Chapter Nine

PAVEMENT SELECTION

This chapter discusses the general criteria, procedures and responsibilities for structural design of highway pavements. In addition there is information given on the various types of pavements, pavement rehabilitation techniques, and other factors that enter into pavement design and final pavement selection.

For the purposes of uniform and consistent design practices, the Department has adopted the criteria and procedures as set forth in the *AASHTO Guide for Design of Pavement Structures 1993*. This chapter briefly reviews the concepts and criteria used. Reference should be made to the AASHTO Guide for more detailed information on design procedures, if needed.

The design procedures include the determination of total thickness of the pavement structure as well as the thickness of the individual components using input parameters specified in the DARWIN 3.01 computer program. Provision is made for the design of equivalent alternate pavement sections, with the selection primarily a function of availability of materials, comparative costs, constructibility, and availability to traffic.

The discussion and explanatory material presented here are intended to give the designer a general understanding of pavement design concepts, alternative paving treatments, and a basic understanding of the information contained in a soil survey and pavement design report.

9.1 DESIGN RESPONSIBILITY

The design of pavement structures has some jointly shared responsibilities between the Materials and Research (M&R) Section and the responsible Project Development section. However, the primary responsibility for structural design and final recommended pavement sections is that of the M&R Section.

9.1.1 SOIL SURVEY/PAVEMENT EVALUATION REQUEST

There are several elements in the design process that need to be accomplished before a pavement section recommendation can be requested from the M&R Section. The project handoff package will describe the project scope. If the intent is to construct new pavement or replace the existing pavement then a soil survey, pavement design and pavement type recommendation will have to be requested.

The following should be available when requesting borings for a soil survey from DelDOT's Geotechnical Engineer and/or corings of the existing pavement from DelDOT's Pavement Design Engineer:

- preliminary surveys,

- survey plans with the location of the investigation, including the road name and state maintenance road number, and any predetermined locations marked,
- existing right-of-way verified,
- Right-of-entry to trespass, if needed,
- Purpose of the investigation in order to determine what pertinent information is required from the cores or the borings.
- If a boring is required, the depth of the boring. If the designer is unsure of depth to sample, contact the Geotechnical Engineer for guidance.

Coring and boring requests are typically processed within 30 days. If a coring and boring request is received simultaneously, they will be processed concurrently. If the boring request is received after the coring request has been completed, it will be treated as a different request and will be processed within 30 days of receipt.

For a pavement design, the following information is required with the request:

- Design year traffic data (AADT)
- Design year truck percentages
- Weight group pattern of trucks
- Directional split
- Existing pavement structure (if applicable)
- Subsurface investigation report (if applicable)
- Description of any existing pavement deterioration

Copies of any existing corings, borings, or subsurface condition reports should be provided to the Pavement Design Engineer when sending the pavement design request. The Pavement Design Engineer may elect to have additional corings, borings, or other investigations performed to ensure the existing conditions are known and considered when performing the pavement design. All information, including the design, will be forwarded to the designer.

For projects designed by a consultant, the design consultants must:

- Develop the subsurface investigation plan to have drilling and inspection services provided under their direction.
- Notify the DelDOT Project Manager of the scope of the subsurface investigation plan and provide a boring plan sheet(s) to the Department. The DelDOT Project Manager will forward the boring plan to the Materials & Research (M&R) Geotechnical Engineer
- Specify to M&R what soil testing is requested.
- Inform the Geotechnical Engineer at least 24 hours in advance when drilling and soil sampling is to begin and provide the name and phone number of the consultant who is to receive the M&R soil test information.
- Arrange to have the soil samples and copies of the field logs brought to the M&R lab within 24 hours after obtaining samples.

The Geotechnical Engineer shall:

- Perform, or arrange for, all soil testing required for the project as requested by the design consultant.
- Furnish completed boring logs and laboratory test summaries to the design consultant with a copy to the DelDOT Project Manager.
- Provide the DelDOT Project Manager regular weekly updates on the progress of the drilling/testing programs.
- Inform the DelDOT Project Manager when problems arise and when the testing programs are completed.

