SUGGESTIONS ON SPECIFYING CONCRETE PAVEMENTS:

VOLUME III: PAVEMENT STRUCTURE, SUBGRADE, AND BASE LAYERS

Volume I of Suggestions on Specifying Concrete Pavements focused on items related to concrete mixes that occasionally contribute to confusion or miscommunication between the design documents and contractors or material suppliers during the bidding process. Volume II looked at nine topics related to delivery and placement of concrete after batching. Volume III looks at eight topics related to pavement structure, subgrade, and base layers.

Structure of a Pavement Section

Soil Cement

Full Depth Reclamation (FDR)

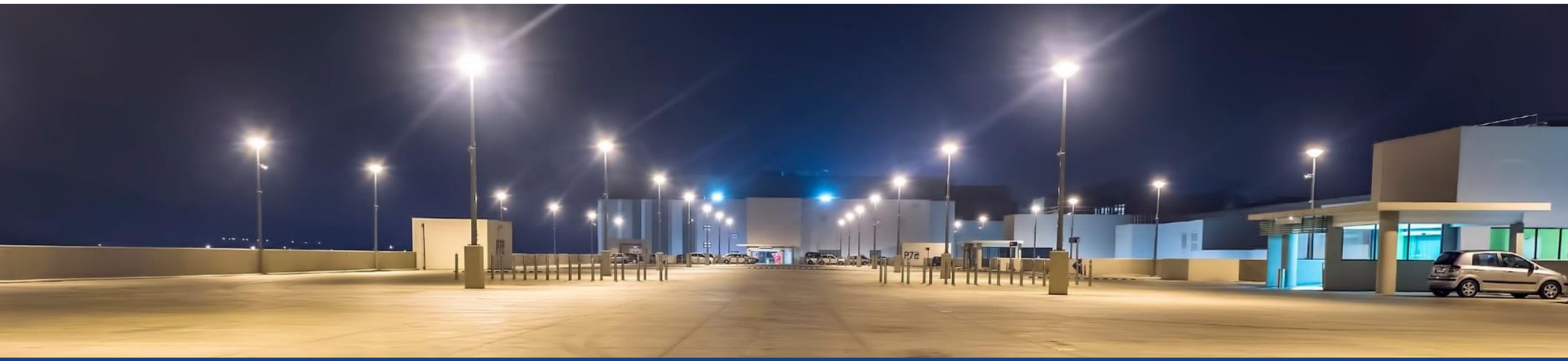
Concrete Overlays Existing Asphalt

LDCC as a Subgrade Replacement

Cement Treated Base (CTB)

Stone Base

Composite Pavements



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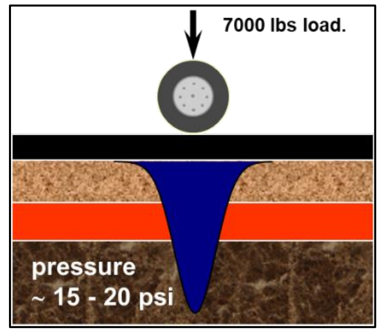
STRUCTURE OF A PAVEMENT SECTION

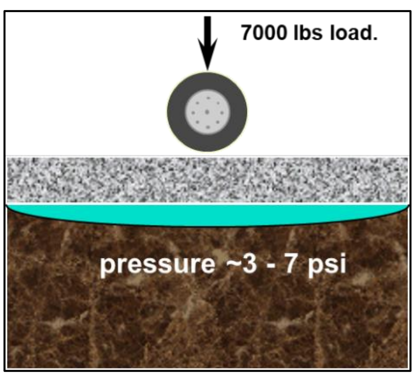
Pavements can typically be divided into two categories, flexible (asphalt) and rigid (concrete). Each type starts on a subgrade of existing soil with additional base layers added as needed before placement of the final wearing course.

