Guidance for Improving Foundation Layers to Increase Pavement Performance on Local Roads

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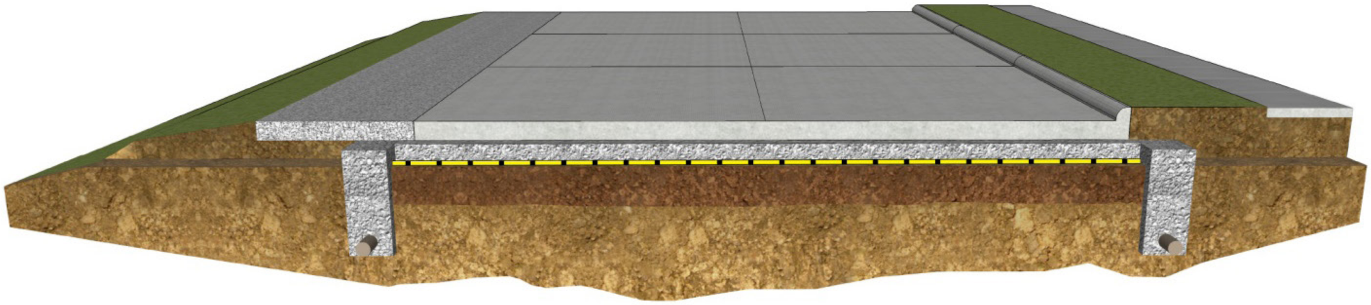
National Concrete Pavement
Technology Center



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16. Abstract

This document is the second of two deliverables for the project Optimizing Pavement Base, Subbase, and Subgrade Layers for Cost and Performance on Local Roads (TR-640). The first deliverable is the 454-page Final Field Data Report. The field data report describes test results and comparative analysis from 16 different portland cement concrete (PCC) pavement sites on local city and county roads in Iowa. At each site the surface conditions of the pavement (i.e., crack survey) and foundation layer strength, stiffness, and hydraulic conductivity properties were documented. The field test results were used to calculate in situ parameters used in pavement design methodologies for AASHTO (1993) and Iowa's Statewide Urban Design and Specifications (SUDAS). Overall, the results of the study demonstrate how in situ and lab testing can be used to assess the support conditions and design values for pavement foundation layers and how the measurements compare to the assumed design values. This guide summarizes the study results and outlines general guidelines for applying them to optimize pavement bases, subbases, and subgrade layers of local roads with PCC pavements and thus their performance.

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PROJECT OBJECTIVES

The purpose of the Iowa Highway Research Board-sponsored research project TR-640 was to better understand how to optimize local pavement foundation support layers in order to understand pavement performance. The project consisted of a field study and the development of a user guide based on the information from the field study. Although the study focused on concrete pavements, the findings and conclusions apply also to asphalt pavements—perhaps even more so, since asphalt pavements depend on a strong subbase system. The site field research and design options covered in this study are for concrete pavements.

The project's objectives were to do the following:

1. **Determine the level of increased performance when Portland Cement Concrete (PCC) is placed on granular subbase or treated subgrade and quantify the performance and cost effectiveness**. Field data was collected on 16 existing PCC pavements to measure in situ foundation parameters and compare them to design assumptions. The 16 Iowa sites, ranging in age from 1 to 42 years, were tested using a falling weight deflectometer, dynamic cone penetrometer, along with permeability testing, physical sampling and pavement condition assessments. The TR-640 field study was completed in May 2014 by the Center for Earthworks Engineering with assistance from the National Concrete Pavement Technology Center, both located at the Institute for Transportation at Iowa State University.

2. **Develop a user guide for various traffic, soils and pavement factors for optimized performance and financial benefits**. This user guide, utilizing the information from the TR-640 field study, was developed to fulfill the second objective of TR-640.

INTRODUCTION

It is common for local street and highway pavements to be constructed from PCC supported on a natural subgrade without considering or using a subgrade stabilized treatment or support layer such as an aggregate subbase. When support layers are considered, they typically serve as a construction platform and improve the level of stability and uniformity for the pavement foundation which can result in increased performance and thus increased pavement life. An aggregate subbase can also improve the drainage under the pavement, minimizing the deterioration caused by water entrapment. The question is how much do they benefit the pavement and is the benefit worth the costs, particularly if the pavement is meeting the design life.

To find answers, field research was conducted on 16 local road sites across the state of Iowa to better understand the effects of aggregate subbases. Before recommendations could be formulated into a guide, what was *understood before* the TR-640 study and what was *learned from* the TR-640 study needed to be examined.

WHAT WAS UNDERSTOOD BEFORE THE IHRB TR-640 STUDY

The pavement design life for local roadways (not including heavily traveled arterials or trunk highways) is normally based on the pavement thickness and less concern is typically given to the support system. Unless there are material related distress failures in concrete pavement (ie. freeze-thaw damage, ASR, D-cracking) the normal mode of failure is the vertical distortions of the pavement surface from subgrade movement. The degradation is normally faulting, slab movement, joint failures, cracking, etc. and is represented by the dropping of the pavement condition index (PCI).

Subgrade Soils

Concrete pavement is relied upon for its durability and strength. In order for a concrete pavement to provide long term performance, its foundation needs to have uniform support. Typically in Iowa, the foundation includes the natural subgrade and in some instances, an aggregate subbase. If the pavement is placed directly on the natural subgrade, preparation is needed to provide uniformity. At a minimum this includes, topsoil removal, scarification of the underlying subgrade to a depth of one foot and compaction to a specified depth, density and moisture content. For additional information see Statewide Urban Design and Specifications (SUDAS) Design Manual Chapter 6.

Subgrade Soil Key Factors

When constructing any pavement (rigid or flexible) on natural subgrade that is subject to poor drainage and/or has poor soils, there will likely be measurable soil breakdown and movement due to freeze-thaw conditions and/or traffic loading.

It should be noted that variability in the soil affects both rigid and flexible pavements. Rigid concrete pavements transfer the traffic load to the aggregate subbase and subgrade foundation at a smaller value then flexible asphalt pavements because they are able to distribute the load to a larger area. For example, a 100 psi tire load typically results in less than 5 psi to the aggregate subbase for concrete pavement and is approximately 20 psi for the aggregate subbase for asphalt pavement. Therefore asphalt pavement requires a thicker aggregate subbase and/or a thicker pavement to provide additional support and strength as compared to a concrete pavement. Although concrete pavements can perform better than asphalt pavements when subjected to poor support characteristics, they are more rigid and are subject to more tensile cracking. Figure 1 illustrates the subgrade reactions for rigid and flexible pavements.

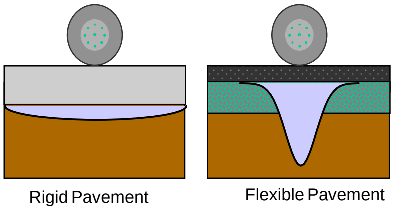


Figure 1. Subgrade reaction

Stabilized Subgrades

The need to stabilize subgrades is primarily due to excessive moisture in the subgrade itself. High moisture in soils may be encountered during construction for reasons ranging from a naturally high water table to seasonal rainfall and even to changes in drainage conditions during construction. Regardless of the cause, in situ wet soils must be addressed before constructing an aggregate subbase or placement of the pavement on the subgrade. Placing subdrains before construction or letting the soil dry out through a natural process is not normally a practical approach because of time constraints. The two most commonly used methods are chemical modification of the soils, particularly in high moisture conditions, and reinforcement/separation.

Stabilized (Chemical) Subgrades

A stabilized subgrade such as soil cement or fly ash stabilization will help to dry out excessive moisture soils and develop the uniformity needed to provide a construction platform and reduce delays during construction. When using chemical stabilizers, such as cement or fly ash, the percent of the stabilizer needs to be stipulated when the water content, soil type and freeze- thaw performance are considered. Recent research on the use of fly ash at the Boone County Expo is available for reference in the May 2013 Tech Brief entitled “Fly Ash Stabilization of Subgrade.”

Cement Modified Soils. Cement Modified Soils (CMS) are soils and/or manufactured aggregates mixed with a small portion of Portland Cement. CMS are normally used to improve material properties in the subgrade. Also, CMS helps prevent migration of subgrade soil and water into the aggregate subbase and provides some additional strength to the subgrade. CMS are principally used to modify fine grained soils such as silts and clays having high plasticity content. Some specifications require enough cement content to reduce the Plastic Index (PI) within a range of 12 to 15. Typically a CMS amount equivalent to 3 to 5 percent of the soil’s dry weight is incorporated into the mix to achieve the desired strength.

This combination allows for the reduction of plasticity, minimization of moisture related volumetric changes, an increase in bearing strength and an improvement in stability. This also provides a weather resistant construction platform. Figure 2 illustrates the application of cement slurry as part of the stabilization process.

Figure 2. Cement slurry application
(Photo courtesy of Guide to Integrated Pavement Solutions, CP Tech Center)

Fly Ash. A successful chemical stabilization can be achieved by incorporating approximately 10 to 15 percent fly ash (measured by dry weight of the native soil) into the existing subgrade. Fly ash can improve the subgrade CBR from 2 to 3 to as much as 25 to 30. It can also improve the unconfined compressive strength from 50 psi to 400 psi. Fly ash stabilized subgrades can also reduce the shrink-swell potential of clay soils and upgrade the condition of marginal soils. It is also a good drying agent for wet soils and provides a working platform during construction.

Stabilized (Reinforced) Subgrades

Reinforced subgrade treatment is typically used when subgrades have an unstable (soft) but not an extremely high moisture content. This may be accomplished through the use of geosynthetics such as geogrids and woven geotextiles.

Geogrid. Geogrid reinforcement of aggregate subbases can help prevent localized shear failure of the subgrade and therefore increase its effective bearing capacity. In addition, geogrids reinforce the granular fill through confinement of the particles, stiffening the base layer for improved load distribution. Figure 3 shows a rectangular geogrid placed at the interface of subgrade and limestone subbase layers in Boone County, Iowa.

Figure 3. Rectangular geogrid placed in Boone County, Iowa (Boone County Expo research phase 1 – Granular road compaction and stabilization; InTrans project 12 – 433)

Suppliers of geogrids should be contacted to assist in determining in situ soil moisture limits for the use of a geogrid. Under measurable wet conditions of the subgrade, a geogrid may not perform as intended. Under those conditions, chemical stabilization would be a better choice. For more information see Boone County Expo Research, Phase I – Granular Road Compaction and Stabilization (InTrans Project 12-433). Section 2010 of the SUDAS (Statewide Urban Design and Specifications) specifications lists the material properties for rectangular/square geogrids and triangular geogrids. These two common types of geogrids can be used to stabilize the subgrade and provide additional bearing capacity.

Geotextiles. Woven geotextiles also help reduce localized shear failure of the subgrade through increased tensile strength and therefore increased bearing capacity. Woven geotextiles have higher tensile strength than nonwoven geotextiles and with smaller openings (less drainable) serve as an excellent separation layer between the subgrade and aggregate subbase. Figure 4 shows a woven geotextile placed at the interface of the subgrade and limestone subbase layer in Boone County, Iowa.

Figure 4. Woven geotextile placed in Boone County, Iowa (Boone County Expo research phase 1 – Granular road compaction and stabilization; InTrans project 12 – 433)

Unstabilized Aggregate Subbases

Unstabilized aggregate subbases are appropriate when a stable and uniform construction platform will benefit construction. (ACPA 2007) An aggregate subbase support layer can provide a working platform during construction as well as provide uniformity as a support layer. A granular support layer will also serve as a drainage system to help drain surface water away from the pavement as well as provide a cutoff layer from subsurface moisture. If an aggregate subbase is used, a subdrain and outlet will be needed to complete the drainage system due to the poor drainage properties of Iowa soils. Figure 5 illustrates the compaction of an unstabilized aggregate subbase.

Figure 5. Unstabilized aggregate subbase

The preferred unstabilized aggregate subbase materials should meet the requirements of AASHTO (American Association of State Highway and Transportation Officials) M147 with the following criteria (ACPA 2007):

- Maximum particle size of no more than one third the subbase thickness*
- Less than 15 percent passing through the number 200 sieve
- Plasticity index of 6 or less
- Liquid limit of 25 or less
- Los Angeles abrasion resistance of 50 percent or less
- Target permeability of about 150 ft/day, but no more than 350 ft/day in laboratory tests

*Macadam stone may not meet the 1/3 aggregate subbase thickness criteria. Note that a 1 to 1½ inch aggregate choke layer is often placed on top of the macadam stone to provide stability.

Commonly used Iowa DOT aggregate subbase materials include modified subbase, granular subbase and special backfill. Table 1 lists the gradation for each of these aggregate subbases as compared to Class A crushed stone along with their relative permeability and stability. Class A crushed stone is not considered a drainable base due to the amount of fines (material passing the number 200 sieve). The Iowa DOT specifications for modified subbase and special backfill allow for crushed stone, gravels, and recycled pavement materials meeting material IM210 or uniformly blended combinations of these materials with a maximum of 50 percent RAP (Reclaimed Asphalt Pavement).