Many projects are initiated with the intent of extending the service life of the existing pavement section. Rather than rebuilding the entire pavement, improvements are made in the riding quality, skid resistance and limited structural improvements through various rehabilitation methods. For projects of this type a pavement

evaluation is requested. A pavement evaluation includes an extensive pavement survey noting pavement conditions, drainage and major distress problems. The initial evaluation will determine which rehabilitation method(s) should be considered. Based upon the alternatives being considered, it may be necessary to conduct detailed measuring and testing, including coring and sampling, and accurately determining structural clearances to any overhead structures. The final report received by the designer will contain most if not all this collected field data and will include the recommended rehabilitation method. Much of the field data collected can be a very valuable tool in designing the project.

9.1.2 SOIL AND PAVEMENT DESIGN REPORT

The M&R Section performs the soil sampling and pavement coring. This field data is tested in the laboratory and the results documented in the form of a Soil Survey. This report includes the soil profile data summary showing the sample location, depth, soil profile description, soil classification and any remarks. The soil samples are tested and a summary of this analysis is included in the report.

Based upon the subgrade soil characteristics, the report may provide recommendations for muck excavation, limits of special fill, need for underdrains, grade adjustments, embankment construction, the use of geotextiles or other special construction considerations.

An important part of the report is the pavement design portion. Using the AASHTO Guide, the soil survey data, and past experience, the recommended pavement type and thickness by components is included in the report. Pavement sections for shoulders and turn lanes are also included.

The report may provide an alternate design including at least one rigid pavement and one or more flexible alternatives. Project Development and M&R will meet and mutually agree on which pavement to use on the project. If necessary, the M&R Section may perform an economic and life cycle cost analysis or other studies in making the final determination and recommendation for pavement type and section. For many projects, only one pavement design recommendation is made.

The Soil and Pavement Design Report should be evaluated thoroughly and considered as the design progresses. In the design process significant changes in the proposed profile or alignment can dramatically affect the pavement design and need to be discussed with M&R, perhaps even before such decisions are finalized. In addition the proposed construction sequencing, methods of construction and maintenance of traffic plan can dramatically affect whether the recommended pavement materials can be placed in a timely manner and meet the in-place performance quality necessary for the intended service life.

9.1.3 PAVEMENT SELECTION

As mentioned in Section 9.1.2, there may be several choices of structurally equivalent pavements. The choice of pavement, particularly on reconstruction and new construction is a major decision and needs to be approved prior to proceeding with the design.

The factors considered in making the final decision on pavement type are quite varied from empirical to subjective and may include several of all of the following:

- Project scope—as initiated,
- Cost to construct or rehabilitate the pavement,
- Available project funding,
- Construction sequencing as it relates to controlling through and local traffic,
- Construction sequencing as it relates to serving commercial areas,

- Construction sequencing as it relates to maintaining quality control of pavement construction,
- Availability of work areas for the paving equipment,
- Projected future traffic control and other costs to perform maintenance, restoration or rehabilitation
- Minimum desirable service life,
- Performance of similar pavements under similar soil conditions and traffic loadings,
- Geotechnical design problems created by the depth of pavement structure, which could increase drainage costs,
- Effect on underground utilities, and
- Effect on existing vertical clearances.

9.2 PAVEMENT TERMINOLOGY

The pavement section is treated as a structural element consisting of several different materials of varying depths and supporting strengths. Knowledge of the following definitions and the terminology as shown on Figure 9-1 is needed to understand the pavement design and rehabilitation concepts in this chapter.