Flexible pavement sections often consist of one or more base layers of varying materials between the subgrade and asphalt wearing course. A flexible pavement will deflect under loading as pressure dips well into the supporting layers, as shown to the right. Each independent, flexible layer contributes to the overall strength of the pavement, or its ability to withstand that loading. The strength of each layer is described by a Structural Coefficient, such as 0.16 for stone and 0.44 for asphalt, multiplied by the thickness of the respective layer, shown in the table to the left, and the Structural Number for the overall section is the sum of the various layer coefficients. When designing a flexible pavement, frequently the thickness of a wearing surface can be reduced by adding, or increasing thickness of, supporting layers while maintaining the overall Structural Number. Structural coefficient values throughout this document are from the Georgia Department of Transportation Pavement Design Manual, Appendix D.



	Structural Coeff.	Thickness (in)	Struct. Number
Asphalt Surface	0.44	3	1.32
Aggregate Subbase	0.16	6	0.96
$SN_{Provided}$			2.28

A rigid pavement is not intended to deflect under load. Instead, the loading is distributed over a large area as shown in the picture at the left. As such, the strength of a rigid pavement section is not dependent on the relative strengths of any flexible layers, such as stone, underneath it. Instead, the base or subgrade materials must provide a uniform platform to support the concrete pavement. The level of that support is defined by the Modulus of Subgrade Reaction (k – value in pounds per cubic inch). Values for the Modulus of Subgrade Reaction can range from 50 pci to over 300 pci depending on the material. Stiffer materials, defined by higher k-values, provide greater resistance to deflection of a rigid pavement, and can sometimes allow for some reduction in the thickness of that section. It is important to note that simply adding supporting layers under a rigid pavement or making those layers thicker does not automatically translate into a thinner wearing course like it does in a flexible pavement.

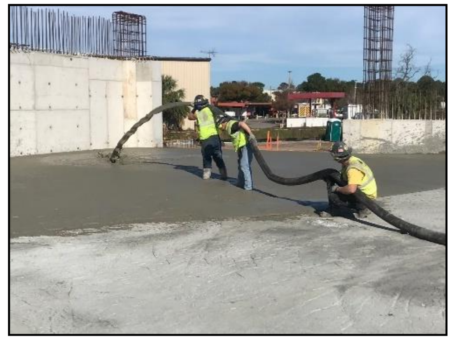


SUGGESTION: When considering which pavement option to use on a project, understanding the differences in behavior between flexible and rigid pavements will lead to an effective pavement structure. We are available to help you review proposed pavements, optimize concrete pavements, and compare truly equivalent sections for your application.

LDCC AS A SUBGRADE REPLACEMENT

One of the ways to address issues related to unsuitable subgrades, such as reduced load carrying capacity, increased maintenance costs, or premature failures is to replace poor subgrade materials with an engineered fill or other suitable material such as Low-Density Cellular Concrete (LDCC), also called Lightweight Cellular Concrete.

Having an oven-dry density of 50 pounds per cubic foot or less, LDCC is a pumped material, as shown in the picture to the right courtesy of Site Mix Pressure Grouting, made of hydraulic cement, water, and a foaming agent. Applications for LDCC include, but not limited to, retaining wall backfill, slope stabilization, void fills, and soft soil remediation/subgrade replacement. The picture at left shows a general correlation between the density of an LDCC material, its compressive strength, and estimated California Bearing Ratio (CBR). By comparison, soils in the local area (Metro Atlanta and North Georgia) typically have CBR values ranging from 3 – 5, so an LDCC material at the lower end of the density range, can significantly improve support characteristics.



Oven-dry density lb/ft^3	Compressive strength psi	Estimated Range CBR
20 to 25	70 to 125	7 to 12
25 to 30	125 to 225	12 to 22
30 to 35	225 to 350	22 to 35
35 to 40	350 to 450	35 to 45
40 to 50	450 to 750	45 to 75

When being used as a component of a pavement structure, LDCC is not intended to be a wearing course. Under a rigid pavement, LDCC offers the uniformity of support important to successful pavement performance as well as increased Modulus of Subgrade Reaction values (k = 200 pci instead of k = 150 pci for example). Under a flexible pavement, LDCC falls in the general "soil cement" category with a Structural Coefficient of 0.20 as compared to 0.16 for Graded Aggregate Base.

