tie Bar Recommendations

Longitudinal joints are required to prevent random longitudinal cracks from forming. The distance from a free edge or another longitudinal joint should be no greater than 15 feet. If the distance is greater than 15 feet, another longitudinal joint should be added to reduce the spacing. However, longitudinal joints should preferably be located at the lane edges if the lane width is 15 feet or less. If longitudinal joints must be located within the lane, they should be located in the center of the lane. Do not place longitudinal joints in the wheel paths where they will be exposed to continuous loading, although it is acceptable to cross the wheel paths in areas where lanes are merging.

On most streets, the pavement is laterally restrained by the backfill behind the curbs and there is no need to tie longitudinal joints with deformed tie bars. However, on streets not restrained from lateral movement, tie bars must be placed at mid-depth of the slab to prevent the joint from opening due to the contraction of the concrete slabs. Tie bars are customarily #4 deformed reinforcing bars, 30 inches long and spaced 30 inches center to center, independent of pavement thickness. Tie bars, unlike dowel bars in transverse joints, should not be coated with grease, oil, or other material that prevents bond to the concrete and should be omitted when the tie bar would fall within 12 inches of a transverse joint.

Transverse Joint Spacing

Transverse joints are either contraction or construction joints placed in concrete pavements to control random cracks. Joint spacing is a very important performance parameter and should be carefully considered in pavement design to minimize curling and warping stresses in the slabs as well as stresses due to restrained thermal movement and drying shrinkage of the concrete.

The maximum joint spacing, as shown in Table 6 is based on slab thickness as recommended in the StreetPave procedure. Pavement performance may be enhanced by reducing the joint spacing in some cases. However, the required calculations are outside the scope of this Guide and joint spacing less than 7.5 feet is not recommended. In cases where dowel bars are required for load transfer, the dowels must be placed at all transverse joints.

Transverse joint spacing should be at integer multiples of the tie bar spacing (2.5 feet at the recommended 30 inch spacing) to avoid having tie bars interfere with transverse joint function. The joint spacings shown in Table 6 are based on a 30 inch tie bar spacing. If a different tie bar spacing is used, the transverse joint spacing should be adjusted to avoid conflicts between the tie bars and the transverse joints.

Slab Thickness (inches)	Maximum Recommended Joint Spacing (feet)
5.0	10
5.5	10
6.0	12.5
6.5	12.5
7.0 or greater	15

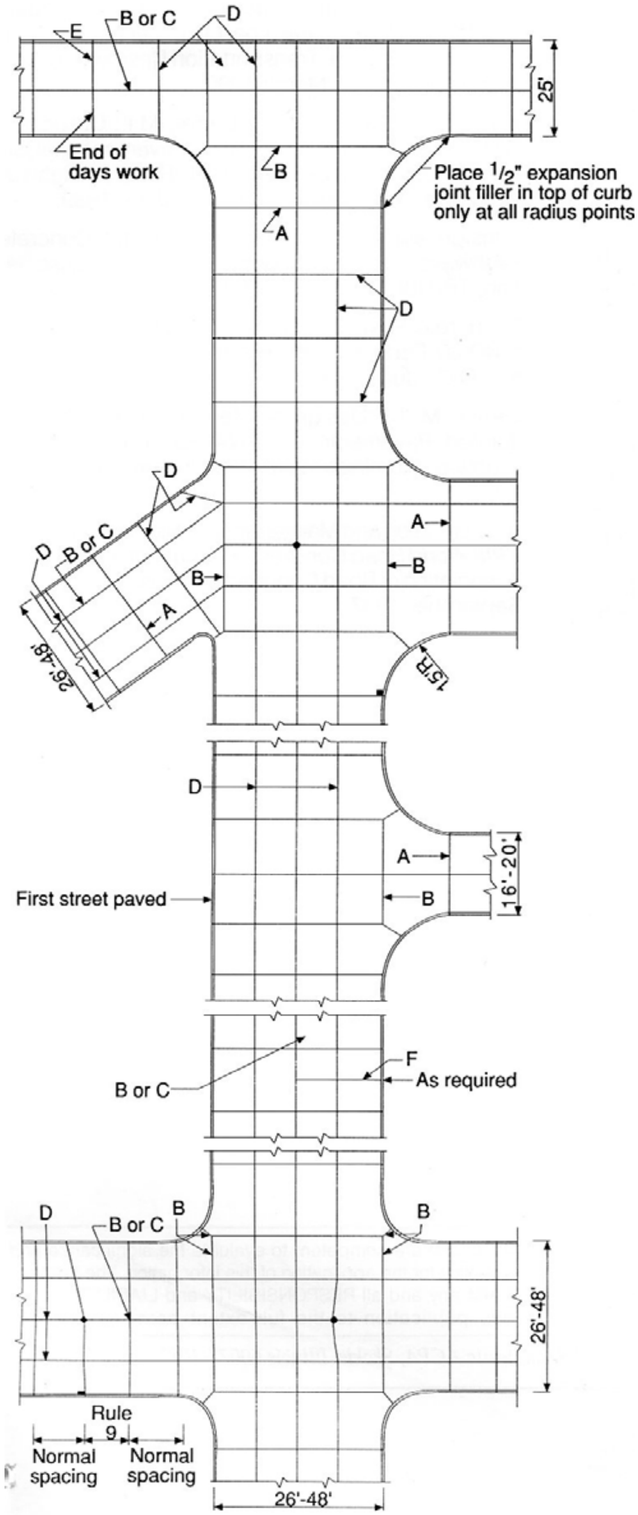
Table 6. Maximum Recommended Transverse Joint Spacing

Jointing Considerations

For a joint design to provide the best performance possible, it must be carefully thought out and designed. A well designed jointing layout can eliminate unsightly random cracking, can enhance the appearance of the pavement and can provide years of low maintenance service. The following recommendations will help in the design of a proper jointing system.