- Base Course—the layer or layers of specified or select material of designed thickness placed on a subgrade to support a surface course
- Bituminous Concrete—A designed combination of dense graded mineral aggregate filler and bituminous cement mixed in a central plant, laid and compacted while hot.
- Bonded Overlay—An overlay of concrete placed over a Portland cement concrete pavement.
- Flexible Pavement—A pavement structure of bituminous concrete that distributes loads to the subgrade and depends on a firm continuous subgrade, aggregate interlock, particle friction, and cohesion for stability.
- Grinding—Patterns cut into a concrete pavement with closely spaced diamond blades to restore pavement smoothness and skid resistance.
- Grooving—Patterns cut in asphalt or concrete pavements to promote surface drainage to reduce wet weather hydroplaning.
- Micro-Surfacing—A polymer modified cold-mix paving system consisting of a mixture of dense-graded aggregate, asphalt emulsion, water, and mineral fillers.
- Modulus of Subgrade Reaction (k)—A value used in rigid pavement design that is the ratio of the load in pounds per square inch [in kilograms per square mm] on a loaded area of the subgrade or subbase divided by the deflection in inches [mm] of the subgrade soil or subbase, psi/in [kPa]. Typically, k is adjusted for potential loss of support due to subbase erosion.
- Open Graded Mix—A special mix, containing aggregate that resists polishing, placed on the surface course to drain surface water, improve skid resistance, and reduce hydroplaning.
- Rigid Pavement—A pavement structure that distributes loads to the subgrade, having as one course a Portland cement concrete slab of relatively high bending resistance.
- Pavement Milling—The use of carbide cutting teeth mounted on a rotary drum to chip off as much 3 to 4 inches [75 to 100 mm] of asphalt concrete surface.
- Pavement Structure—A combination of subbase, base course and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed
- Recycling—Salvaging and processing portions of existing pavement for use in construction of new pavement structures.
- Resilient Modulus (M_R)—A measure of the essential properties of untreated subgrade soils through determination of dynamic elastic modulus under conditions that represent a

reasonable simulation of the physical conditions and stress states of subgrade materials beneath flexible pavements subjected to moving loads.