SUGGESTION: When looking at subgrade replacement options, Low-Density Cellular Concrete is another tool available for use in addressing problems related to unsuitable soils under a pavement. We are available to help you assess the effectiveness of this approach on your next paving project.

SOIL CEMENT (CMS & CSS)

According to the Guide to Cement-Stabilized Subgrade Soils published by the National Concrete Pavement Technology Center at Iowa State University, "Soil-Cement refers to a compacted engineered mixture of soil, cement, and water designed and constructed for various pavement and geotechnical applications and characteristics". Soil-cement, in common use, is a catch-all term that encompasses four different materials; Cement Modified Soils (CMS), Cement Stabilized Subgrade (CSS), Cement Treated Base (CTB), and Full Depth Reclamation (FDR).

A Cement Modified Soil (CMS) is a way to improve properties of a soft, wet subgrade without removing and replacing the material. A small amount of cement (2%-4%) is added to the soil to help dry it out, improve workability, and reduce susceptibility to adverse effects of moisture. This creates a platform on which to build any pavement section. While Cement Modified Soils do show some increase in bearing capacity over virgin material, that increase is generally not enough to offer the potential for reduction in pavement thickness, whether that pavement is flexible or rigid.

A Cement Stabilized Subgrade (CSS) takes the soil improvements seen with a Cement Modified Soil a step further. An increased amount of cement (4%-6%) added to the in-place material shows a corrsponding increase in the material's stiffness, which often gives unconfined compressive strengths in the range of 100 -300 pounds per square inch (psi). The strength of a CSS material often translates to increases in the layer coefficient, used in flexible pavement design, or the Modulus of Subgrade Reaction (k-value), used in rigid pavement design, offering the potential for reduction in thickness of your pavement section.

SUGGESTION: The use of Cement Modified Soils or Cement Stabilized Subgrades can be highly dependent on the specific conditions at your project site. We are available to help you determine whether, and to what extent, cement treatment of soils is a viable option for the pavement subgrade on your next project.

CEMENT TREATED BASE (CTB)

Cement Treated Base (CTB) is another material that falls under the overall umbrella of "Soil-Cement". Again borrowing from the Guide to Cement-Stabilized Subgrade Soils published by the National Concrete Pavement Technology Center at Iowa State University, "Cement-treated base (CTB) is a fully bound, compacted, engineered mixture of aggregate, water, and sufficient cement to meet the project-specified minimum durability and strength requirements". CTB uses similar cement volume as Cement Stabilized Subgrade (4%-6%) but differs from CSS in that it incorporates larger aggregates and can be produced in a central batch Ready Mix plant or pugmill, in addition to being mixed on site. The larger aggregate in the mixture contributes to an increase in rigidity and strength over virgin materials and CSS, with seven-day Unconfined Compressive Strengths typically in the range of 300 – 800 pounds per square inch (psi).

For flexible pavements, the support, or strength, provided by various base layers improves as the rigidity of the base layer increases. Using an un-stabilized granular base (commonly referred to as a Graded Aggregate Base here in Georgia) as a baseline, the table to the right shows improved layer structural coefficients from the use of cement stabilized material.