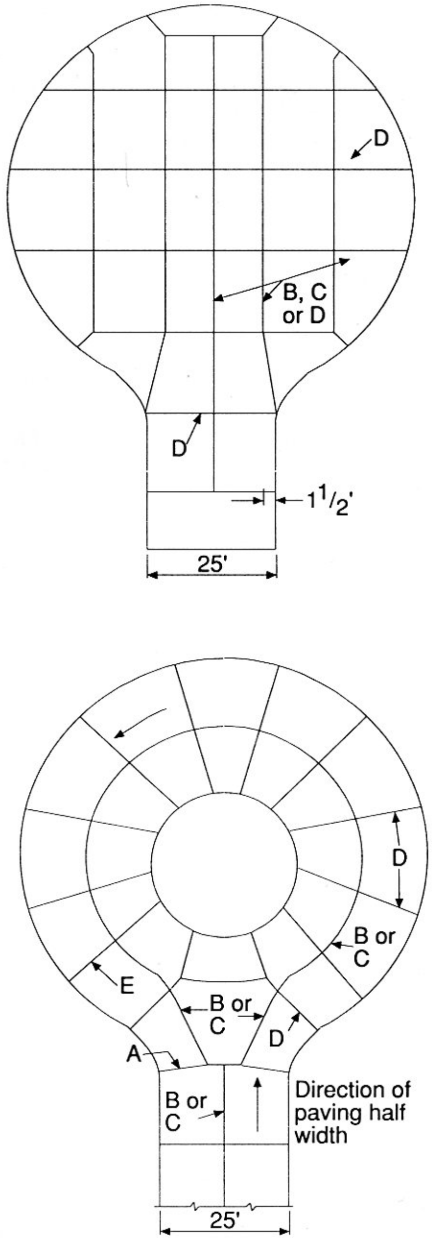
1. Avoid odd-shaped slabs.
2. Keep slabs as square as possible. Long narrow slabs tend to crack more than square ones.
3. In isolation joints, the filler must be full depth and extend through the curb.
4. If there is no curb, longitudinal joints should be tied with deformed tie bars.
5. Offsets at radius points should be at least 1.5 feet wide. Joint intersection angles of less than 60 degrees should be avoided.
6. Minor adjustments in joint location made by shifting or skewing to meet inlets and manholes will improve pavement performance.
7. When the pavement area has drainage structures, place joints to meet the structures, if possible.

General layouts showing the details of these recommendations are shown in Figures 5 and 6.



A. Isolation joints
B. Longitudinal construction joints
C. Longitudinal contraction joints
D. Transverse contraction joint
E. Planned transverse construction joint
F. Emergency transverse construction joint

Figure 5. Pavement joint detail example.



A. Isolation joints
B. Longitudinal construction joints
C. Longitudinal contraction joints
D. Transverse contraction joint
E. Planned transverse construction joint
F. Emergency transverse construction joint

Figure 6. – Jointing example for cul-de-sacs.

DESIGN DEVELOPMENT USING THE GUIDE

Methodology

For any given project, there are numerous pavement designs that will meet the specified performance criteria. Selection of realistic and appropriate input values establishes a baseline from which to generate the designs. Designing the most economical pavement section requires sound engineering judgment and a thorough understanding of the inter-relationship between design variables.

The purpose of the Guide is to minimize the decisions that must be made to design a well performing concrete pavement. It is possible to optimize the design by considering the economic impact of the design-related inputs. For instance, a cement treated base will reduce the required slab thickness compared with an unbound granular base. Optimization is used to select the most economically feasible alternative for a fixed level of pavement performance.

The Guide uses a stepwise process to generate feasible designs. Numerous options can be evaluated once a baseline design has been generated. The following steps should be followed for all designs:

1. Determine the traffic category that most closely fits the descriptions presented in Table 1.
2. Determine an AADT value either through truck traffic counts (preferred) or by estimating within the range shown in Table 1.
3. Determine the composite k value.
    a. Determine the subgrade k value through laboratory testing (preferred) or by estimating within the range shown in Table 3 based on the subgrade type description.
    b. If a base is to be used, determine the composite k value by use of Figures 2, 3 or 4. In general terms, unbound granular bases are suitable for most pavement types while cement or asphalt treated bases are generally used for higher trafficked roadways. For initial analyses, a composite k value of 100 psi/in or greater is recommended as a reasonable starting point.
    c. If chemical or mechanical stabilization is required, the use of Figure 2 or Table 5 can be used to approximate the composite k value.

4. Establish the desired modulus of rupture (MR) for the concrete. The design charts have been developed for 550 and 650 psi. Determine if edge support will be used.
5. Based on the information above and using Figures 7 through 14 (Design Charts A through H), determine the required slab thickness.
6. Depending on the slab thickness, the need for load transfer is determined in Table 6.
7. The final step is to determine the recommended joint spacing as shown in Table 7.

This process will result in a design that meets the performance criteria specified for the project. Note that the minimum design thickness for residential and collector roadways has been set at 5 and 5.5 inches, respectively. The design charts reflect these minimum values and in cases where no designs are shown, correspond to higher reliability levels than specified in Table 2. For example, referring to Figure 7, the required thicknesses for a k value of 400 pci are less than the specified minimum thickness of 5 inches and do not appear on the design chart. Therefore, in theory, the 5 inch thickness is a significant over design compared with the actual calculated design thickness and should yield reliability greater than 85 percent. However, practical construction considerations require the minimum thicknesses even if the design theory indicates a thinner pavement would be acceptable.

Developing a baseline design and feasible alternatives is shown in the following example. Although optimization is not required, substantial savings in initial and long-term costs can oftentimes be realized. The design-related variables that are most used in design optimization are the concrete strength properties, composite k value and edge support.

Pavement Design Process, Example 1.

The following example is based on reconstruction of a two lane city street and illustrates the key points involved in the pavement design process using the Guide.

Site Variables.

A visual survey of the existing 61 year old concrete pavement shows that the pavement has performed well but is distressed sufficiently to warrant reconstruction. The curb and gutter are cracked and will need to be replaced as well as the driving lanes. There is low to moderate faulting at some of the joints and random cracks.

Traffic

A recent traffic count indicates that the average two-way daily truck traffic (AADT) is 300 trucks per day. According to Table 1, the most appropriate traffic category designation is collector. The traffic study also showed that the traffic in both directions was approximately the same.

Subgrade Soil Properties

The existing pavement was cored and material samples of the subgrade soil were extracted at three locations. A base course was not used in the original pavement structure. A cursory examination showed the subgrade to be a predominantly sandy soil with moderate clay content.

Since the project has a substantial level of truck traffic and is of relatively high importance, a resilient modulus test was performed on the subgrade samples at the in situ moisture content. The average resilient modulus value was approximately 3050 psi. The three subgrade samples had percentages passing the No. 200 sieve of 12, 14, and 15 percent.