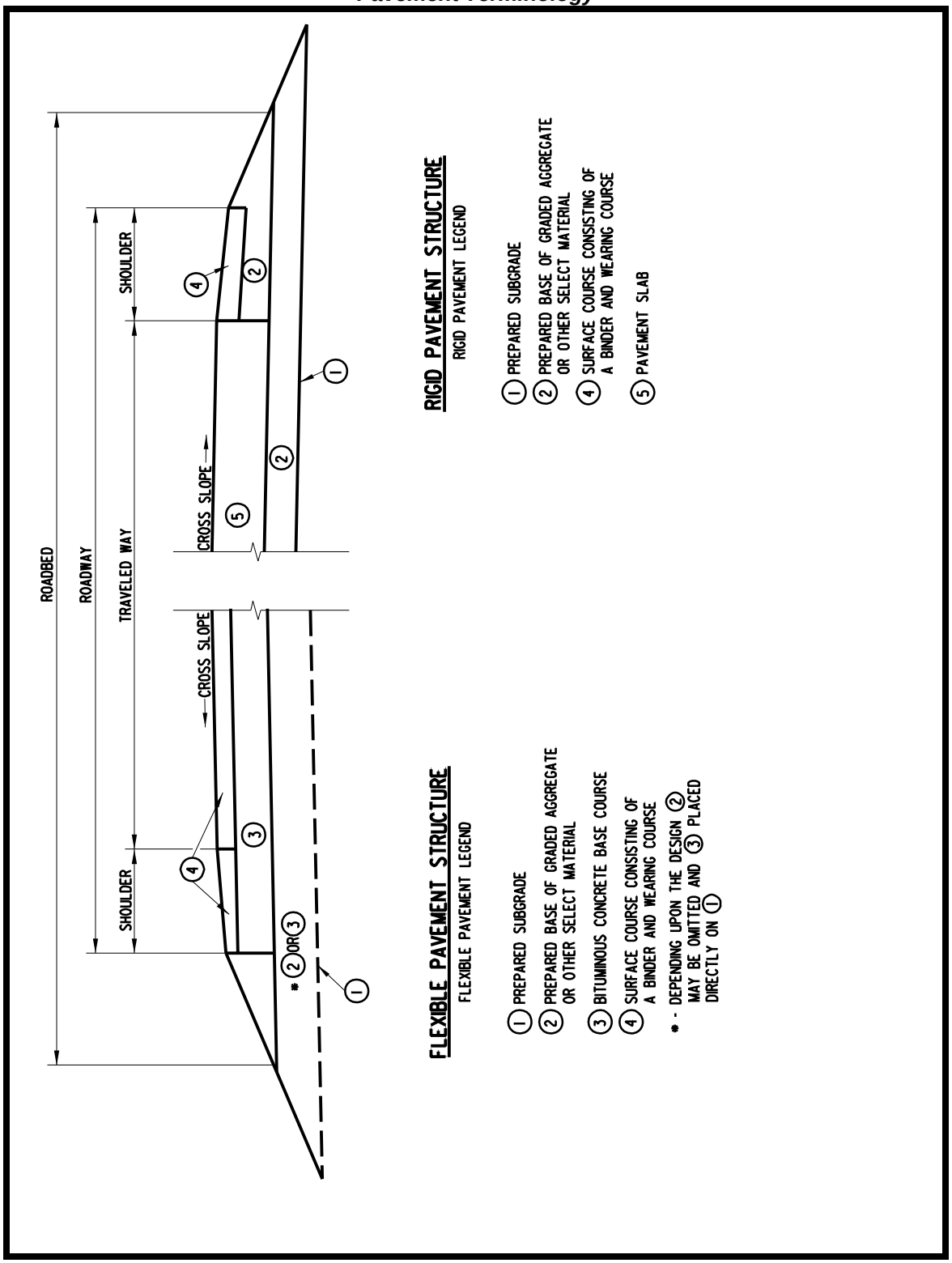
- Roadbed Material—The material below the subgrade in cuts and embankments and in embankment foundations, extending to such depth as affects the support of the pavement structure.
- Roadbed—The graded portion of a highway between top and side slopes prepared as a foundation for the pavement structure and shoulders.
- Select Material—A suitable native material obtained from a specified source such as a particular roadway cut or borrow area having specified characteristics to be used for a specific purpose.
- Subbase—The layer or layers of specified or select material of designed thickness placed on a subgrade to support a base course (or in the case of rigid pavements, the Portland cement concrete slab).
- Subgrade—The top surface of a roadbed soil upon which the pavement structure and shoulders are constructed.
- Superpave—An asphalt pavement with a laboratory design mix that provides superior performance.
- Surface Course—One or more layers of a pavement structure designed to accommodate the traffic load, the top layer of which resists skidding, traffic abrasion, and the disintegrating effects of climate. The top layer of flexible pavements is sometimes called "wearing course."
- Ultra-Thin-Whitetopping—An overlay of concrete less than 4 inches [100 mm] thick placed over an asphalt base, usually 2 to 3.5 inches [50 to 90 mm].
- Whitetopping—A concrete overlay of an asphalt pavement of 4 inches [100 mm] or more.

9.3 PAVEMENT DESIGN FACTORS

Pavement design methodology for both new pavements or rehabilitation of existing pavements consider several, if not all, of the following factors:

- Pavement design life,
- Pavement performance,
- Traffic volume and vehicle class,
- Roadbed soil,
- Materials of construction,
- Temperature changes,
- Drainage,
- Reliability,
- Life-cycle costs, and
- Shoulder design

Figure 9-1
Pavement Terminology



Of these factors, the most influential factors in determining a pavement's required structural strength are the characteristics of the underlying roadbed material, the projected traffic volumes and the percentage and weight of vehicles in the traffic mix using the facility over the expected design life of the pavement. The following sections briefly discuss the factors considered.