BASE MATERIAL	COEFFICIENT
Graded Aggregate and Crushed Limestone (Compacted to Modified Density)	0.16
Soil Cement (Cement Stabilized Subgrade (CSS))	0.20
Cement Stabilized Graded Aggregate (Cement Treated Base (CTB))	0.22

Subgrade k-value (psi/in)	4-inch Base	6-inch Base
	Granular Aggregate Subbase	
50	65	75
100	130	140
	Cement-Treated Subbase	
50	170	230
100	280	400
	Other Treated Subbase	
50	85	115
100	175	210

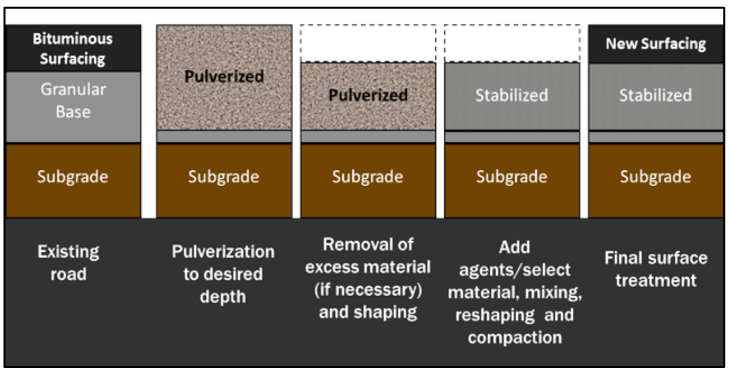
Values for the Modulus of Subgrade Reaction (k-value) used in rigid pavement design can be found in Table 3.2 of ACI 330 R-08 – Guide for the Design and Construction of Concrete Parking Lots. In this table a subbase layer can be used interchangeably with a base layer. The subgrade k-value (left column) is the starting point for natural, in-place materials. Granular Aggregate Subbase is equivalent to the Graded Aggregate Base above and Other Treated Subbase, generally represents improvements to the subgrade provided by a Cement Stabilized Subgrade.

SUGGESTION: When looking at a pavement design, using a Cement-treated base offers a strong and durable support platform for any pavement and can contribute to thinner overall sections. We are available to help you determine the viability of a Cement-treated base on your next paving project.

FULL DEPTH RECLAMATION (FDR)

Full Depth Reclamation (FDR) is the last topic under the overall umbrella of Soil Cement that we will address. The volume of cement (4% - 6%) and seven-day Unconfined Compressive Strengths (300 – 600 psi) for FDR are consistent with the same properties in a Cement Treated Base (CTB). What makes Full Depth Reclamation different, and cost effective, is its use of existing deteriorated asphalt material as a component of the final pavement base, minimizing the amount of existing material removal and replacement when compared to the full reconstruction of a failed pavement.

The Full Depth Reclamation process, outlined in the picture below, involves pulverizing an existing asphalt surface and aggregate base, blending the materials into a single matrix. Once this blended material is graded and shaped, it is mixed with cement which stabilizes it and creates a suitable base on which to place a final pavement surface. The dotted rectangles in steps three and four of the picture represent a signiifcant reduction in material removed from the project site when compared to the full depth of bituminous surfacing and granular base shown in step one. Fewer trucks leaving the site helps minimize wear and tear on adjacent roadways used as haul routes in addition to lowering project costs. FDR is commonly associated with roadway rehabilitation but it has also been successfully used on large parking areas such as those associated with regional malls or other large retail centers.



A common concern related to the overall term "Soil Cement" is reflective cracking which refers to cracks in a rigid base layer reflecting upward into the pavement surface. A rigid base course can inhibit normal movement of a pavement surface that would typically prevent this reflective cracking. As that movement is constrained, stresses tend to be released in the form of block shaped cracks in the pavement surface. While Cement Modified Soil and Cement Stabilized Subgrade layers typically are not rigid enough for reflective cracking to be a concern, CTB and FDR are rigid enough to be at risk of reflective cracking. This risk can be reduced by limiting the restriction of normal movement in the pavement surface. Among the methods used to counter reflective cracking are installation of a stress-relieving interlayer, consisting of a geotextile fabric or open graded asphalt course, or pre-cracking, known as "microcracking" the rigid base layer using a vibratory roller.