According to Table 3, the soil offers medium support and has a corresponding k value of approximately 150 psi/in. Because of the potential for clay content to exceed 15 percent and an AADT greater than 20, a subbase will be required.

Design Variables

The existing pavement has performed well above expectations given that the original design life was estimated at 20 years. However, the level of cracking and faulting show that the subgrade soil may be slightly moisture sensitive and moderately unstable.

Composite k value

One of the least expensive means to ensure good long-term pavement performance is to provide a non-erodible, uniform and stable support. Given that the existing subgrade may not provide the desired level of support, an unbound granular base will be used.

It is generally not warranted to construct an unbound granular base less than 4 inches or greater than 6 inches thick for concrete pavement. Figure 2 is used to estimate the composite k value for an unbound granular base. Given a subgrade k value of 150 psi/in and a 4 inch granular base, the composite k value for the design is approximately 165 psi/in.

Concrete Modulus of Rupture (MR)

The concrete MR is assumed to be 650 psi .

Edge Support

The existing street has a curb and gutter that is need of replacement. For constructability and pavement performance reasons, a tied curb and gutter will be used for the new construction.

Required Pavement Structure

The pavement structure is determined using the appropriate design chart and based on the site and design-related variables. Using Figure 13 (Design Chart G), the estimated design thickness is approximately 5.8 inches through interpolation. The design thickness should be rounded up to the nearest .5 inch increment thereby making the recommended thickness 6 inches.

Assuming the design thickness is specified as 6 inches, the net effect is that the design is very conservative and the reliability that was originally assumed at 85% in now in excess of 90%. The pavement is highly likely to remain at a high level of serviceability considerably longer than the specified 30 year design life.

Assuming that the final design calls for a 6 inch thick pavement, dowel bars are not required for effective load transfer (Table 5) and a maximum joint spacing of 12.5 feet is recommended. (Table 6)

At this point of the process, a baseline design has been generated that easily meets or exceeds the project performance criteria. However, the designer may wish to consider other input variables to optimize the design. For instance, if the concrete MR is reduced to 550 psi, the design thickness would increase to 6.5 inches, according to Figure 9, while other aspects of the design remain the same. The designer may wish to consider the relative cost reduction of lower strength concrete against an 8.3 percent increase in quantity required for construction.

Pavement Design Process, Example 2

The following example is based on construction of a new, dead-end residential street and illustrates the key points involved in the pavement design process using the Guide.

Site Variables

Traffic

Based on the number of houses in the proposed subdivision and historic traffic data from similar roadways, it is anticipated that the initial average daily truck traffic (AADT) is 4 trucks per day. According to Table 1, the most appropriate traffic category designation is residential. As is common with residential streets, the majority of truck traffic will be during construction and thereafter, delivery vehicles and garbage trucks. In cases where the streets will be used as part of a bus route, an accurate assessment of the number of buses is very important and a more detailed design analysis should be conducted with an appropriate axle load spectra.

Subgrade Soil Properties

A cursory examination showed the subgrade to be predominantly sand. Since the project has only a minor amount of truck traffic and is only of moderate importance, hand auger soil samples were obtained and analyzed for gradation and Atterburg limits. All of the samples contained less than 10 percent passing the No. 200 sieve and were found to be non-plastic. Based on the classification data and Table 1, a k value of 200 psi/in is assumed.

Design Variables

Composite k value

A base layer is not required when the percent passing the No. 200 sieve is 15 percent or less, the PI is 6 or less, and the LL is 25 or less and the AADTT is 20 or less. This site meets these criteria, consequently no base is required. However, it is critical that the subgrade be appropriately compacted and this compaction level is maintained at the time of paving to ensure the design performs as expected. Uniform support is key to a successful concrete pavement design.

Concrete Modulus of Rupture (MR)

The concrete MR is assumed to be 550 psi based on cost and materials readily available at the local ready mixed supplier.

Edge Support

For constructability and pavement performance reasons, a tied curb and gutter will be used for the new construction.

Required Pavement Structure

The pavement structure is determined using the appropriate design chart and based on the site and design-related variables. Using Figure 7 (Design Chart A), the estimated design thickness is less than 5 inches, which will be rounded up to the minimum thickness of 5 inches for the final design.

Assuming the design thickness is specified as 5 inches, the net effect is that the design is very conservative and the reliability that was originally assumed at 85% in now in excess of 90%. Alternately, it is likely that the pavement will remain at a high level of serviceability considerably longer than the specified 30 year design life.

Assuming that the final design calls for a 5 inch thick pavement, dowel bars are not required for effective load transfer (Table 5) and a maximum joint spacing of 10 feet is recommended (Table 6).

At this point of the process, a baseline design has been generated that easily meets or exceeds the project performance criteria. Adequate specifications, regarding materials, joint design, and placement, will be required to achieve these goals.

DESIGN CHARTS

The design charts are based on the input values previously discussed in the Guide. Note that the charts are differentiated by traffic category, concrete MR value and whether or not edge support is present. The charts are used by selecting the appropriate truck traffic on the x-axis, projecting a line to the interpolated composite k value and reading off the required slab thickness from the y-axis. Design thicknesses should be specified by rounding up to the nearest half-inch from the exact value shown in the charts. For k values indicated in the key, but greater than shown in the chart, and traffic values lower than shown in the chart, specify the lowest thickness shown in the chart.