9.3.1 PAVEMENT DESIGN LIFE

Each pavement design has a selected design life. Roadway cross section elements and other components of the project such as the pavement structure are expected to remain structurally sound for a designated period of time defined as design life. Although the roadway cross section may become operationally obsolete or the pavement distressed and in need of restoration or rehabilitation, they have not reached the end of their design life but rather have reach the end of a condition defined as service life. Not until they need complete replacement are they considered to have reached the end of their design life.

9.3.2 PAVEMENT PERFORMANCE

The goal of a pavement design is to produce a pavement that when placed will perform functionally and structurally while maintaining its safety characteristics for at least the selected service life.

Functional performance of a pavement identifies how well a pavement will serve the user. The characteristics identified are riding comfort and ride quality. This concept is called serviceabilty-perfomance and provides a means to measure functional performance. In the pavement design procedure, this factor is expressed in terms of the present serviceability index (PSI). PSI is a measurement of roughness and distress of a pavement during the service life of a pavement. Therefore, a reliable method of measuring roughness and maintaining and updating historical performance data is an integral part of pavement design. The major factors influencing the loss of serviceability are traffic, age, and environment.

The structural performance of a pavement relates to its physical condition; including occurrence of cracking, faulting, raveling, or other conditions which would adversely affect the load-carrying capability of the pavement or would require maintenance.

A pavement's safety performance primarily relates to its ability to provide adequate skid resistance during its service-life but also can be affected by its ability to maintain a smooth and rut free surface. Age, traffic, physical properties of materials used to construct the pavement and environmental conditions influence a pavement's safety performance.

9.3.3 TRAFFIC

Traffic volumes using a facility, in particular the number and weight class of trucks, is a major factor in determining how strong a pavement structure must be. In the design procedure, traffic data is reduced into axle loads, axle configuration, and number of applications of these loads. The result is a design number representing the damage done to the pavement caused by the effect a single axle carrying a load on the pavement over its design-life. For the design calculations, traffic data is converted into 18-kip [80 kN] equivalent single axle loads or ESAL's. Since it is one of the more important design considerations, accurate traffic data will ensure that a pavement's design life will be attained and the pavement sections selected will not be over or under designed.

9.3.4 ROADBED SOIL

The pavement structure rests on a graded and compacted roadbed either of suitable natural material or on specified imported material. The roadbed soil has measurable material characteristics that are used in the pavement design. This measurement is defined as a soil's resilient modulus (M_R) and is a measure of the elastic

property of soil. The resilient modulus is used directly for designing flexible pavements but must be converted to a modulus of subgrade reaction (k-value) for the design of rigid pavements or composite pavements. The resilient modulus is also a soil property used in analyzing multilayered material systems for predicting roughness, cracking, faulting, rutting, and other potential distresses.

The value of a roadbed's resilient modulus is dependent on how well the roadbed soil is placed in conformance with the specified compaction parameters. For most projects, the material is to be placed in accordance with the *Standard Specifications* with no special treatment. However, the Soil and Pavement Design Report may indicate that there is anticipated difficulty with the existing roadbed soil meeting the design M_R value. For soils that are excessively expansive the report may recommend these soils be covered by select material sufficiently deep enough to reduce or eliminate the expansive affect of the natural material. Other solutions may include the adding of an admixture to reduce the water content or the use of a geotextile.

One of the more difficult soils encountered on projects are those having a large organic content. These materials are extremely compressible, unstable and frequently non-uniform in properties and depth. These soils are the most complicated and expensive to deal with in order to provide an adequate roadbed. Small, shallow or localized deposits are most often excavated and replaced with suitable material. Deeper and more expansive areas involve more detailed geotechnical design, more complicated construction techniques and costs. Treatments other than complete removal are more time dependent allowing for the slow consolidation and removal of excess moisture. Methods available include surcharge embankments for preconsolidation of the underlying material usually involving sand drains which allow the water to rise to the surface and be removed. The M&R Section is responsible for identifying and designing the most economical method treating this type of problem area.

Underdrains (a system of perforated pipes to collect and transmit the water to an outfall site) are recommended for use on all roadway projects to adequately address drainage and removing water from the roadbed. If site conditions indicate that underdrains may not be required, contact the M&R Section to initiate further investigation.