Table 1. Unstabilized Aggregate Subbase Gradations

	Percent Passing			
Sieve	**Class A Crushed Stone (Iowa DOT Gradation 11)**	**Special Backfill (Iowa DOT Gradation 29)**	**Modified Subbase (Iowa DOT Gradation 14)**	**Granular Subbase (Iowa DOT Gradation 12a)**
1½″		100	100	100
1.0″	100			
¾″	95–100		70–90	
½″	70–90			
⅜″				40–80
# 4	30–55			
# 8	15–40	10–40	10–40	5–25
# 200	6–16	0–10	3–10	0–6
Permeability	Low	Low to Moderate	Moderate	High
Stability	High	Moderate	Moderate	Low

The target permeability of approximately 150 feet per day provides the adequate drainage necessary for a pavement foundation layer. Although materials as coarse and open-graded as ASTM No. 57 stone have been used as draining layers, they are not recommended for concrete pavements due to their lack of adequate stability for construction operations and their susceptibility to long-term settlement under heavy truck traffic. It is better to design the gradation of the unstabilized aggregate subbase to include more fines for the sake of stability than to omit the fines for the sake of drainage. (ACPA 2007)

Subdrains

It is known that drainage is also important to the long term performance of concrete pavement. Drainage can be achieved with the use of an aggregate subbase with subdrain outlets. It is important to prepare the natural subgrade prior to the placement of the aggregate subbase to achieve the best performance.

When specifying the subdrain material it is very important to select a product that is durable. Consideration should be given to the use of a rigid plastic pipe. A rigid pipe should perform better than a flexible plastic pipe when subject to loading from construction equipment. Flexible, lightweight subdrain has been known to be crushed under normal construction traffic and thereby jeopardizing the entire function of the drainage system.

In addition, proper maintenance of the subdrain system is imperative. It is important that the owner of the pavement pay attention to the performance of the subdrain over the life of the pavement. Subdrains should be reviewed and cleaned periodically to ensure proper performance. Figure 6 shows a proper rural subdrain outlet. Figure 7 shows a rural subdrain outlet that has become clogged and is no longer functional. Figure 8 shows a properly installed urban subdrain outlet in a storm intake structure that is properly functioning.

Figure 6. Rural subdrain outlet (Photo courtesy of Chapter 7, Concrete Pavement Preservation Guide, CP Tech Center)

Figure 7. Clogged subdrain outlet (Photo courtesy of Chapter 7, Concrete Pavement Preservation Guide, CP Tech Center)

Figure 8. Urban subdrain outlet

Measuring Pavement Performance

Pavement performance is measured by the pavement’s physical condition. The Pavement Condition Index (PCI) is a numerical value that rates the pavement surface condition from 0 to 100 with 100 being an excellent pavement condition and 0 being a pavement that has failed and is no longer serviceable. The PCI is determined based on the severity and the amount of distress within the pavement. One other type of performance measure is the IRI (International Roughness Index) which is a measurement of the pavement smoothness measured in vertical inches per mile. The IRI value is typically suited for pavements with higher traffic volume and at higher speeds. Figure 9 shows the PCI rating scale.

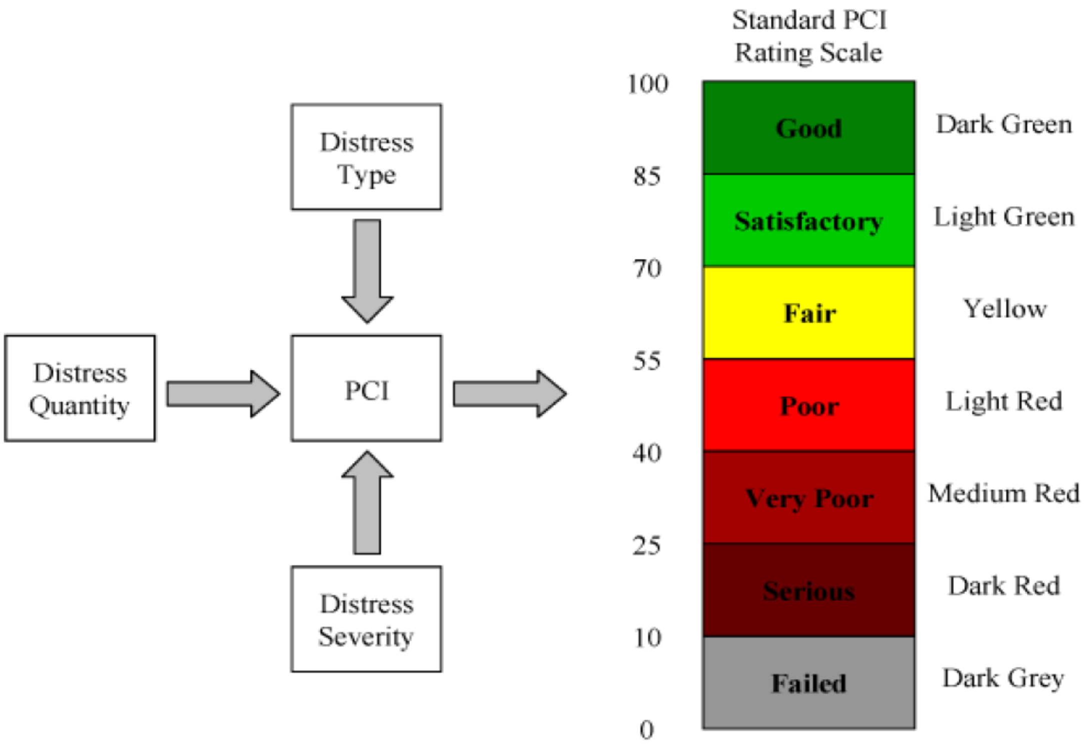


Figure 9. PCI rating scale
(Photo courtesy of US Army Corps of Engineers Paver 6.5 Brochure)

Pavement Thickness Design

- It is typical and current practice to use a pre-determined minimum pavement thickness for local roads. These minimum thicknesses are typically 6 or 7 inches.
- Some current thickness design methodologies were developed for facilities with more traffic and may not be applicable for local roads with lower traffic volumes.
- Because local roads do not carry significant levels of heavy traffic and because some thickness design methodologies revert to predetermined minimums, modifying the design parameters for improved foundations with geotextiles and aggregate subbases will not decrease the thickness design significantly.
- It is common for PCC pavements to be designed for 40 to 50 years of service based on a pavement thickness design. Some older pavements were designed for only 20 years. Although pavements are reaching the specified design life, the last 15 to 20 percent of its design life may be at a low level of service including poor rideability. On a PCI scale this may include the lower end of the fair category and possibly the poor category.

- On low traffic local roadways, including residential streets, the aggregate subbase is not needed to increase the structural capacity of the slab, but the benefit is a uniform construction platform and base to improve the serviceability over time.

WHAT WAS LEARNED FROM THE IHRB TR-640 STUDY

The purpose of the Iowa Highway Research Board TR-640 project was to better understand how to optimize concrete pavement foundation support layers on local roads. A field data report that summarizes in situ testing and analysis from 16 existing concrete pavement sites in Iowa and the summary section of this guide provides recommendations that were developed from this research.

The study was needed to measure actual pavement design parameter values to determine if they were being met during construction and several years after construction. In addition, a measure of performance was needed on local roads to compare pavements placed on a natural subgrade against those placed on an aggregate subbase or other improved foundation such as geosythetics or subgrade stabilization. Figure 10 shows a permeability test on the support layers.

Figure 10. Permeability test

The study would then show if improved foundation layers over time provided better performance with better serviceability, good rideability and less maintenance. The tested parameter values for the good pavements would be compared with those of pavements that did not perform as well.

Test Sites

To meet this objective, 16 existing Iowa PCC pavements at 15 different sites with ages ranging from less than 1 year to 42 years old were tested to measure in situ foundation parameters as a link to design assumptions. Figure 11 shows the map of Iowa with the test sites shown in red. The shaded counties are representative of the cities and counties that responded to the initial questionnaire. Field testing involved falling weight deflectometer, dynamic cone penetration, permeability, physical sampling, and pavement condition assessments.

Table 2 defines the various design parameters used in PCC pavement thickness design and also those parameters used in the IHRB TR-640 Field Data Report. A complete glossary of terms is found in the TR-640 Field Data Report.

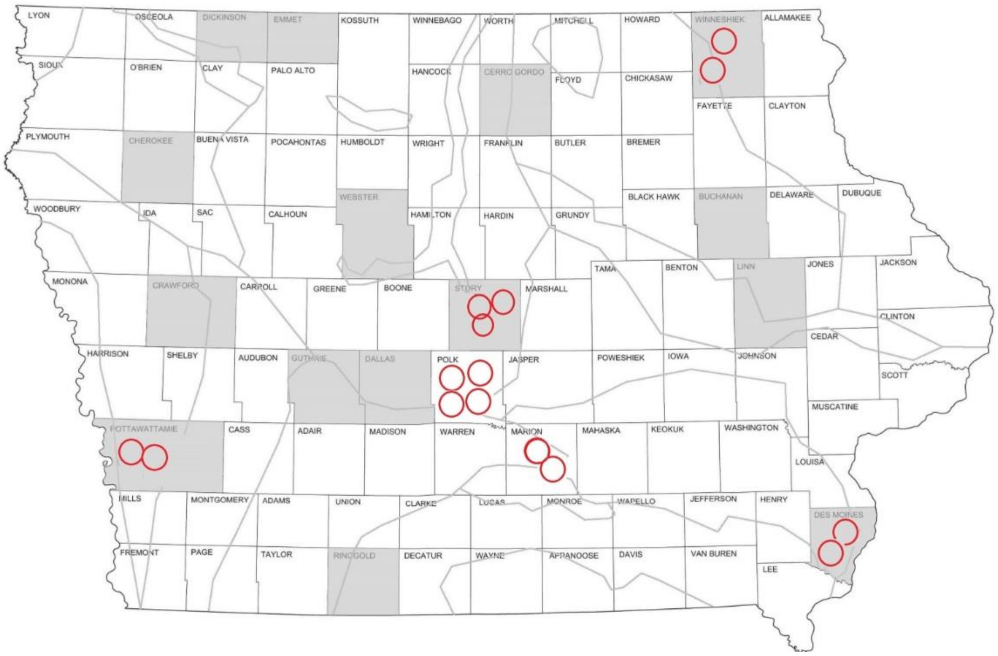


Figure 11. IHRB TR-640 test sites

Table 2. PCC Design Parameters

Abbreviation	Parameter
CBR	California bearing ratio
CBR_{SG}	California bearing ratio of subgrade (averaged over the top 12 in. of subgrade)
$CBR_{SG\text{-}Weak}$	California bearing ratio of subgrade (averaged over a minimum 3 in. “weak” layer within the top 16 in. of subgrade)
DCP	Dynamic cone penetrometer
E_{SB}	Elastic modulus of subbase determined from CBR_{SB}
FWD	Falling weight deflectometer
k	Modulus of subgrade reaction
k_{FWD}	Modulus of subgrade reaction determined from FWD test
k_{comp}	Composite modulus of subgrade reaction (determined based on M_r, E_{SB}, and H)
$k_{comp\text{-}DCP}$	Composite modulus of subgrade reaction (determined based on M_r estimated from CBR_{SG}, E_{SB} estimated from CBR_{SB}, and H)
$k_{comp\text{-}DCP\text{-}Weak}$	Composite modulus of subgrade reaction (determined based on M_r estimated from $CBR_{SG\text{-}Weak}$, E_{SB} estimated from CBR_{SB}, and H)
$k_{comp\text{-}FWD\text{-}Corr}$	Static modulus of subgrade reaction determined from FWD test that is corrected for slab size and converted to composite value based on M_r estimated from Static $k_{FWD\text{-}Corr}$, E_{SB} estimated from CBR_{SB}, and H
LS	Loss of support
M_r	Resilient modulus of subgrade
Static k_{FWD}	Static modulus of subgrade reaction determined from FWD test (which is equivalent to ½ Dynamic $k_{FWD)}$
Static $k_{FWD\text{-}Corr}$	Static modulus of subgrade reaction determined from FWD test that is corrected for slab size

Testing Data

The testing collected various information including age, current traffic, thickness, subgrade and aggregate subbase type, California Bearing Ratio (CBR), modulus of subgrade reaction (k) & composite modulus of subgrade reaction ($k_{c)}$, Coefficient of Drainage (C_d), and Loss of Support (LS). Table 3 lists this information from the test sites. The test methods and approach for data analysis are discussed in the field report.