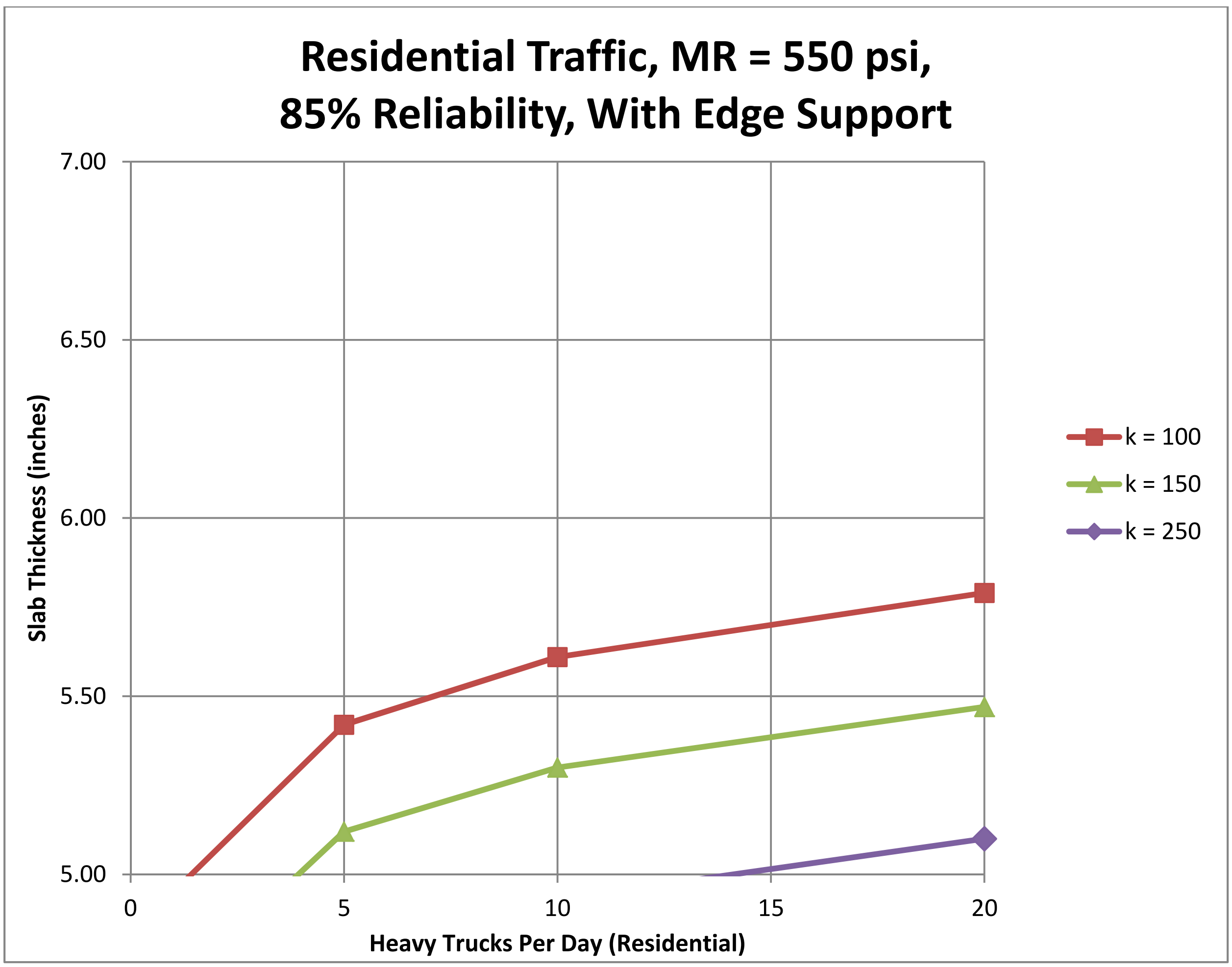


Figure 7. Design Chart A.

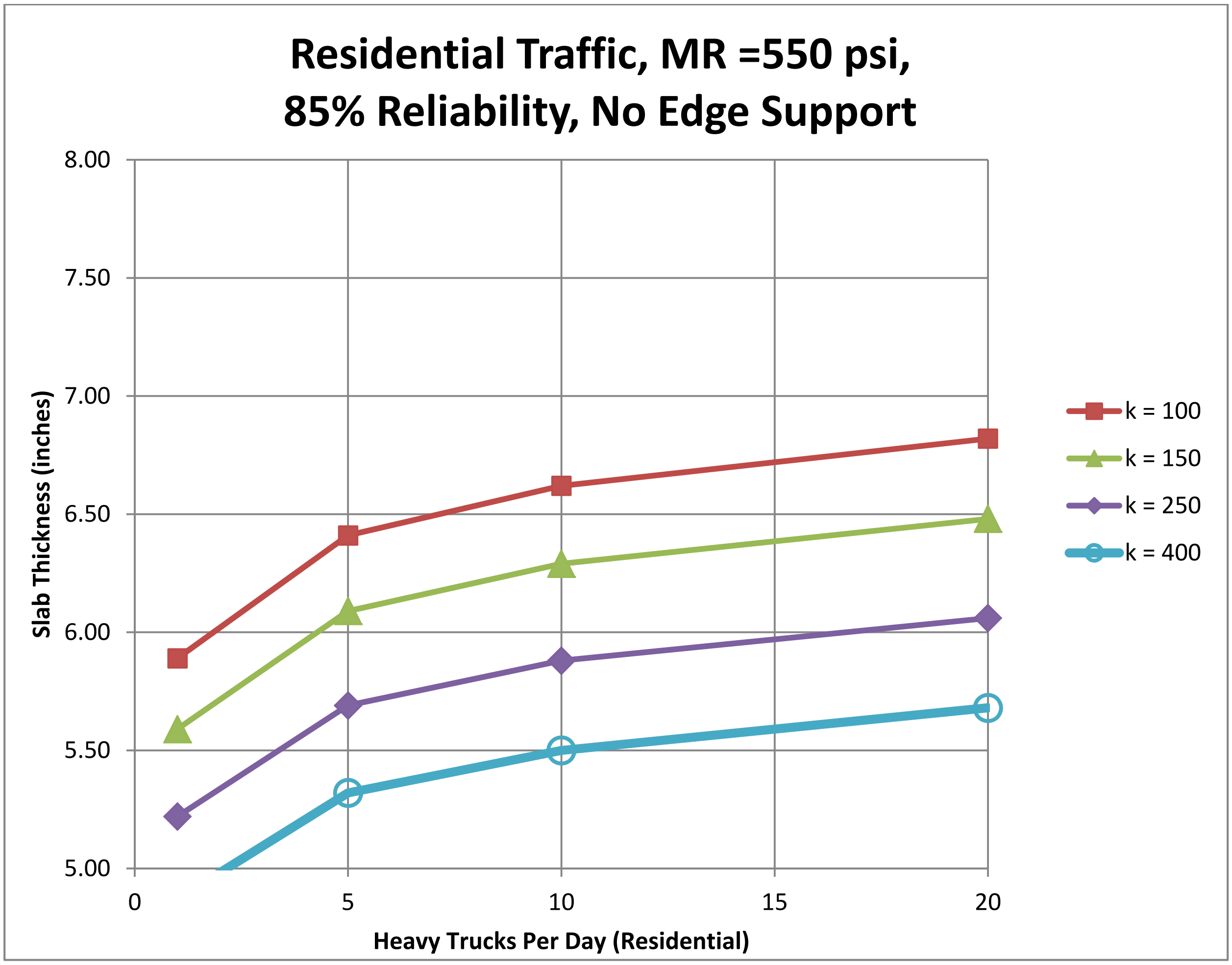


Figure 8. Design Chart B.