The soil and pavement condition survey will normally identify roadbed drainage problem areas or soils highly susceptible to expansion or loss of strength with increase in water content. When either of these conditions exist, the M&R Section may recommend additional work and/or materials to address the existing conditions.

Another type of material encountered in constructing roadbeds is classified as cohesionless (sandy) soil and is much more difficult for the contractor to place and compact; it is readily displaced under the load of the equipment. To stabilize this type of soil it may be necessary to blend granular material or add a suitable admixture. Wet clay soils may also be encountered. Because of high moisture content this type of soil is unstable and cannot be compacted. Long periods of dry weather and exposure to the air are required to reduce the water content. To reduce the time necessary to reuse these materials, the recommendation may be to add a suitable admixture that hastens drying or cover the area with a more suitable select material. Removing the material and replacing it with suitable material allowing construction to continue is an option. The material may be used in areas that don't require compaction or moved to an available site for air-drying and reuse at a later time.

9.3.5 PAVING MATERIALS

Depending upon materials that comprise a pavement, the pavement structure is identified as either a flexible or rigid pavement. Combining these two types of paving materials in a pavement structure as a subbase or surface course results in a composite pavement.

9.3.5.1 FLEXIBLE PAVEMENTS

Flexible pavements consist of a prepared roadbed with a subbase of graded aggregate or bituminous concrete and a bituminous concrete base with a surface course. Properly preparing a uniform roadbed compacted to the prescribed density is especially important for providing the design support value necessary for flexible pavement to perform as designed.

The subbase course usually consists of a compacted layer of granular material or an untreated graded aggregate. If additional support strength is needed or the roadbed soil is questionable either of these materials may be treated with an admixture. In some instances, the subbase may be recommended to be a freely draining-highly permeable material to provide a means for water to migrate from under the pavement structure to the side slopes or to an underdrain system. The subbase also prevents intrusion of fine-grained roadbed soils into the base course, minimizes the damaging affects of frost action, and provides a working platform for construction equipment.

The base course is a specified depth of bituminous concrete that is primarily designed to provide the structural strength needed to support and distribute the projected traffic loads.

The surface course is a bituminous concrete mixture placed as the upper course and is usually constructed on a base course. The surface course provides some structural strength. However, the major functions of the surface course are to provide a smooth riding surface that resists distress, minimizes the amount of water that may penetrate the lower more porous layers, provides and maintains its skid resistance for selected service life. To meet these requirements, the surface course mix must have the optimum gradation of aggregate and percent of bituminous binder to prevent raveling, provide durability, resist fracture, and remain stable under traffic use and adverse climate changes.

9.3.5.2 RIGID PAVEMENTS

Rigid pavements consist of a prepared roadbed, a layer of subbase material and a Portland cement concrete pavement slab. The subbase may be either stabilized or unstablized. Although concrete pavements can span failed subgrade and subbase areas easier than flexible pavements, they are still susceptible to damage and failure from excessive moisture in the support structure.

The subbase of a rigid pavement structure consists of one or more compacted layers of granular or stabilized material placed between the roadbed and the rigid slab. The subbase functions to:

- Provide uniform, stable, and permanent support,
- Increase the modulus of subgrade reaction,
- Minimize the damaging effects of frost action,
- Prevent pumping of fine-grained soils at joints, cracks, and edges of the rigid slabs, and
- Provide a working platform for construction equipment.

The pavement slab is composed of Portland cement concrete, longitudinal tie steel, load transfer devices between slabs, and joint sealing materials.

Joint sealing is a critical element in the long-term performance of a rigid pavement. Proper joint sealing prevents infiltration of water under the slab that reduces the support strength of the subgrade and reduces pumping action between slabs caused by the transfer of moving traffic loads between joints. The vertical movement of the slabs eventually erodes the subgrade material through any unsealed joints allowing a slab to break or settle.