Table 3. TR-640 Test Site Data

SITES WITH PAVEMENT ON SUBGRADE

Site Location	Year Constructed	Traffic (ADT)	Traffic (ADTT)	PCC Thickness	Subgrade	Subbase	Measured Subgrade CBR	Measured Subbase CBR	Calculated Static k_c (FWD)	Calculated C_d (min.)	LOS (Avg)
NW Greenwood & 3rd St. Ankeny	1989	2000	30	8.5	A-2-6	none	5.9	-	39	0.71	1.8
NW Greenwood & 5th St. Ankeny	1976	2000	30	8.3	A-7-6	none	1.5	-	33	0.71	1.0
E63 Story Co.	1990	1040	52	8	A-4 & A-7-6	none	9.9	-	53	0.77	1.6
175th St. Winneshiek Co.	1970	560	16.8	6	A-4	none	6.8	-	51	0.83	1.6
E23 Story Co.	1986	150	7.5	6.8	A-6	none	11	-	66	0.78	1.8
9th Ave. Council Bluffs	1989	7600	380	7.75	A-5 to A-7-5, fly ash	(1" sand)	8.8	-	29	0.7	1.9
Averages				7.6			7.32		45	0.75	1.6

SITES WITH PAVEMENT ON SUBBASE OR STABILIZED SUBGRADE

Site Location	Year Constructed	Traffic (ADT)	Traffic (ADTT)	PCC Thickness	Subgrade	Subbase	Measured Subgrade CBR	Measured Subbase CBR	Software Static k_c (FWD)	Calculated C_d (min.)	LOS (Avg)
Riverside Rd, Story Co.	1994	2910	582	11	-	6" limestone	20	78	73	0.88	1.3
SW Westlawn Ankeny	2008	1000	10	7.3	A-6, woven fabric	8.5" - 10" limestone	11, 1.9	64, 54	38,25	0.84	1.3
SW Logan Ankeny	2012	500	5	7.5	A-4 , fly ash	3.5" limestone	34	60	56	0.72	1.8
W. Main Knoxville	2007	500	15	7	fly ash	12" limestone	11	46	52	0.71	1.2
S. 5th Knoxville	2009	680	13.6	8	fly ash	12" limestone	26	39	104	0.71	1.1
Valley View Dr. Council Bluffs	1997	8900	712	9	A-6 to A-4	6" limestone	24	122	74	0.7	1.5
Cliff Rd. A Burlington	1993	1120	56	6.5	A-4	5" limestone	8.2	20	65	0.73	1.2
Cliff Rd B Burlington	1993	1120	56	7.5	A-7-6	4.5" limestone	8.7	20	38	0.92	1.8
Meadowbrook Burlington	1994	300	4.5	6.5	A-6	4" limestone	7.3	22	91	0.94	1.0
W38 Winneshiek Co.	1996	600	36	7	-	12" limestone	56	111	111	0.8	1.0
Averages				5			19	58	73.8	0.8	1.3

Test Results

The results of the testing found that the pavement foundation conditions were generally variable between projects and non-uniform over the length of a given pavement evaluation section. Engineering analysis generally showed that the in situ modulus of subgrade reaction and drainage coefficient (C_d) were variable and lower than typically assumed in design. Analysis of the Loss of Support (LS) values showed that the field values were higher than suggested in SUDAS design manual but were within range of the AASHTO (1993) design guidelines. These findings suggest that the field conditions do not always match the design values and that foundation layers are not being designed or tested to ensure optimum performance.

Pavement Performance

Although field results showed that in situ parameter values were lower on the average than the assumed design values, some pavement sections showed satisfactory performance based on PCI. PCI predictions as a function of pavement age, however, showed that reliably predicting performance is difficult (PCI error = ±12) for the range of pavements sections evaluated. More advanced statistical analysis were used to identify the link between PCI and foundation support values and drainage conditions. Findings from the advanced analysis support the concept that quality pavement foundation conditions and proper testing have the potential to improve long term performance while improving reliability in PCI predictions.

Aggregate Subbases Thickness Impact on k_c (Modulus of Subgrade Reaction)

The TR-640 research data found that, on average, the composite modulus of subgrade reaction (k_c) values increased with increasing aggregate subbase layer thickness. Figure 12 illustrates the k_c values of the test sites. The red data points represent the test sections without aggregate subbase and the blue data points represent the test sections with aggregate subbase. The test sections include aggregate subbase layer thickness varying from 0 to 12 inches. Understandably, the k_c values were higher for the test sites with aggregate subbase. Thicker aggregate subbase layers are successful over the design life because they allow for the migration of soil into only a portion of the aggregate subbase without losing all of the aggregate subbase.

CBR and Subgrade Weak Zones Impact Modulus of Subgrade Reaction

The TR-640 field study research showed that a majority of the soils had a “weak” layer in the subgrade at depths varying from 6 to18 inches below the pavement and/or subbase layer. An analysis was performed that calculated the CBR_{SG} and the $CBR_{SG\text{-}Weak}$ based on DCP testing. The CBR_{SG} was calculated as the average CBR in the top 12 inches of the subgrade. The $CBR_{SG\text{-}Weak}$ was calculated as the average CBR of the subgrade within a minimum 3 inch thick layer within the top 16 inches of subgrade. Figure 13 (from IHRB TR-640 field study) illustrates the “weak” zone within a typical CBR profile as well as the average CBR_{SG}.

Examination of each of the CBR profiles showed that the weak layer in the subgrade did have an impact on the k values as determined by the DCP tests. A low $CBR_{SG\text{-}Weak}$ corresponds to a lower k value and a higher $CBR_{SG\text{-}weak}$ value corresponds to a higher k value. This is illustrated in Figure14 when following the y axis along a specified test site.

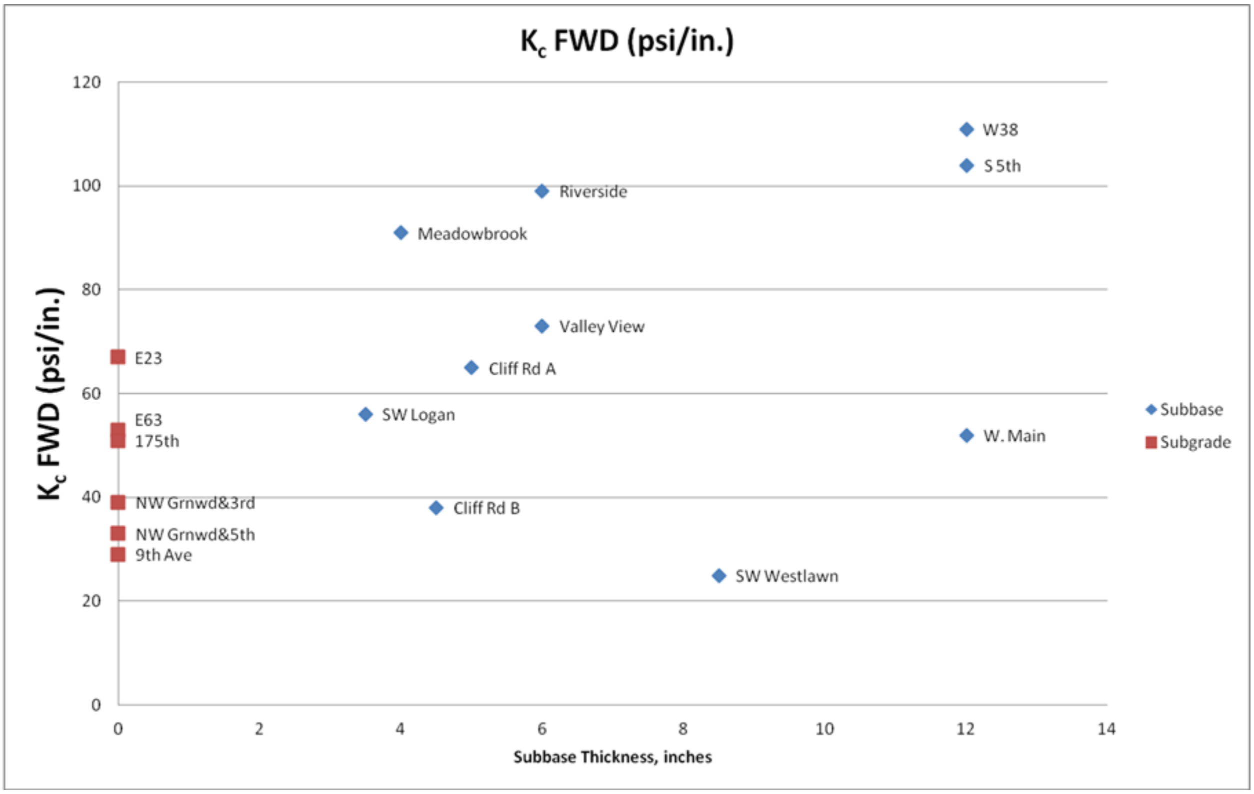


Figure 12. k_c vs. Subbase thickness (IHRB TR640 test sections)

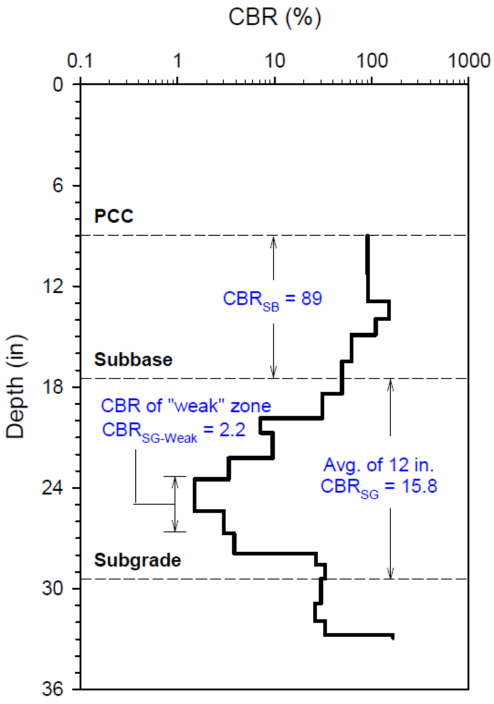


Figure 13. CBR profile

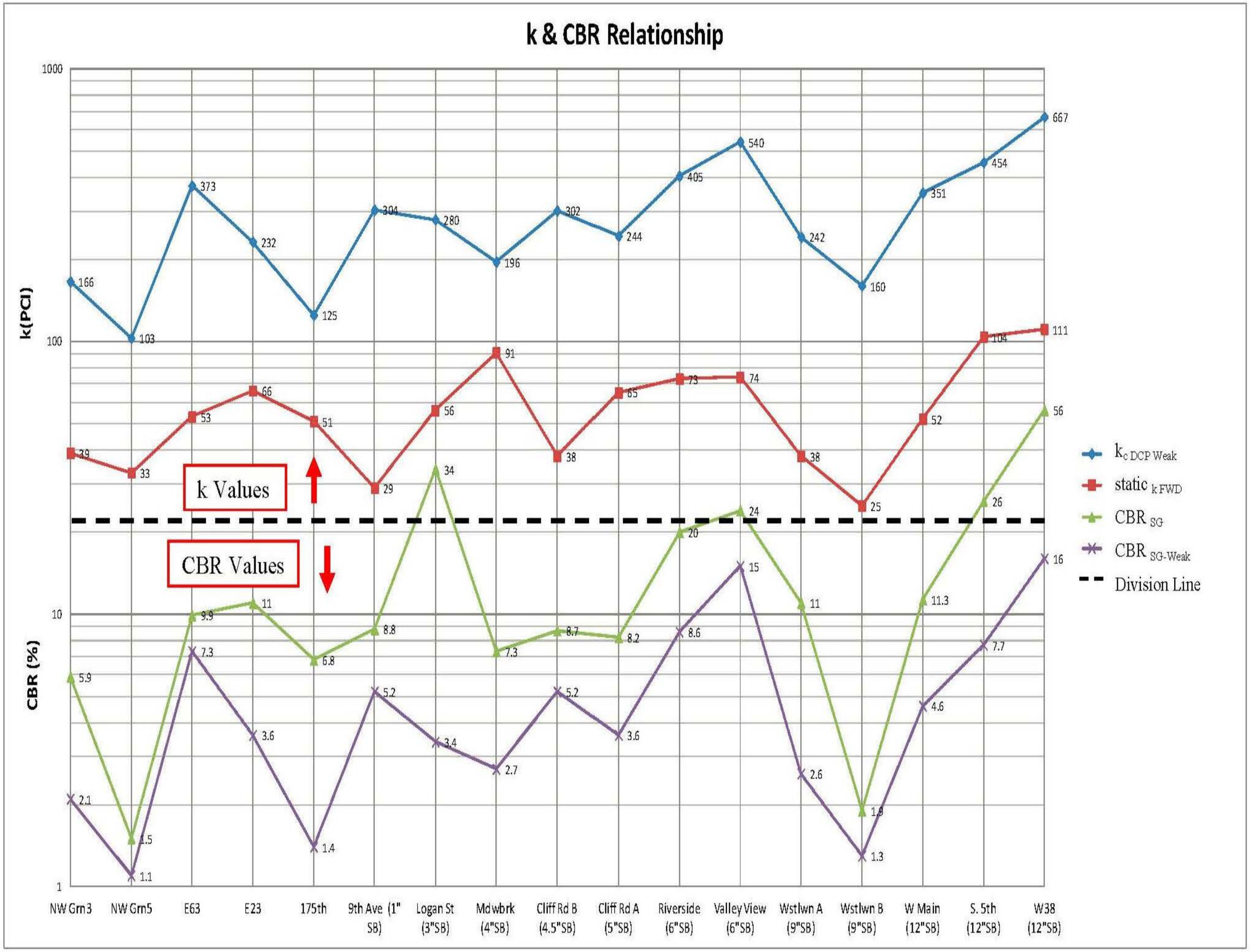


Figure 14. IHRB TR-640 CBR and k values

Pavement Performance - Pavement Condition Index

In reference to Figure 9, the Pavement Condition Index (PCI) was determined for the pavement at each test site. The PCI from the IHRB TR-640 research shows that pavements with an aggregate subbase are performing better than those placed on natural subgrade. The PCI vs. Age graph in Figure 15 shows the majority of the test sites with aggregate subbase have a better level of service based on the higher PCI values.