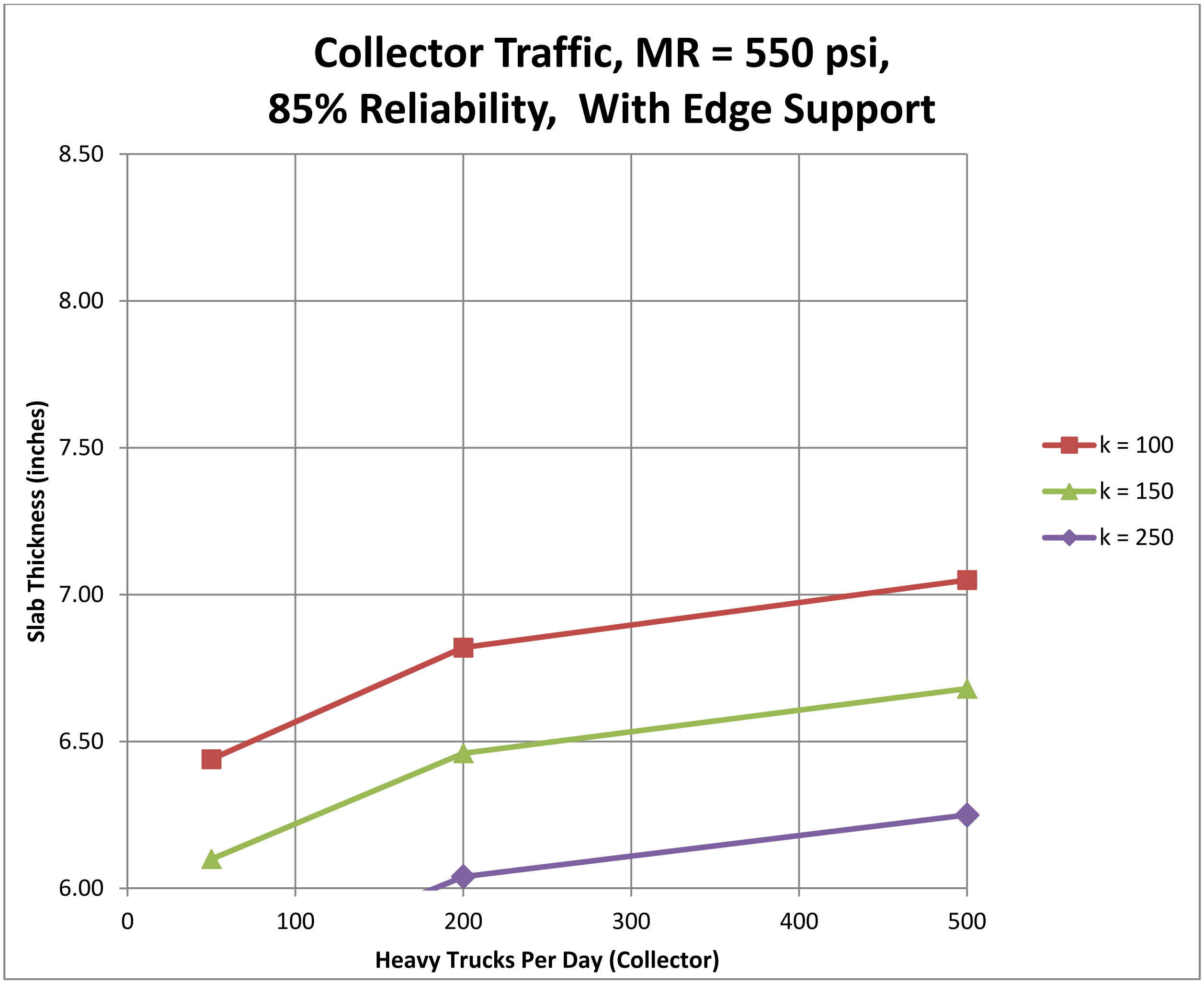


Figure 9. Design Chart C.