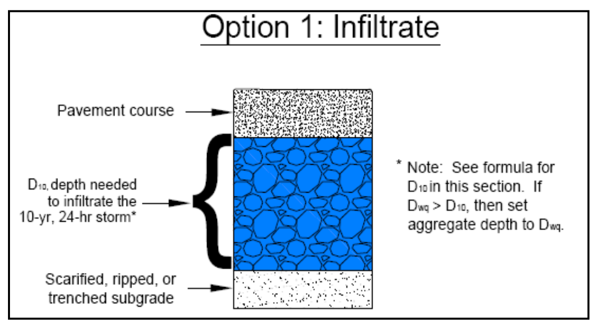
SUGGESTION: When considering rehabilitating or reconstructing existing, failed pavements, Full Depth Reclamation is an effective, and economically feasible, means of extending service life of large paved areas. We are available to help you determine the viability of an FDR approach to existing paved surfaces on your next development project.

STONE BASE FOR CONVENTIONAL AND PERVIOUS CONCRETE

While the use of a stone base under concrete pavement can, and frequently does, improve the Modulus of Subgrade Reaction (k-value), that improvement is rarely enough to result in a reduction of concrete thickness. The amount of stone required to affect a reduction in concrete thickness would not be cost effective. ACI 330R-08 Guide for the Design and Construction of Concrete Parking Lots states "it probably is not economical to use imported subbase material……….for the sole purpose of increasing k-values, though such measures are sometimes used to improve the contractor's working platform or to reduce subgrade susceptibility to pumping and erosion".

Soil type, moisture content, inadequate compaction, and other factors can make achieving the uniform platform necessary for long term perfomance of a concrete pavement difficult. The use of a relatively thin (4"-6") stone base can help to reduce the impact from those issues as well as adding a layer of protection from the pumping of fine materials out of the subgrade under frequent heavy loading. Material loss from this pumping action can lead to voids under the pavement, as shown in the picture to the right, and contribute to failures. With the relatively shallow influence of loading on rigid pavments, as discussed in the first section, a stone base reduces or eliminates effects from frequent, heavy wheel loads on the finer subgrade soils beneath the stone.

A Pervious concrete pavement system is often referred to as part of the stormwater management system that doubles as a pavement and a stone base is a critical component of the system as a reservoir to temporarily hold water. In a pervious concrete mix, shown in the picture to the left, fine aggregates (sand) are typically removed leaving the cement-water paste and a single sized rock with a 10%-15% void space. Water from rainfall readily passes through the concrete surface layer into the stone base reservoir which has a 30%-40% void space. As pervious concrete is not often intended for frequent heavy loading, the stone base is not densely graded which maintains the void space necessary to hold water. The picture to the right, from the North Carolina Stormwater Manual, shows one option (not the only option) for using pervious concrete pavement where stormwater runoff is detained and allowed to infiltrate into the subgrade over a period of time, often 24 hours.



SUGGESTION: Manage expectations for the function of a stone base, to improve a paving platform or to act as a temporary stormwater reservoir, under concrete pavements. We are available to help you determine an effective application for a stone base on your next project.

CONCRETE OVERLAYS OF EXISTING ASPHALT

An intact asphalt pavement is another platform on which a concrete surface can be placed. Overlays of existing asphalt can be bonded (typically 2" – 6" thick) or unbonded (typically 5" – 11" thick).

Bonded Concrete Overlays of asphalt, make use of the existing pavement as a structural component of the overall pavement section. These overlays are also called Thin Whitetopping (4" – 6" thick) or Ultra-thin Whitetopping (2" – 4" thick) with the Ultra-thin Whitetopping being the least commonly used. The existing pavement is generally in good structural condition with minor distresses such as shallow cracking, rutting, shoving, or localized alligator cracking. Prior to construction of a bonded overaly, the existing surface is cleaned and often milled to a depth that eliminates various shallow distresses to provide a suitable surface for bonding. For structural purposes, three inches of the exisitng asphalt section, minimum, is required to be left in place after milling.