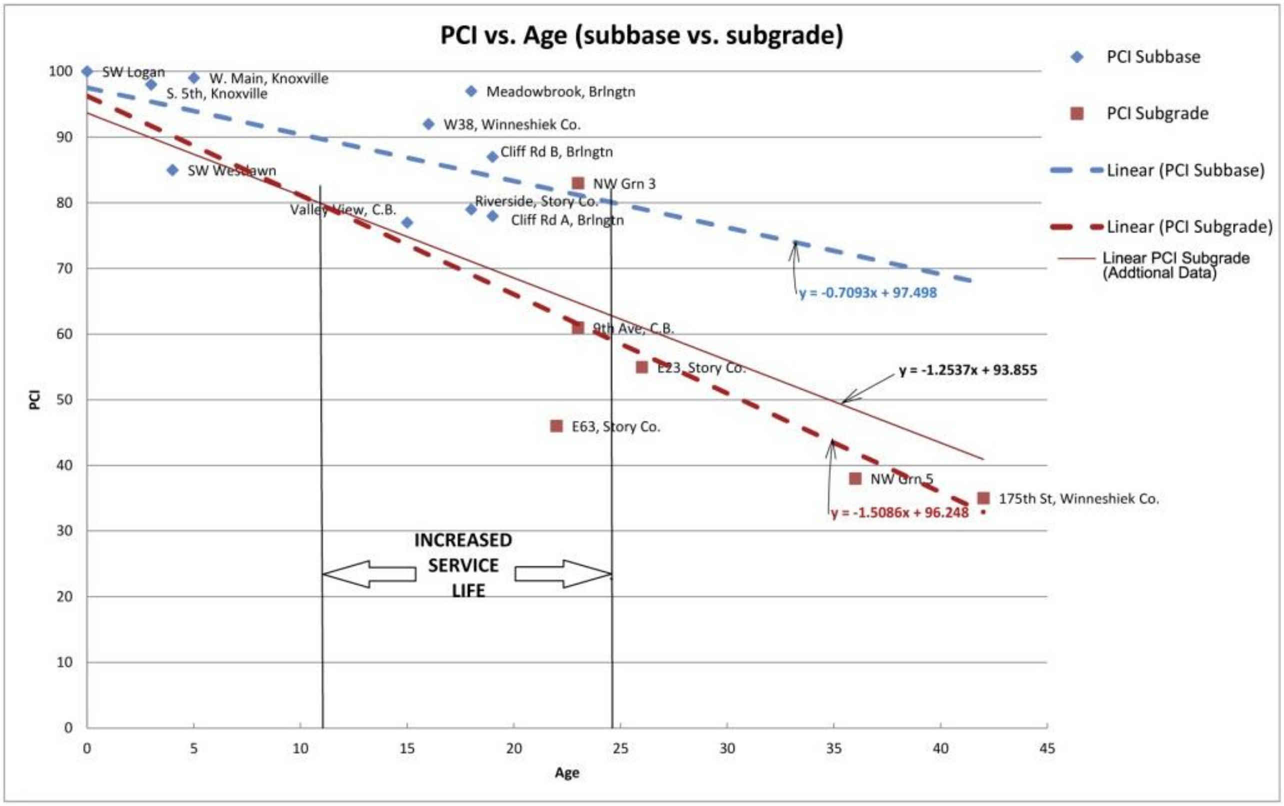


Figure 15. PCI vs. age, IHRB TR-640 test sites

Although the sample size is small (16 sites), it does reflect the increase in PCI when an aggregate subbase is used. The blue and red dashed lines represent the linear trend lines of the 16 test sites. The solid red line is a linear trend line of the subgrade PCI using data from other pavements previously studied. The linear trend lines and their equations were established using Microsoft Excel software.

PCI Prediction Model

The TR-640 Field Data Report developed a PCI prediction model based on the data from the 16 sites. This model is a formula (Figure 16) that can be used to predict the PCI of the pavement based on its age, subgrade CBR, coefficient of drainage, traffic and PCC thickness. Figure 17, PCI vs. age, illustrates the TR-640 PCI data as well as those in a 2008 study of Interstate

Highways. The figure shows that although the PCI of the TR-640 data is more variable, the general trend of values falls in line with the 2008 study.

Prediction Model

$$PCI = 5.553 - 1.615\ (Age) - 2.009\ (CBR_{SG-Weak}) - 0.2245\ (COV\ of\ CBR_{SG-Weak}) + 205.907\ (C_d) + 0.004\ (AADT) - 1.055\ (COV\ of\ k_{FWD-Corr}) - 2.395\ (PCC\ Thickness) + a$$

[a = +6.891 if subbase is present and -6.891 if subbase is not present]

Figure 16. PCI prediction model equation

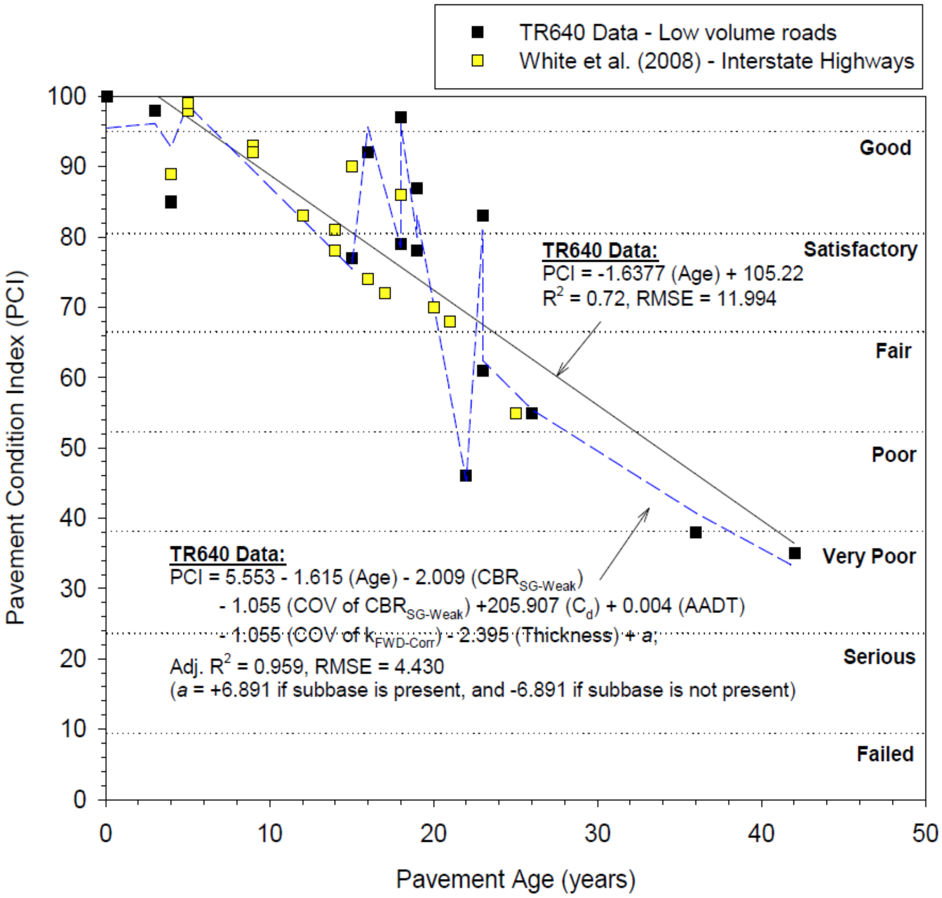


Figure 17. PCI vs age

From the model, two important conclusions can be drawn. First, the coefficient of drainage (C_d) is an important parameter in the performance of the pavement. Since the testing showed lower C_d values, it can be assumed that that over time, the coefficient of drainage may decrease based on migration of soil into the aggregate subbase layer. Therefore it is important to maintain separation between the soil and aggregate subbase. Secondly, if the pavement has aggregate subbase, it will have the potential for a higher PCI. This is based on the “a” variable in the formula.

The TR-640 field study also presented a multivariate analysis of the IHRB TR-640 testing. The analysis shows the effect that various design parameters have on the pavement performance. In the graphs in Figure 18 the vertical axis is the PCI and the horizontal axis represents the design parameters. The multi-variate statistical analysis revealed that when improving drainage, a positive effect is made on the PCI. The analysis also shows that increasing age, and increasing the coefficient of variation of the k-value both have a negative effect on the PCI. An increase in the drainage has the largest effect on the PCI thereby improving performance and the level of service for the road user.

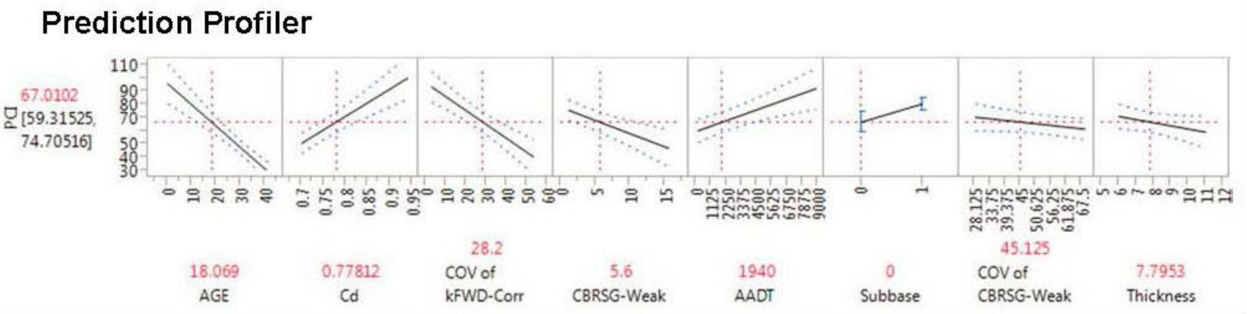


Figure 18. IHRB TR-640 multivariate analysis (IHRB TR-640 Field Data Report)

Summary of TR-640 Testing

Core hole permeameter (CHP) tests were conducted to determine in situ hydraulic conductivity (KCHP) values. The C_d values were determined by estimating the time of drainage using the KCHP values, pavement geometry (i.e., width and cross slope), and effective porosity of the drainage layer material.

In addition to these design input parameters, frost-heave susceptibility classification of the foundation materials was determined.

Previous research indicated that uniformity of pavement support conditions plays a critical role in long-term performance of PCC pavements (White et al. 2004). Uniformity of pavement support conditions was also evaluated in this study based on FWD test results. A uniformity classification matrix was developed to compare results from each site.

Overall, the results of this study demonstrate how in situ and lab testing can be used to assess the support conditions and design values for pavement foundation layers. The measurements show that in Iowa, a wide range of pavement conditions and foundation layer support values exist. The calculated design input (modulus of subgrade reaction, coefficient of drainage, and loss of support) values are different than typically assumed. This finding was true for the full range of materials tested. This finding supports the recommendation to incorporate field testing as part of the process to field verify the selected pavement design values.

Following is a summary of key analysis results obtained from all field sites:

- The joint LTE at 13 out of the 15 sites showed an average of ≥ 92% at the joints, irrespective of the foundation layer conditions. The remaining three projects showed average LTE < 50 percent.

- It is found that modulus of subgrade reaction values determined from FWD test (Static $k_{\text{FWD-Corr}}$) correlate well with subgrade layer CBR, when the weakest layer CBR within the top 16 in. of subgrade ($\text{CBR}_{\text{SG-Weak}}$) is used. These correlations are also in line with the data published previously by the U.S. Army Corps of Engineers (Barker and Alexander 2012), Thornton (1983), and Darter et al. (1995). There is significant variability in the *k* versus CBR relationships, however.

- Composite *k* values determined that account for subbase layer modulus and thickness based on FWD tests (Static $k_{\text{comp-FWD-Corr}}$) were on average about 0.9 to 6.2 times lower than the values determined from DCP test results using $\text{CBR}_{\text{SG-Weak}}$ ($k_{\text{comp-DCP-Weak}}$).

- The $k_{\text{comp-DCP-Weak}}$ values do not account for LS under the pavement in situ, while the $k_{\text{comp-FWD-Corr}}$ values do as the measurement is directly on the pavement. The LS values back-calculated by comparing the averages (per site) of these values ranged from about 0.7 to 1.7. These LS values are higher than the values currently suggested in the SUDAS design procedures (1 for natural subgrade and 0 for subbase). For sections with subbase, the LS values ranged from 0.7 to 1.3.

- On average, the $k_{\text{comp-FWD-Corr}}$ and $k_{\text{comp-DCP}}$ values increased with increasing subbase layer thickness. The Westlawn Dr. site (with 8.5 to 10 in. of subbase) was an exception because of poorly compacted backfill material in the subgrade at that site, which contributed to LS and lower $k_{\text{comp-FWD-Corr}}$ values. The W38/Locust Rd. section with 12 in. of subbase (3 in. of subbase and 9 in. of macadam subbase) showed the highest $k_{\text{comp-FWD-Corr}}$ and $k_{\text{comp-DCP}}$ values.