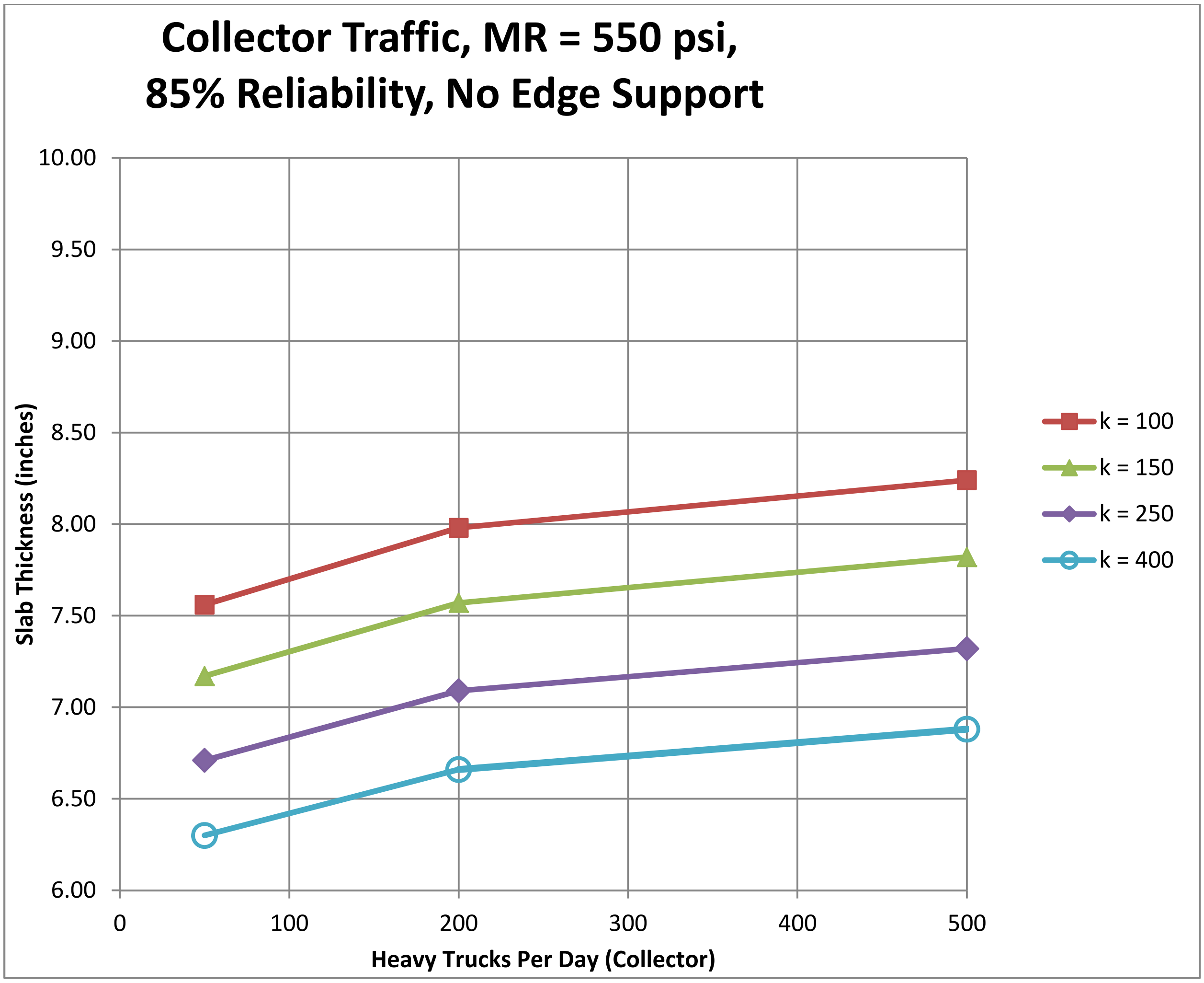


Figure 10. Design Chart D.

(Note: For design thicknesses greater than 8 inches, a more detailed pavement design analysis is recommended.)

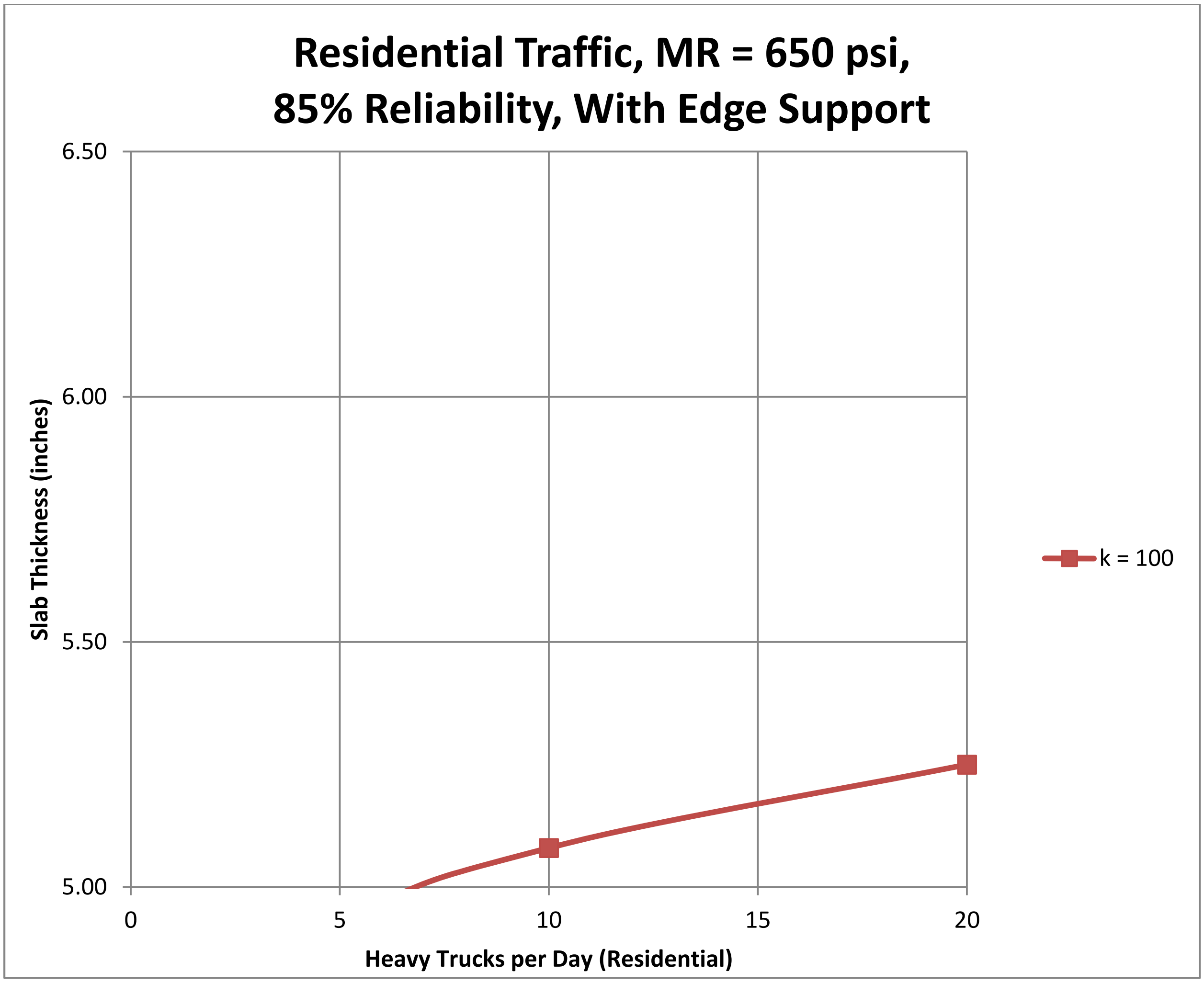


Figure 11. Design Chart E.