There are two types of joint sealants in use, liquid sealants and preformed elastomeric seals. Liquid sealants include a wide variety of materials including hot-poured rubber, elastomeric compounds, and polymers. The materials are

placed in the joint in a liquid form and allowed to set. Preformed seals are extruded neoprene seals having internal webs that exert an outward force against the joint face. The size is determined by the amount of joint movement anticipated.

Transverse joints are needed in a rigid slab to form cracks at desired locations that can be controlled and sealed. Joints can be keyed, butted or tied. Transverse joints are sawed or formed to a depth of one quarter to one third the slab thickness. Timing the saw cutting operation to the curing of the concrete is critical.

Load transfer devices are used between slabs and usually consist of smooth round steel dowels. The dowels should distribute the load stresses without over stressing the concrete surrounding it, offer little restraint to longitudinal movement of the joint, be mechanically stable under the loads and load frequencies expected during the design period, and should be resistant to corrosion from moisture and road salts.

Materials used in the design of shoulders can be either flexible or rigid. Differences in material types and the subbase combined with unexpected wheel loads along the pavement edge can cause joint problems. With proper care and attention, this potential problem can be minimized. Solutions include widening the full depth pavement slab, using tied concrete shoulders, properly sealing the joint, and ensuring compatibility between subbase materials.

9.3.6 TEMPERATURE CHANGES

Temperature changes affect (1) the creep properties of asphalt concrete, (2) thermal-induce stresses in asphalt concrete, (3) contraction and expansion in Portland cement concrete, and (4) freezing and thawing of the roadbed soil. Temperature differences between the top and bottom of concrete slabs create uneven stresses on the slab and can be of concern. Temperature and a poorly drained pavement structure or subgrade, although normally not a concern in Delaware, can combine to create freeze-thaw cycles that rapidly deteriorate the pavement.

9.3.7 DRAINAGE

Keeping the pavement subgrade and soilbed dry is a major design consideration. Excessive moisture combined with increasing traffic and load applications will inevitably lead to premature pavement distress. Water can enter the pavement structure from many directions including a permeable pavement surface, unsealed or poorly sealed joints, surface cracks, high water tables, and even local springs. If water is trapped within the pavement structure, pavement performance will be affected through loss of support due to erosion of any granular material and loss of material strength.

Addressing the problem areas that allow water to enter the pavement structure is difficult to prevent and expensive to correct. In fact it is a shared responsibility. The pavement designer should recommend pavement designs that use dense non-permeable surface courses to reduce surface infiltration, specify underlying material courses that freely drain, and a pavement structure that is strong enough to resist the effects of the traffic loads and water. The roadway designer must ensure proper pavement crown, drainable grade lines, proper ditching and other adequate drainage systems to remove water quickly.

9.3.8 RELIABILITY

Reliability is a method to determine the probability that a particular pavement design will perform as desired during its design life. In selecting the appropriate level of reliability, the pavement designer relates the projected level of usage to the risks involved if a thinner pavement section is recommended.

For facilities with higher importance to the transportation system a pavement design considers the traffic disruption caused by closing or restricting traffic flow due to higher levels of distress, maintenance, and rehabilitation associated with an inadequate or a marginal initial

pavement structure. For lesser facilities, it may be perfectly acceptable and even economical to use a reduced thickness.

9.3.9 LIFE-CYCLE COSTS

Life-cycle costs are costs and benefits that accrue during a pavement's complete life cycle. These costs include the initial construction costs, maintenance costs, rehabilitation costs, resurfacing costs, maintenance of traffic costs, salvage or residual value and user costs.

As a part of the pavement selection decision, particularly when more than one pavement design or rehabilitation procedure is proposed, an economic comparison may be needed. Two methods are detailed in the ASSHTO Guide to determine life cycle cost comparisons, net present worth and equivalent uniform annual cost. Whichever method is used, it is essential that the analysis periods be of equal length.