- In situ hydraulic conductivity measurements (K_{CHP}) values measured for the seven different foundation layer support categories did not show improvement in C_d values with increasing subbase layer thickness and were generally lower than suggested for design in SUDAS ($C_d = 1.0$ for natural subgrade and 1.1 when subbase is present).

- Multi-variate statistical analysis performed on various parameters measured during this study revealed that improving subgrade strength/stiffness (within about the top 16 in. of the subgrade layer), improving drainage, providing a subbase layer, and reducing variability, can contribute to increasing the PCI value. Subgrade layer properties can be improved by stabilization, drainage can be improved by the presence of a relatively thin drainable subbase layer (note that subbase layer thickness was not statistically significant), and variability can be reduced by adequate in situ testing. Some recommendations regarding these aspects are provided in Chapter 8 of the Field Data Report. The PCI prediction model developed from this analysis is based on limited data (16 sites), and must be validated with a larger pool of data.

The field investigation demonstrates that there can be several factors that affect pavement foundation performance including at least the following:

a. Poor support (due to low stiffness or CBR)
b. Poor drainage
c. Seasonal variations (freeze-thaw and frost-heave)
d. Shrink-swell due to moisture variations
e. Loss of support (due to erosion, non-uniform settlement, curling/warping)
f. Poorly compacted utility trench backfill
g. Differential settlement of foundation layers
h. Overall non-uniformity

Characterization of these problems can be determined from in situ testing. Options for field testing are summarized.

The PCI prediction model developed from multi-variate analysis in this study demonstrated a link between pavement foundation conditions and PCI. These results should be validated with data collected from more projects. The key aspect of this model is that by measuring properties of the pavement foundation, the engineer will be able to predict long term performance with higher reliability (by factor of 2.4 based on ratio of standard errors) than by considering age alone. This prediction can be used as motivation to then control the engineering properties of the pavement foundation for new or re-constructed PCC pavements to achieve some desired level of performance (i.e. PCI) with time.

GUIDANCE FOR IMPROVING PCC PAVEMENT PERFORMANCE

Geotechnical Investigation

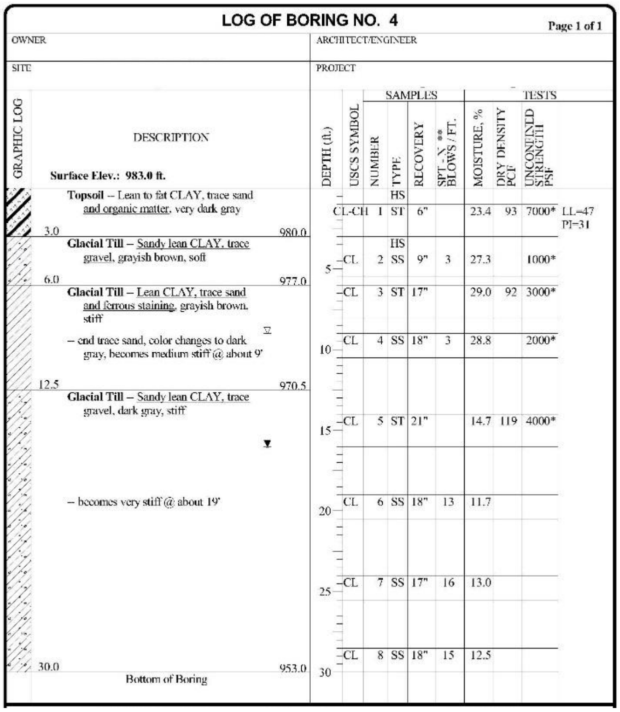
In order to determine what soils are present and understand their characteristics, it is essential to complete a geotechnical investigation. It is very important that the conditions of the subgrade are known prior to design in order to select various treatments if necessary, and specify various materials and preparation to provide uniformity and support for the pavement section.

The following information should be provided from a geotechnical investigation:

- Soil classification – (USCS or AASHTO)
- Soil profile from boring logs
- Stratification lines and depths of the soil profile
- Moisture or water content (measured as a percentage)
- Groundwater level
- Dry density or dry unit weight
- Unconfined strength
- Standard penetration resistance value (N)
- Liquid and plastic limits and plastic index of the soil

The geotechnical investigation should identify potential problematic conditions such as highly plastic and expansive soils, areas of non-native fill, and amount of organic materials. Highly plastic and potentially expansive soils include lean to fat clay (USCS classification CL/CH and AASHTO classification A-7).

Soil boring sampling is typically completed using thin-walled, seamless steel tubes. A split barrel procedure is also typically performed using a specified process. The number of blows to advance the spoon the last 12 inches of an 18 inch penetration is known as the standard penetration resistance value (N). The Standard Penetration Test (SPT) estimates the relative density and approximate shear strength of the soil. From the sampling, the soil profile is determined. Figure 19 shows a typical soil boring log.



LOG OF BORING NO. 4

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OWNER

ARCHITECT/ENGINEER

SITE

PROJECT

GRAPHIC LOG

DESCRIPTION

Surface Elev.: 983.0 ft.

Topsoil -- Lean to fat CLAY, trace sand and organic matter, very dark gray

3.0 980.0

Glacial Till – Sandy lean CLAY, trace gravel, grayish brown, soft

6.0 977.0

Glacial Till – Lean CLAY, trace sand and ferrous staining, grayish brown, stiff

– end trace sand, color changes to dark gray, becomes medium stiff @ about 9'

12.5 970.5

Glacial Till – Sandy lean CLAY, trace gravel, dark gray, stiff

– becomes very stiff @ about 19'

30.0 953.0

Bottom of Boring

DEPTH (ft.)	USCS SYMBOL	SAMPLES				TESTS			
		NUMBER	TYPE	RECOVERY	SPT - N ** BLOWS / FT.	MOISTURE, %	DRY DENSITY PCF	UNCONFINED STRENGTH PSF	
			HS						
	CL-CH	1	ST	6"		23.4	93	7000*	LL=47 PI=31
			HS						
5	CL	2	SS	9"	3	27.3		1000*	
	CL	3	ST	17"		29.0	92	3000*	
10	CL	4	SS	18"	3	28.8		2000*	
15	CL	5	ST	21"		14.7	119	4000*	
20	CL	6	SS	18"	13	11.7			
25	CL	7	SS	17"	16	13.0			
30	CL	8	SS	18"	15	12.5			

Figure 19. Sample soil boring log

The geotechnical investigation should provide recommendations for proper roadway subgrade preparation as well as for treatment of potentially problematic conditions. This may include:

Typical subgrade preparation

- Strip vegetation, organics and unsuitable materials
- Review of subgrade to identify expansive soils
- Fill material with low plasticity, cohesive soils (LL of 45 or less and PI of 23 or less)
- Place fill in horizontal lifts of 8-9 inches in depth and compacted with proper moisture

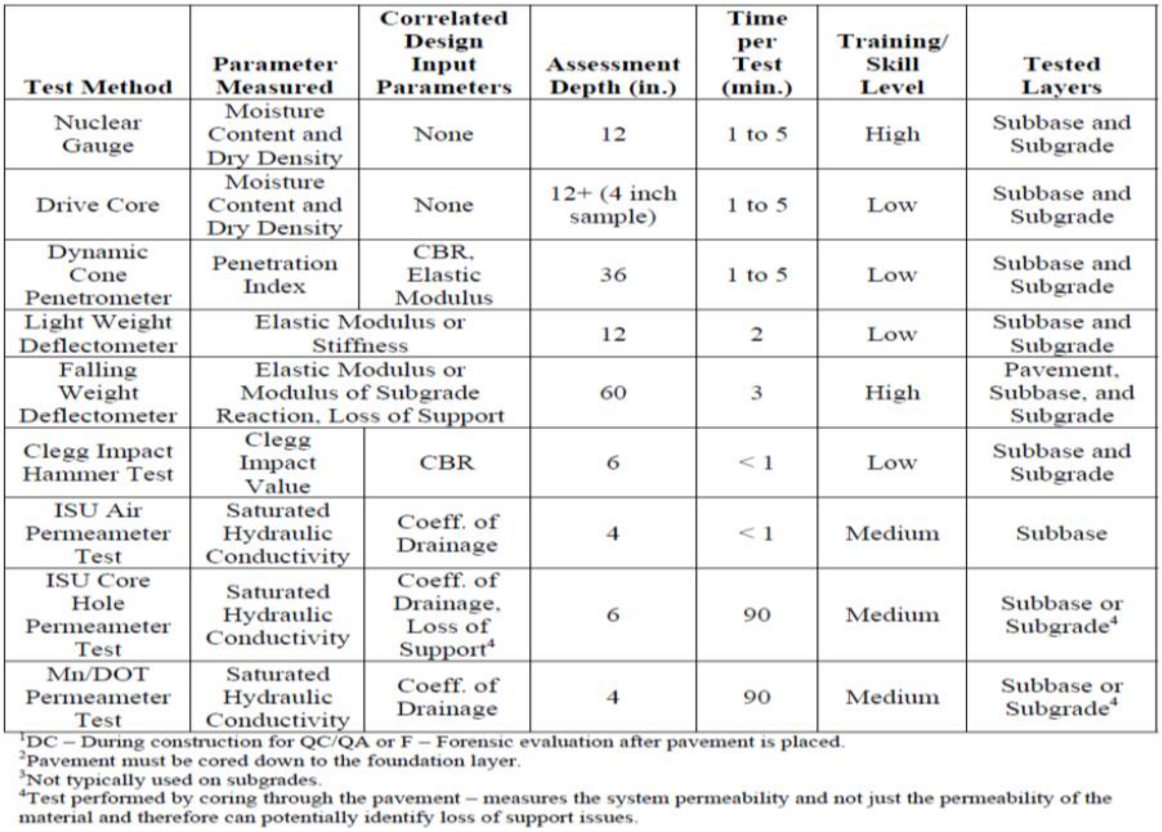
Treatment of problematic areas

- Over excavate and placement of select fill or low volume change material (LVC)
- Chemical stabilization (including incorporation of cement, class c fly ash or lime)

Pre-Design Testing Options to Characterize Foundation Layers

There are several types of in situ tests that can be performed to determine the characteristics and properties of the foundation layers. Table 4 lists common tests, design input parameters, and tested layers. This table was provided from the IHRB TR640 Field Data Report.

Table 4. Testing Options to Characterize Foundation Layers



Test Method	Parameter Measured	Correlated Design Input Parameters	Assessment Depth (in.)	Time per Test (min.)	Training/ Skill Level	Tested Layers
Nuclear Gauge	Moisture Content and Dry Density	None	12	1 to 5	High	Subbase and Subgrade
Drive Core	Moisture Content and Dry Density	None	12+ (4 inch sample)	1 to 5	Low	Subbase and Subgrade
Dynamic Cone Penetrometer	Penetration Index	CBR, Elastic Modulus	36	1 to 5	Low	Subbase and Subgrade
Light Weight Deflectometer	Elastic Modulus or Stiffness		12	2	Low	Subbase and Subgrade
Falling Weight Deflectometer	Elastic Modulus or Modulus of Subgrade Reaction, Loss of Support		60	3	High	Pavement, Subbase, and Subgrade
Clegg Impact Hammer Test	Clegg Impact Value	CBR	6	< 1	Low	Subbase and Subgrade
ISU Air Permeameter Test	Saturated Hydraulic Conductivity	Coeff. of Drainage	4	< 1	Medium	Subbase
ISU Core Hole Permeameter Test	Saturated Hydraulic Conductivity	Coeff. of Drainage, Loss of Support[4]	6	90	Medium	Subbase or Subgrade[4]
Mn/DOT Permeameter Test	Saturated Hydraulic Conductivity	Coeff. of Drainage	4	90	Medium	Subbase or Subgrade[4]

[1] DC – During construction for QC/QA or F – Forensic evaluation after pavement is placed.

[2] Pavement must be cored down to the foundation layer.

[3] Not typically used on subgrades.

[4] Test performed by coring through the pavement – measures the system permeability and not just the permeability of the material and therefore can potentially identify loss of support issues.

Several of these in situ tests can be conducted on existing roads using non-destructive testing such as a drilling cores or small diameter holes in the pavement. Figure 20 illustrates drilling a small diameter hole for DCP testing. Figure 21 illustrates the ISU Core Hole Permeameter (CHP) test.

Figure 20. Drilling prior to DCP test

Figure 21. CHP test

Foundation Treatment

Once the pavement designer is familiar with the subgrade conditions, consideration should be given to subgrade treatment if necessary. There are several variations of treatments that can be performed on the subgrade to improve uniformity and strength and control movement for the pavement foundation. It is critical to manage or control the movement of the subgrade by uniform compaction, minimize the moisture in the subgrade and provide a uniform support layer. Non uniform soils will often have differing moisture contents and will behave differently when subjected to loading. Different moisture contents can cause differential deflections causing stress concentrations in the pavement which may then lead to cracking. Other than removing unsuitable soils and replacing with select fill, the treatments and control of subgrade movement can be done by any one or a combination of the treatments.

Table 5 provides foundation treatment options for various subgrade conditions. This information gives the pavement designer options to consider for cost effective treatments once the proper soil investigation has been completed. Subgrade stabilization treatments are discussed in the first section of this guide. This table is based on Table 25 from IHRB TR-640.