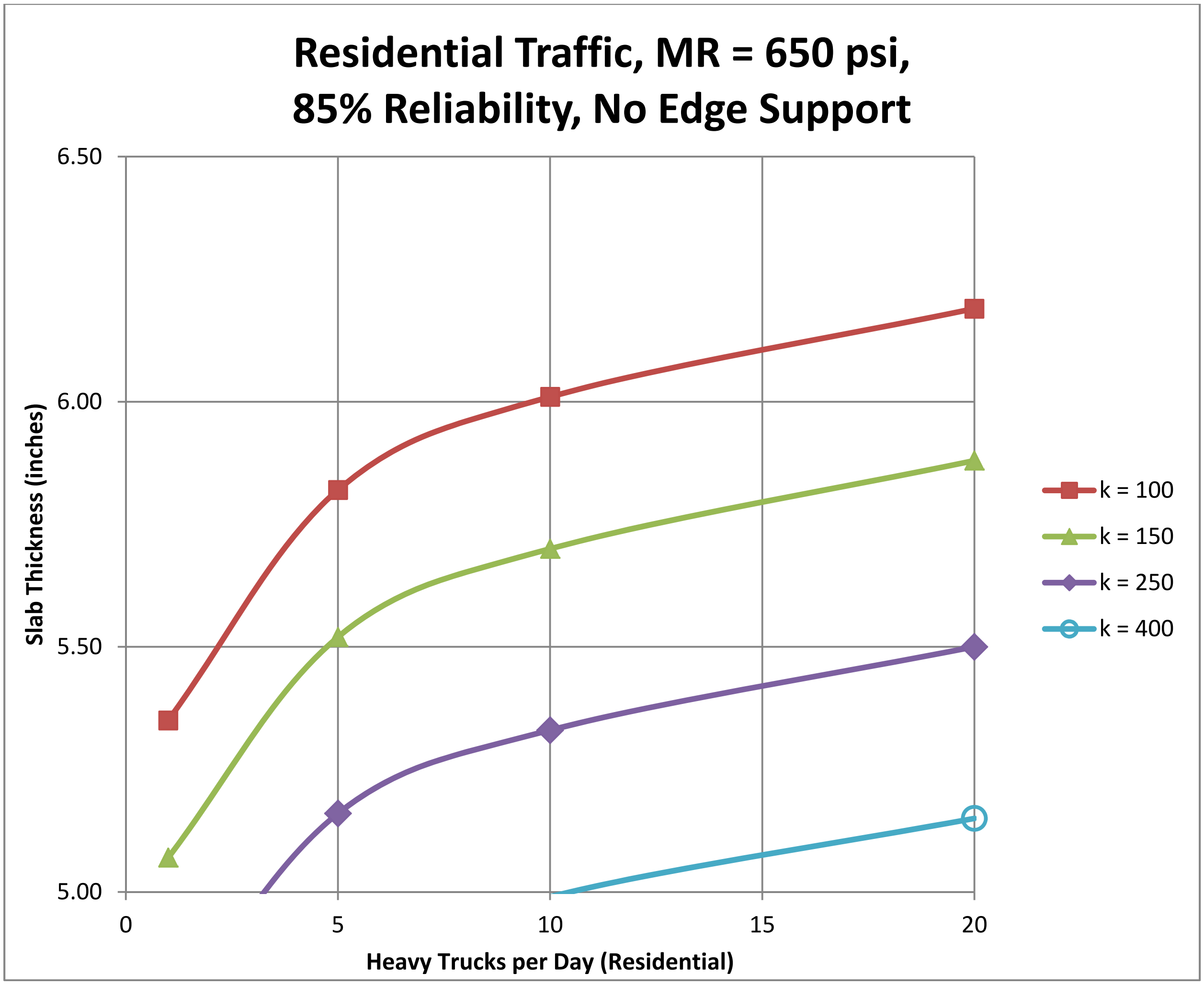


Figure 12. Design Chart F.

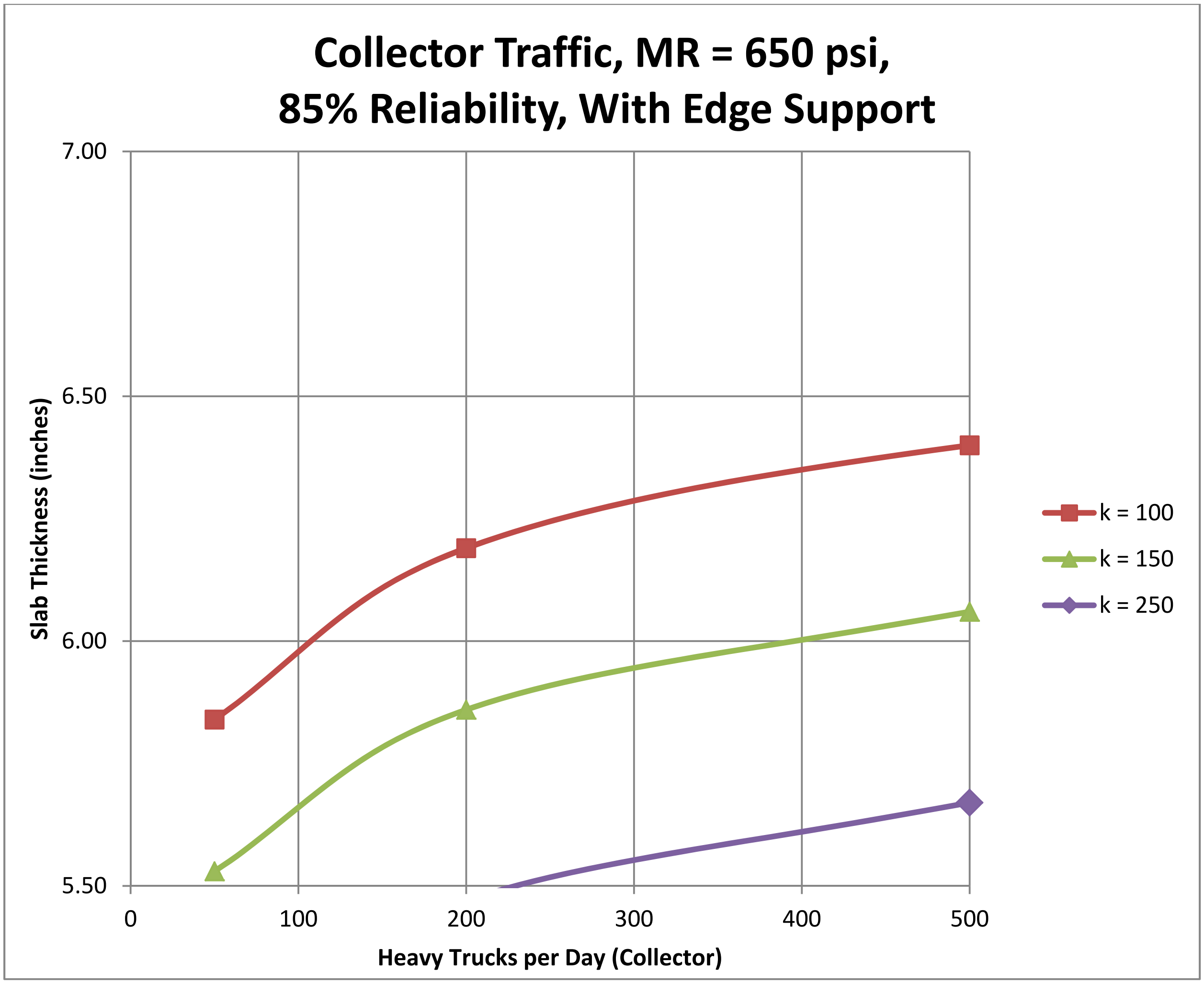


Figure 13. Design Chart G.