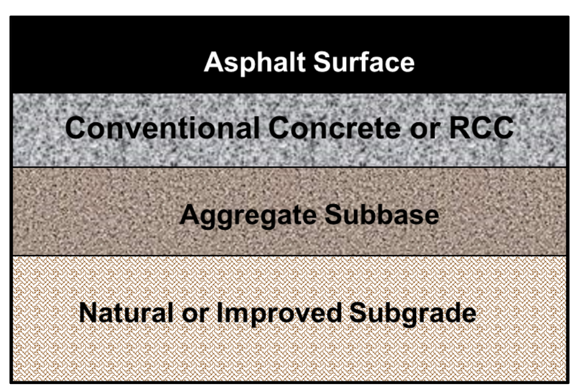
In an Unbonded Overlay of asphalt, the existing pavement is in poor structural condition with severe distresses that include, but are not limited to, widespread alligator cracking, potholes, and deep rutting. The existing pavement is not an integral part of the new concrete pavement section but functions as a base for the new concrete pavement. Unbonded overlays are designed as new pavements and are significantly thicker than the bonded overlays. Surface prepartion prior to installation is often limited to isolated full-depth repairs to restore some structural integrity for its function as a base course or milling in areas where distortions in the surface exceed two inches. Due to the thickness of unbonded overlays, specific bond-breaking efforts, such as geotextile fabric, are not required between the concrete and the existing asphalt.

SUGGESTION: the condition of the existing pavement is a primary factor when considering the use of a concrete overlay, don't neglect other considerations, including elevation of adjacent features, clearance beneath bridges or overpasses, and existing drainage patterns. We are available to help you assess any of these factors when considering the suitability of a concrete overlay as a paving option on your next project.

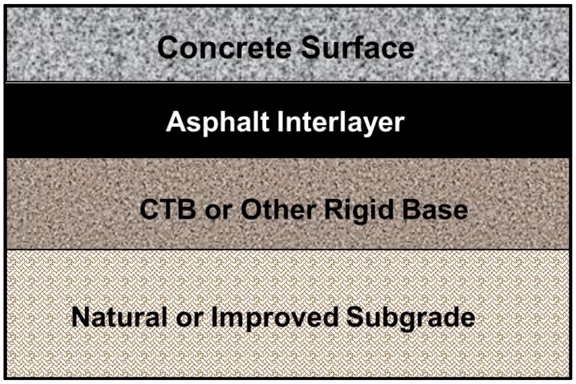
COMPOSITE PAVEMENTS

The various support layers discussed thus far become an integral part of the respective pavement section. A different type of pavement section, introduced with the topic of a concrete overlay on an existing asphalt pavement, is a Composite Pavement, which is one that uses both concrete and asphalt in its section.

In the composite pavement section pictured on the right, concrete is a supporting layer under an asphalt wearing course. Without the asphalt surface course, this looks like a typical concrete paving section, so why add the asphalt? Asphalt is often percieved to offer a smoother riding surface so it is used as a topping on concrete pavement. Asphalt may also be added on top of the conventional or RCC layer for aesthetic value to match adjacent paved areas. From the persepctive of long term or recurring maintenance, the asphalt can be milled off an replaced with relative ease while the concrete's durability reduces the need for more significant, and costly, deep repair or rehabilitation efforts.



In the picture below, the composite pavement is flipped and concrete is used as the wearing course with asphalt providing a bit of a cushion between two rigid layers. As mentioned above, the Cement Treated Base (CTB) is, rigid. The rigidity of the CTB can restrict movement during setting of the concrete surface leading to the risk of reflective cracking in that surface. The flexibility of the asphalt interlayer allows the concrete surface layer to move independently of the CTB layer, reducing stresses that lead to reflective cracking. When an open graded (reduced or no fine aggregate) asphalt mix is used, this interlayer can also help in draining the pavement section.



SUGGESTION: When considering pavement options keep in mind that there may be factors beyond heavy loading, such as those mentioned above, that influence the paving section. We are available to help you determine whether a composite pavement is a feasible option and which pavement components best fit your unique project application.