Table 5. Typical Foundation Treatment Options

Subgrade Condition	Foundation Treatment
Clayey soil (A-6, A-7) swell potential High PI	• Dry out the subgrades by disking • Blending the soils • Compaction with M & D and lift thickness control • Portland Cement Stabilization of Subgrade (Cement Modified Soil) • Fly Ash Stabilization of Subgrade
Frost Heave (A-4) Thaw Softening	• Dry out the subgrades by disking • Blending the soils • Cement + Fiber Stabilization of Aggregate subbase • Cement or Asphalt Stabilization of Aggregate subbase • Macadam Stone with Choke Stone Cover • Unstabilized aggregate subbase
Wet Soft subgrade Silty Soil (A-4,A-5) low LL	• Portland Cement Stabilization of Subgrade (Cement Modified Soils)

Treatment Options

There are four typical subgrade treatment options:

- Dry out the subgrade
- Blend the soils
- Stabilize with macadam stone
- Remove unsuitable soils and replace with select fill

Dry Out the Subgrade

Drying of the subgrade can often be completed by disking the material on site. This process however can delay construction and is not typically successful in colder weather. Removal of excessive moisture in wet soils can be completed by providing drainage through trenches, toe drains or a combination of a drainable support layer and subdrain. It can also be completed by compacting the subgrade using heavy compaction equipment to compress the soils and drive out the moisture; or adjusting the moisture content through chemical modification.

Blend the Soils

Proper compaction and consolidation can prevent settlement and differential deflections with non uniform soils. Subgrade preparation should include blending of the non-uniform soils in 8 inch lifts to near 2 ft. deep and compaction with moisture and density control. Compaction should be within 95 percent of the standard proctor density. Although this method is less expensive as compared to other methods, there have been mixed results with subgrade performance.

Stabilize with Macadam Stone

In some instances, aggregate stabilization can help to provide uniformity and support. In this method, unsuitable material is removed and replaced with Macadam stone (Iowa DOT gradation 13). This is a 3 inch nominal maximum size screened over a ¾ or 1 inch screen. The Macadam stone is then topped with a choke stone of nominal ¾ inch size. (Iowa DOT gradation 11).

Remove Unsuitable Soils and Replace with Select Fill

Removal of unsuitable, unstable or excessively wet soils and replacement with select fill can be completed if acceptable materials are available. Although this method is very successful, the availability of quality fill can lead to higher costs. This method is typically more successful in the rural areas due to the availability of select fill and the ability for trucks hauling materials to and from the site.

Construction Testing

It is very important to undertake field compaction testing to ensure that the design values assumed for the foundation support are being realized in the field. Traditionally this verification has involved determination of Proctor densities either by nuclear gauge by other means.

Benefits of Aggregate Subbase and a Drainage System

The benefits of an aggregate subbase and drainage system include the following:

- Increases performance and service life
- Provides a construction platform
- Maintains uniform support
- Provides drainage from water infiltration
- Helps reduce shrink and swell of high volume-change soils
- Controls excessive or differential frost heave
- Minimizes mud-pumping of fine-grained soils
- Prevents consolidation of subgrade
- Provides capillary cut off for highwater table

Aggregate Subbase Thickness

Based on calculations from the Pavement ME Design by AASHTOWare software programs, there is a benefit in performance when using an aggregate subbase layer. Figures 22 and 23 show MEPDG (Mechanistic Empirical Pavement Design Guide) failure modes for cracking and IRI for a local road with 500 and 1000 AADT and using 10 percent trucks. The pavement analysis shows similar pavements with varying thickness of aggregate subbase. The results of the sample pavement analysis indicate a significant reduction in failure modes for cracking and IRI when aggregate subbase is used on low traffic roadways. According to the MEPDG analysis for these low volume roads, PCC pavement systems with aggregate subbase thickness above 5 inches, do not show a significant benefit over thicker sections.

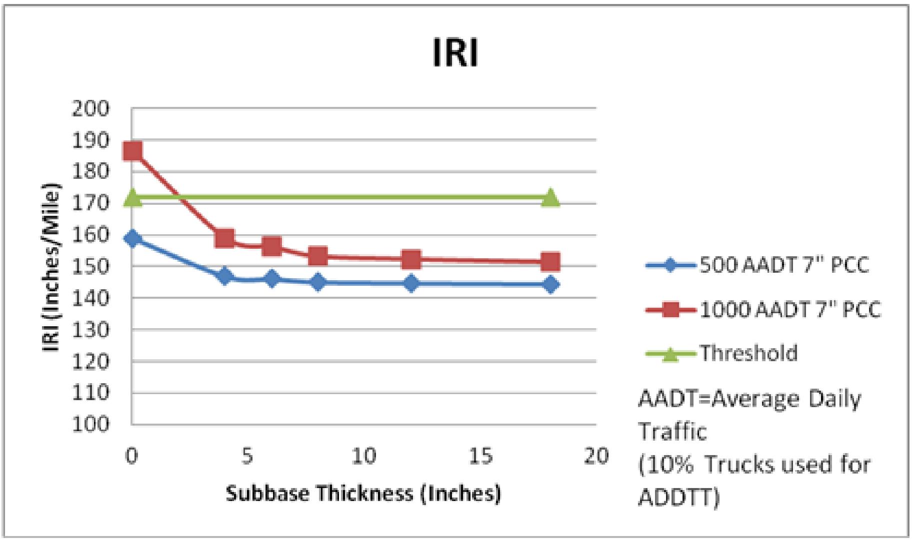


Figure 22. IRI failure mode from Pavement ME Design

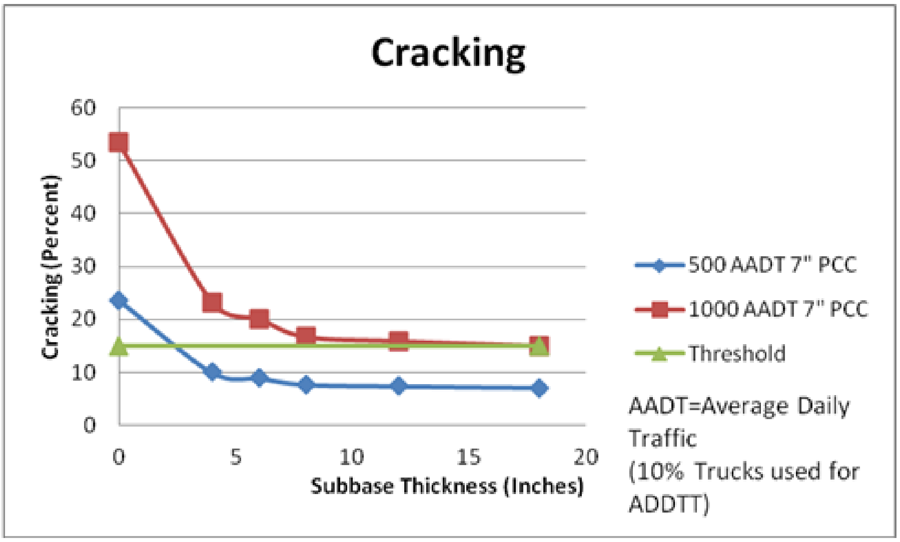


Figure 23. Cracking failure mode from Pavement ME Design

Current practice includes placing a thicker layer of aggregate subbase (8 to 9 inches for example); this additional thickness allows for the migration of soil into the aggregate subbase. Over the design life of the pavement, the effective thickness is likely reduced after soil migration. Another option would be to place a layer less than 6 inches and provide separation between the aggregate subbase and subgrade in the form of a geotextile. This option may be more cost effective depending on the selection and availability of materials.

Therefore, it is reasonable and may be cost effective to consider a support system consisting of a relatively thin aggregate subbase with proper drainage to reduce the effects of soil variability as long as there is a mechanism to provide separation from the variations in the natural soil.

Separation Barrier Using Geotextiles

The TR-640 testing shows that over time, the aggregate subbase loses some of its drainage and support capabilities due to the migration of soils into the aggregate subbase. If the pavement designer chooses to maintain a uniform support platform and drainage system for an extended service life, an affordable and effective separation barrier between the granular material and the natural subgrade is an option. This barrier reduces the migration of soil into the aggregate subbase allowing the pavement system to perform at a higher level of service for not only the design life but also the rehabilitation life of the pavement. The barrier can be accomplished by either stabilizing the natural soil with cement or fly ash or the placement of a geotextile between the aggregate subbase and subgrade. Figure 24 shows a poor pavement with moist subgrade conditions.

Figure 24. Moist subgrade conditions

Use of an aggregate subbase and stabilized subgrade or separation barrier such as a geotextile will help to achieve an increased level of uniformity for the PCC pavement support system. In addition, the aggregate subbase helps the drainage of the pavement support system. The reliability of the pavement increases when the effect of natural variables within the support system are reduced or eliminated.

An option to using a thicker aggregate subbase (8 inches or more) is a thinner aggregate subbase (4 to 5 inches) with a separation barrier. A thinner granular layer with a separation barrier, such as a geotextile, is typically a less costly option than a thicker granular layer.

According to research by product manufacturers, geotextiles provide the best performance when it comes to separation of soil particles from aggregate subbase. Geotextiles provide three important functions:

1. Separation/stabilization
2. Drainage
3. Reinforcement

There are two types of geotextiles; non-woven and woven. Both types are permeable and allow water to pass through. When selecting the appropriate geotextile, the Apparent Opening Size (AOS) is critical. The selection of the geotextile should be based on the size of the fine-grained soil particles. The AOS of the material should be smaller than the surrounding soil particles, allowing he water to pass through, but not the soil particles.

Nonwoven geotextiles are geotextiles with greater than 50 percent elongation. Having tighter openings allows for decreased filtration over typical woven geotextiles, therefore allowing for greater separation between dissimilar materials. While non-woven geotextiles perform better for filtration, separation, and drainage, design between subgrade and base layers should be carefully examined before deciding on type of geotextile for separation/ stabilization.

Woven geotextiles are higher strength geotextiles with lower than 50 percent elongation, which are good for very poor soil properties in areas with high water tables. Soil properties such as allowable bearing pressure or CBR as well as the AOS play a very important role in the selection of the right geotextile for the design. Typical design considerations can be determined using the AASHTO property requirement tables for geotextiles.

Separation of dissimilar materials indicates greater stabilization properties by preventing contamination of the subgrade and base materials. Figure 25 shows the migration of soils into the aggregate subbase.

Generally, aggregate thickness is designed to account for a certain amount of loss due to dissimilar material migration from subgrade into the base aggregate layer. Geotextiles help decrease the aggregate thickness by separation, not allowing the materials to mix, therefore stabilizing the pavement structure and potentially allowing a thinner aggregate subbase layer.

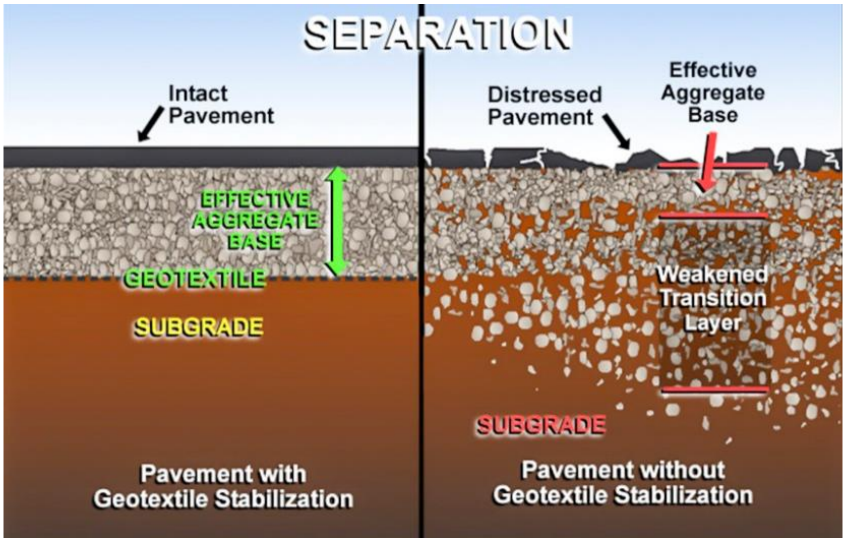


Figure 25. Migration of fines into aggregate subbase (Image courtesy of Propex Infrastructure Solutions)

Non-woven Geotextiles

Non-woven geotextiles resemble a felt material and are made of polypropylene. They are commonly referred to as “filter fabric”. Non-woven geotextiles typically have an AOS range from sieve size number 50 to 100. Figure 26 illustrates a non-woven geotextile.

Figure 26. Non-Woven geotextile (Photo courtesy of Propex Infrastructure Solutions)

Soils with CBR greater than 3 and lower water tables are good candidates for nonwoven geotextiles. Typical nonwoven geotextiles for roadway applications range from 6 to 10 ounces per square yard. Strengths range from 160 to 250 pounds per square yard.

The medium weight material is used for separation and drainage between aggregate subbases and subgrades. Weights range from 6 to 10 ounces per square yard with tensile grab strengths ranging from 160 to 200 pounds. An 8 ounce per square yard is typically recommended for Iowa soils.

In 2014, install pricing for medium weight nonwoven geotextiles ounces per square yard is $1.00 to $2.50 per square yard.