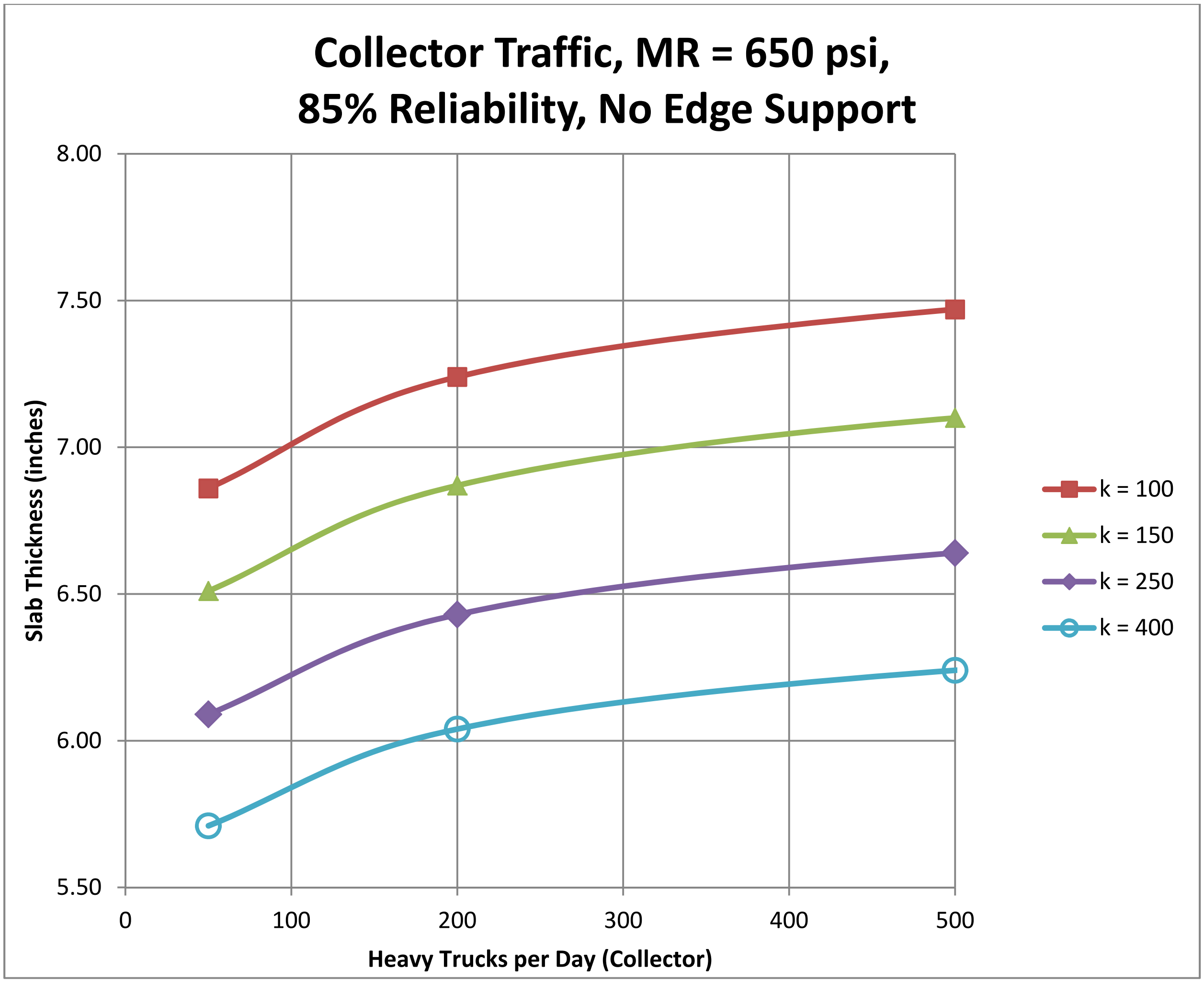


Figure 14. Design Chart H.

Summary

Concrete pavement design procedures are dictated by either Agency policy or the level of traffic and the type of roadway. The StreetPave methodology is applicable to a wide range of conditions and was therefore selected as the design method for development of the Guide.

The intent of the Guide was to simplify and standardize, to the extent possible, concrete pavement designs from lightly travelled residential streets to moderately trafficked collector roadways. In cases where the estimated pavement thickness exceeds 8-inches, it is strongly suggested that the design be verified with a more detailed engineering analysis consistent with DOT practice for higher volume roadways.

The Guide is not intended to replace sound engineering judgment in generating feasible pavement designs. The results of the analysis are only as sound as the input values on which they are based. Low volume residential streets can generally rely on estimated soil support values and traffic values as shown in the Guide. However, as traffic volumes, vehicle weights and speeds increase, it is crucial that the estimates are based on actual site data.

In order for the pavement to fulfill the performance requirements established by the Agency, the specifications, plans and construction operations must be a coordinated effort.

APPENDIX

Traffic Characterization

Axle Load Distributions for Traffic Categories in the Guide

Axle Loads (1000 pounds)	**Traffic Categories (Axles per 1000 Trucks)**	
	Residential	**Collector**
Single Axles		
4	1693.31	
6	732	
8	28	233.60
10	483.10	142.70
12	204.96	116.76
14	124.00	47.76
16	56.11	23.88
18	38.03	16.61
20	15.81	6.63
22	4.23	2.60
24	0.96	1.60
26		0.07
Table continues next page		

Tandem Axles		
4	31.90	
8	85.89	47.01
12	139.30	91.15
16	75.02	59.25
20	57.10	45.00
24	39.18	30.74
28	68.48	44.43
32	69.59	54.76
36	4.19	39.79
40		7.76
44		1.16