Woven Geotextiles

As suggested earlier, geotextile selection should be determined based on soil properties and geotextile specifications. Manufacturers have design software that can determine proper geotextile selection for reduced aggregate per the roadway design. Refer to the state qualified products list to ensure materials have been tested and meet AASHTO and state specifications for each geotextile. Figure 27 illustrates a woven geotextile. The use of geotextiles can increase performance of the pavement system by providing strength and separation between the aggregate subbase and subgrade. It is still important to properly prepare the subgrade by scarification, compaction and moisture treatment to gain the full benefit of the geotextile. Figure 28 illustrates a pavement section with aggregate subbase separating the subgrade with a geotextile material.

Figure 27. Woven geotextile (Photo courtesy of Propex Infrastructure Solutions)

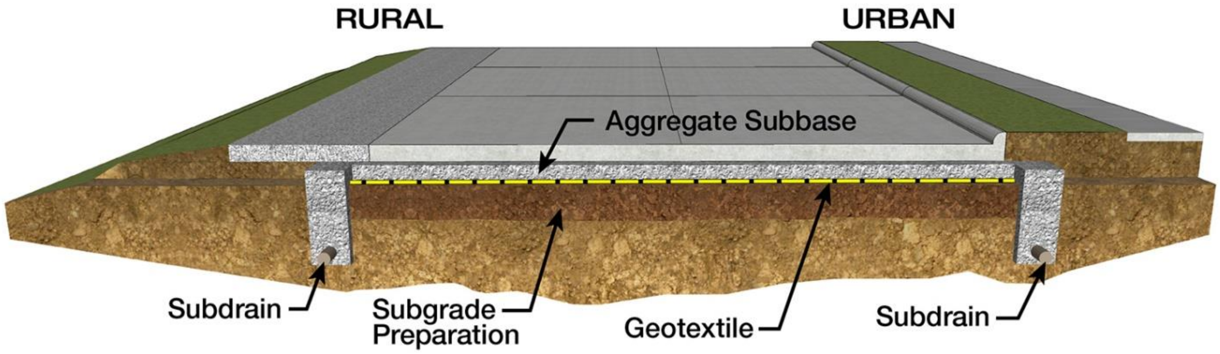


Figure 28. Typical section with aggregate subbase and geotextile separation

Cost Comparison

In order to properly compare foundation treatments their costs need to be known. Cement modified soils (CMS) are typically installed at a minimum of 6 inches thick using 3 to 5 percent cement content. The cost for CMS is typically $0.70 to $0.75 per square yard per inch of thickness in 2014 dollars. For 6 inches this would represent an average of approximately $4.35 per square yard.

The geotextile option is less expensive with a range from approximately $1.75 to $2.50 per square yard. Geotextiles will provide the separation and drainage but also provide potential tensile reinforcement at the top of the subgrade. However, the nonwoven geotextile does need to have an outlet into the aggregate subbase subgrade system.

The cost for aggregate subbase is approximately $1.15 per square yard per inch of thickness based on recent bid history. If the aggregate subbase is reduced in thickness by 2 inches, this would represent the equivalent cost for the geotextile. For example, a pavement support system with 8 inches of aggregate subbase has approximately the same cost as a system with 6 inches of aggregate subbase and a geotextile.

Table 6 lists the average installation costs (labor plus materials) of various separation materials including the average costs of woven and non-woven geotextiles and Iowa DOT Modified Subbase. The values below are statewide averages and actual costs may vary depending on the project location and availability.

Table 6. Separation Material Costs (per square yard)

Separation Type	Geotextile ($ per SY)	Modified Subbase ($ per SY per inch)
Cost	$1.75–$2.50	$1.10-$1.20

Even with a subgrade that has been stabilized, it is important to include an aggregate subbase layer to provide drainage away from the pavement support layers and to provide separation between the stabilized subgrade and the pavement.

Quality Assurance

Improvements to the pavement support system including subgrade treatments, the addition of an aggregate subbase layer, the addition of geotextile and a subdrain system will undoubtedly improve the pavement performance and provide an increased level of service to the roadway users. However without proper construction practices and materials, the benefit may be short-lived. Proper inspection is needed to provide oversight, assure conformity with the plans and specifications and also provide timely remedial action to problems that may occur in the field. The cost of inspection is minimal when spread out over the life of the pavement.

Increased Performance

Using the PCI prediction model from the IHRB TR-640 study (see Figure 16), an analysis was conducted to determine the increase in performance on a sample pavement. Using average foundation layer values from the 16 test sites, it is shown that the service life of concrete pavements can be increased when a properly drained aggregate subbase is used as a support layer. Figures 29 and 30 illustrate the increase in performance using the PCI prediction model. These figures are based on a sample 7 inch PCC pavement and include the average C_d, average CBR and average k values for the aggregate subbases and subgrades of the 16 test sites measured in the field. Using the PCI prediction model equation, the PCI is calculated at 5 year intervals.

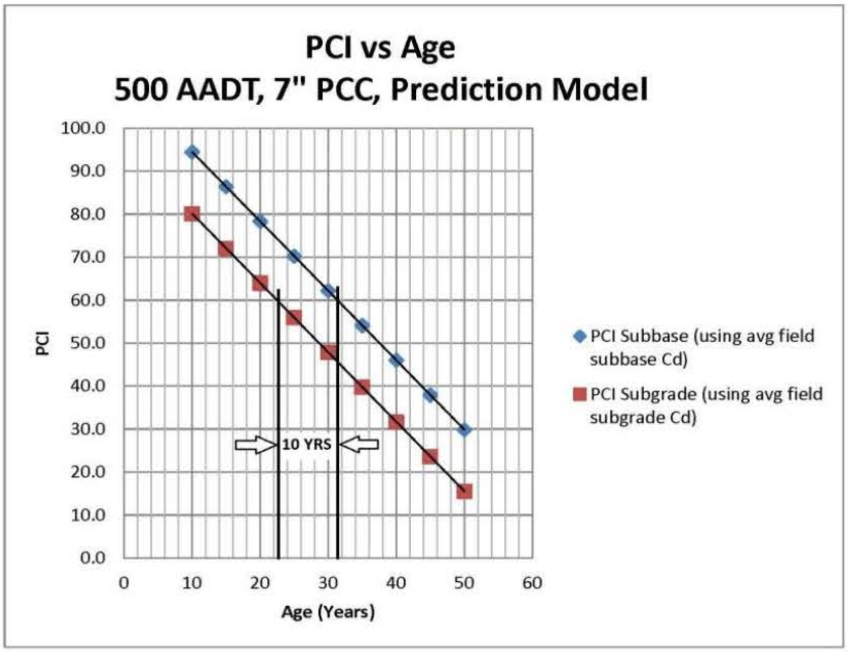


Figure 29. PCI vs. age 500 AADT (PCI Prediction Model)

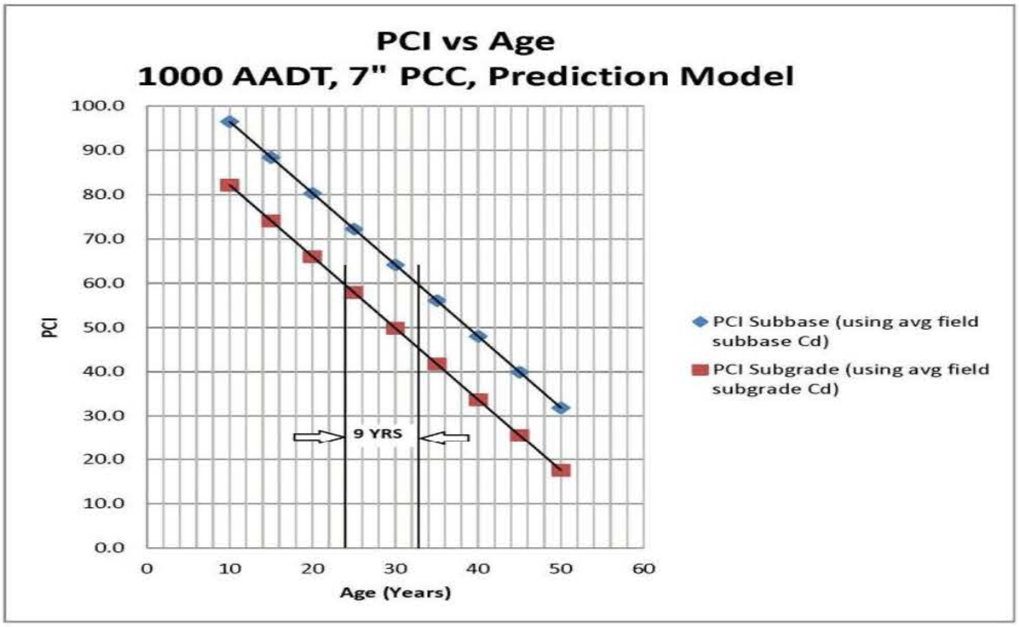
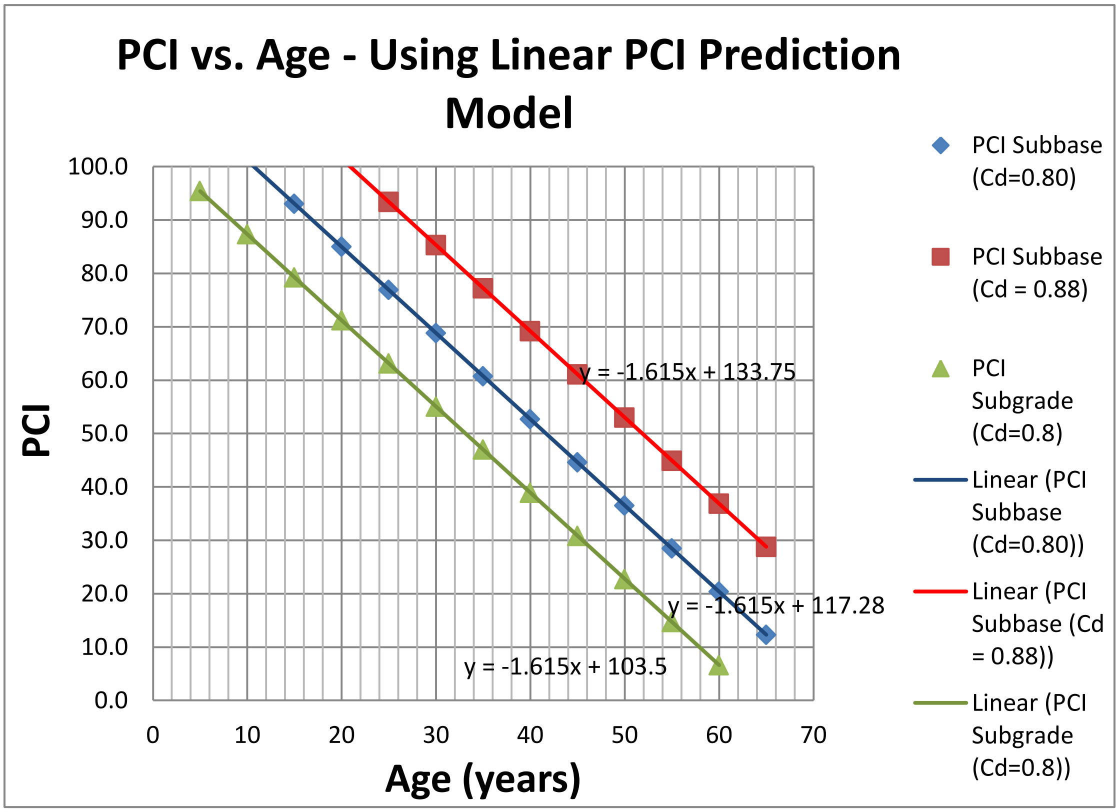


Figure 30. PCI vs. age 1000 AADT (PCI Prediction Model)

Figure 31 was developed using the PCI prediction model and compared drainage coefficient values for a pavement on natural subgrade and a pavement on aggregate subbase. Other parameters used were based on the average values of the test sites in the IHRB TR-640 study.

The blue line is representative of a 7 inch PCC on aggregate subbase with a drainage coefficient of 0.8. The Green line represents a 7 inch PCC pavement on natural subgrade with the same drainage coefficient (0.8). The red line represents a 7 inch PCC pavement on aggregate subbase with an improvement in the drainage coefficient to 0.88. Using the model, the improved drainage coefficient predicts a PCI of approximately 68 at year 40.



PCI Prediction Model (TR640 site averages)

- CBR $_{\text{SGWeak}}$ = 3.5* (average CBR$_{\text{SG-weak}}$)
- CBR Subgrade = 16
- CBR Subbase = 58
- COV $_{\text{SGWeak}}$ = 42.8
- COV $_{\text{kFWD}}$ = 29
- AADT = 1000
- PCC = 7"

Figure 31. Increased C_d results in increased performance (from linear PCI prediction model)

Increased Reliability

An analysis using WinPAS 12 was completed to determine the increase in reliability between a PCC pavement placed on natural subgrade and a PCC pavement placed on a 5 inch aggregate subbase. A sample pavement with thicknesses of 6 inch and 7 inch was used along with varying levels of traffic from 1000 AADT to 5000 AADT. Standard design parameters were used for concrete strength, load transfer, and serviceability. A coefficient of drainage C_d value of 0.8 was used for the pavement on subgrade based on the average C_d from the TR-640 site values. A coefficient of drainage value of 0.9 was used for the pavement on 5 inch aggregate subbase based on using a geotextile interlayer that maintains an aggregate subbase for the pavement life. This value corresponds to the improved drainage coefficient as shown in the increased performance above. The modulus of subgrade reaction values of 100 psi/in. and 194 psi/in. were used for the subgrade and aggregate subbase respectively. The analysis shows an increase of 15 to 31 percent in reliability based on the varying levels of traffic for a 40 year pavement thickness design and an increase of 8 to 23 percent in reliability for a 30 year pavement thickness design. Table 7 lists the design parameter values of the WinPAS analysis.

Table 7. Increased Reliability Using WinPAS

40 Year Design	1000 AADT		2000 AADT		5000 AADT	
	Natural Subgrade	5" subbase	Natural Subgrade	5" subbase	Natural Subgrade	5" subbase
PCC thickness	6"	6"	6"	6"	7"	7"
Rigid ESALS (5% trucks, 1% growth)	339,259	339,259	678,518	678,518	1,696,296	1,696,296
Overall Standard Deviation	0.35	0.35	0.35	0.35	0.35	0.35
Flexural Strength	650 psi	650 psi	650 psi	650 psi	650 psi	650 psi
Modulus of Elasticity	4,400,000 psi	4,400,000 psi	4,400,000 psi	4,400,000 psi	4,400,000 psi	4,400,000 psi
Load Transfer Coefficient	3.0	3.0	3.0	3.0	3.0	3.0
Modulus of Subgrade Reaction (k)	100 psi/in.	194 psi/in.	100 psi/in.	194 psi/in.	100 psi/in.	194 psi/in.
Drainage Coeffiecient	0.8	0.9	0.8	0.9	0.8	0.9
Initial Serviceability	4.5	4.5	4.5	4.5	4.5	4.5
Terminal Serviceability	2.0	2.0	2.0	2.0	2.0	2.0
Reliability	**82%**	**97%**	**53%**	**84%**	**52%**	**82%**
	15% increase in Reliability		**31% increase in Reliability**		**30% increase in Reliability**	

30 Year Design	1000 AADT		2000 AADT		5000 AADT	
	Natural Subgrade	5" subbase	Natural Subgrade	5" subbase	Natural Subgrade	5" subbase
PCC thickness	6"	6"	6"	6"	7"	7"
Rigid ESALS (5% trucks, 1% growth)	241,398	241,398	482,797	482,797	1,206,992	1,206,992
Overall Standard Deviation	0.35	0.35	0.35	0.35	0.35	0.35
Flexural Strength	650 psi	650 psi	650 psi	650 psi	650 psi	650 psi
Modulus of Elasticity	4,400,000 psi	4,400,000 psi	4,400,000 psi	4,400,000 psi	4,400,000 psi	4,400,000 psi
Load Transfer Coefficient	3.0	3.0	3.0	3.0	3.0	3.0
Modulus of Subgrade Reaction (k)	100 psi/in.	194 psi/in.	100 psi/in.	194 psi/in.	100 psi/in.	194 psi/in.
Drainage Coeffiecient	0.8	0.9	0.8	0.9	0.8	0.9
Initial Serviceability	4.5	4.5	4.5	4.5	4.5	4.5
Terminal Serviceability	2.0	2.0	2.0	2.0	2.0	2.0
Reliability	**91%**	**99%**	**69%**	**92%**	**68%**	**91%**
	8% increase in Reliability		**23% increase in Reliability**		**23% increase in Reliability**	

SUMMARY

The following conclusions are made with respect to pavement design and improved foundation layers:

- Engineering analysis generally showed that the in situ modulus of subgrade reaction and drainage coefficient (C_d) were variable and found to be lower than typical design parameter values used in thickness design calculations. Analysis of the LS values showed that the field values were higher than suggested by the SUDAS thickness

- The pavement foundation conditions were generally variable between projects and non-uniform over the length of a given pavement evaluation section. The field study also presented a multivariate analysis of the IHRB TR-640 testing. The analysis shows the effect that various design parameters have on the pavement performance. These are age, drainage coefficient, coefficient of variation for k and CBR, weak subgrade layer, traffic, pavement thickness and subbase.

- The TR-640 field data report developed a PCI prediction model based on the data from the 16 field sites that were researched. This model is a formula that can be used to predict the PCI of pavement based on the above multivariate parameters. The lower the variability and higher coefficient of drainage through the use of an aggregate subbase, the higher the pavement condition for a given period of time. This is an important point because it reinforces the concept that if the subgrade variables are reduced and the drainage is increased performance of the pavement also increases. An increase in the drainage has the largest effect on the PCI thereby improving performance and the level of service for the road user.

- Five of the sites had a 3 to 6 inch thick “weak” (CBR below 3) layer located in the soil subgrade from 18 to 28 inches below the pavement and/or subbase layer. The other sites had a lower CBR layer than adjacent soil layers in the same region. Examination of the CBR profiles showed that the weaker layer lowered the overall k values of all the sites as determined by the DCP test. However, the average CBR of the test site for the weak layers was 3.5 of the subgrade and the average CBR of all test sites was 16 which was higher than expected.

- Pavement design parameters within the thickness design software programs often do not adequately reflect actual pavement foundation conditions except immediately after construction. Field data indicates a migration of natural soils into the aggregate subbases. This causes some LS which in turn lowers the overall modulus of subgrade reaction (k-value) and can lower the drainage coefficient (C_d) of the aggregate subbase. The overall average CBR of those sites containing an aggregate subbase was 58 as compared to a CBR of 100 for a new aggregate subbase. The lower parameter values are consistent with common design methodologies and LS should not be double counted. Design methodologies have assumed some level of degradation of support over the design life until reaching their terminal serviceability.

- In order to maintain a high coefficient of drainage it is important to maintain separation between the soil and aggregate subbase which can be achieved with a geotextile interlayer between the natural subgrade and granular material.

- If common support failures are addressed to provide long term performance, a pavement at 40 years of age for example, could have a PCI of 70 (good) rather than a PCI of 40 (poor). At this point in the pavement life, the pavement with the improved support system will provide a higher, more reliable and desired level of service to the road user. The pavement with the improved support system has the ability to maintain a higher PCI and a slower decline of the PCI over time.

- Remaining life of the pavement increases considerably when the effect of natural variables within the support system are reduced or eliminated. The PCI from the IHRB TR-640 research shows that pavements with an aggregate subbase are performing better than those placed on natural subgrade. The PCI vs. Age trend lines show the majority of the test sites that had an aggregate subbase layer have a higher PCI value and thus a better serviceability throughout the life of the pavement. On an average, this should lead to an increase in pavement life.

- For low volume roads, the design reliability has a measurable increase with an aggregate subbase of only 5 inches and a geotextile interlayer as compared to a natural subgrade. It shows an increase of 15 to 31percent based on various traffic for the 40 year pavement thickness design and an increase of 8 to 23 percent for a 30 year pavement design life. A lot of that has to do with increasing the coefficient of drainage from a 0.8 from natural subgrades to a 0.9 for aggregate subbase. It should be kept in mind that according to MEPDG an increase over 5 inches of aggregate subbase does not provide any additional structural support for local roads with 1000 ADT and10 percent trucks.

- For local roads, in most cases aggregate subbase does not affect pavement thickness to any measurable degree. Calculated thickness for low volume local roads are typically less than the standard minimum thickness and therefore the design pavement thickness is not reduced when aggregate subbase is used.

- Even when the pavement design life and serviceability is increased by the use of granular base and geotextile interlayer, there will be a time when the pavement needs rehabilitation. Since the pavement foundation will not need to be included in the rehabilitation work, the cost to upgrade the pavement is likely to be lower. Figure 32 shows a typical pavement performance curve and the effect of improved foundation layers.

- Engineers need to examine their agency standard pavement foundation support system based on using good engineering practices and understanding the level of service they desire for the life of the pavement. As a result of the TR – 640 research, it is now more clearly understood how designs that improve foundations will extend the pavement life, improve the level of service throughout the pavement life and provide for more economic rehabilitation approaches at the end of the pavement life. Of course the initial cost to the

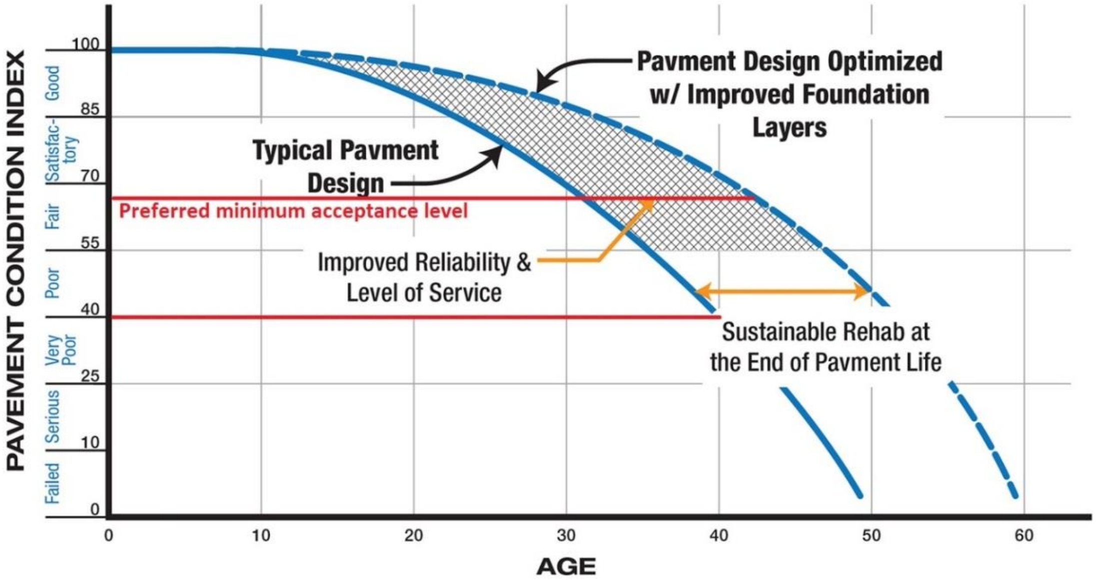


Figure 32. Pavement performance curve with improved foundation layers

pavement will be higher than placing pavement on natural subgrade soils, but the overall lifecycle cost will be greatly improved. This cost includes such items as soil manipulation (drying or treating wet soils), a subdrain system, and an aggregate subbase and geotextile interlayer.

- If after an agency examines the pros and cons of improving their pavement support system or continuing to place a pavement on natural soils, it is at least based on informed options. If an agency feels they are reaching a desirable pavement design life at an acceptable level of service, then there is no real reason to change. However, the pavement design engineer should be prepared to assign resources for pavement preservation above those that would be required for improved foundation support system.

- It is important to understand the characteristics of the soil and what cost effective soil manipulation can be achieved whether an aggregate subbase is or is not employed. These manipulations can include drying out the soils or if the soils are extremely wet, then either replacing the soil or utilizing a soil stabilized treatment such as cement or fly ash. If different soil types are encountered, and an aggregate subbase is not utilized, properly blending and compacting the soils can help reduce differential movement and help prevent pavement cracking.

- Good construction practices, with a proper inspection/observation program, and established maintenance program are important to realize the full performance potential of the pavement.

AREAS OF FUTURE STUDY

Recommended areas of future study include re-visiting the test sites to preform similar foundation layer testing and re-evaluate the pavement condition. With this additional data, changes in the foundation layers and changes in the pavement conditions can be monitored over time.

Another recommendation is to expand the overall number of test sites including those with pavements placed on stabilized subgrade and geotextiles to compare performance with data. The results from the TR-640 study are based on a limited number of 16 test sections. A larger pool of data, with and without aggregate subbase, needs to be evaluated for PCI. This will provide more accurate performance information between the two pavement systems.

Based on previous research that states the majority of pavement damage occurs during the spring thaw, it is recommended to conduct tests at the same sites during the spring season. With this data, a comparison can be made between seasonal changes.

The questionnaire and interview process did not investigate whether aggregate subbases were recycled Portland Cement Concrete (RPCC). Performance Evaluation of Concrete Pavement Aggregate Subbase – Pavement Surface Condition Evaluation (White 2008) showed that there was a decrease in PCI over time for the studied pavements that had RPCC as an aggregate subbase. Further investigation into the aggregate subbase materials and future pavement condition evaluation for the sites in this study may provide the data necessary to make a comparison. With further data collection, it is important to determine if pavement thickness design parameters for coefficient of drainage and loss of support should be modified to reflect field conditions.

IMPLEMENTATION PLAN

This document will benefit municipalities, counties, consultants and the Iowa Department of Transportation. The CP Tech Center will develop a one-hour PowerPoint presentation for use at the Lunch Hour Forums sponsored by the Iowa DOT and ICPA (Iowa Concrete Paving Association).

SUDAS will consider adding supplemental information to the pavement design parameters in Chapter 5 of the Design Manual. Supplemental information may include the benefits of using aggregate subbase including the improvement to the loss of support, improvement to drainage and an increase in service life.

This document, along with the Final Field Data Report for the IHRB TR-640 project, will be available on the CP Tech Center website, www.cptechcenter.org.

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