9.3.10 SHOULDER DESIGN

The inclusion of a shoulder adjacent to the main pavement structure improves pavement performance. The AASHTO guide does not provide a design method for determining the shoulder section. The M&R Section recommends a shoulder section that is compatible with the proposed mainline pavement section, has good constructibility and has performed well in the past. Shoulders are usually designed to carry 10 percent of the projected Average Daily Traffic (ADT).

9.4 DESIGN FOR NEW CONSTRUCTION OR RECONSTRUCTION

Constructing a pavement section is one of the most costly items on new construction and reconstruction projects. In making a selection on the type of pavement to construct it is usually necessary to analyze alternate pavement types and combinations of various support materials. In performing the analyses, the AASHTO procedure requires the pavement designer to provide input in several categories:

- Design variables,
- Performance criteria,
- Material properties for structural design,
- Structural characteristics, and
- Reinforcement variables.

9.4.1 DESIGN VARIABLES

A set of design criteria is established for each project including the pavement's expected service life (performance period) and projected design life (replacement). The traffic projection for the cumulative expected 18-kip [80 kN] equivalent single axle loads (ESAL) during the analysis is determined. The level of reliability is selected and any detrimental environmental factors identified. There is a heirachy of application of these variables with the most important roadways assigned the most stringent and detrimental values to a pavement's performance.

9.4.2 PERFORMANCE CRITERIA

Performance of a pavement is measured by its serviceability to the expected users. The concept is to design a pavement, which at the end of the proposed performance period will still have a predefined minimum level of serviceability (PSI). The terminal level of serviceability is selected based on the lowest index the user will tolerate, or as defined in a pavement management strategy before rehabilitation, resurfacing or reconstruction becomes necessary. DelDOT typically uses a terminal PSI of 2.5 or 3.0, which varies based on functional classification and use.

9.4.3 MATERIAL PROPERTIES FOR STRUCTURAL DESIGN

For the design of flexible pavements, roadbed materials are characterized based on their effective elasticity or resilient modulus, M_R. Their

resilient modulus is determined for periods of stress and moisture conditions simulated for the primary moisture season.

For rigid pavement designs, an effective modulus of subgrade reaction (k-value) is developed. The k-value is directly proportional to roadbed soil resilient modulus. However, the effective design k-value is also dependent upon the effects of the characteristics of the subbase.

Another important input is the compressive strength of the materials composing the pavement structure. In the design of rigid pavements, the modulus of rupture (flexural strength) is determined using the mean value as tested at 28 days. This value is specified in the Standard Specifications and verified as being consistently met or exceeded through laboratory records.

In flexible pavement design, the layer coefficient method is used. Each structural layer is assigned a layer coefficient value which is the relationship between the Structural Number (SN) and thickness of the layer. (See Section 9.5.5.) It is an empirical means to represent the relative ability of the material to function as a structural component of the pavement.

9.4.4 PAVEMENT STRUCTURAL CHARACTERISTICS

Drainage is an important element in the ultimate performance of all pavements. The designer assigns a factor that represents the expected quality of a project's drainage system to minimize moisture intrusion into the pavement structure.

For flexible pavements, the layer coefficients are modified to reflect the expected quality of drainage and percent of time during the year the pavement structure would normally be exposed to moisture levels approaching saturation.

For rigid pavement design, the level of drainage is addressed through the use of a drainage coefficient. This coefficient represents the quality and effectiveness of drainage systems and the percent of time during the year the pavement structure would be subjected to moisture levels approaching saturation.

For rigid pavements, another structural factor used is its load transfer ability. Rigid pavements have the ability to distribute loads across discontinuities, such as joints or cracks and small voids under the slab. Load transfer devices, aggregate interlock, and the presence of tied longitudinal joints and concrete shoulders influence this value.

Another structural factor applied to rigid pavement designs is a loss of support value. This factor accounts for the potential loss of support arising from subbase erosion and/or differential vertical movement.

9.4.5 REINFORCEMENT VARIABLES

Rigid pavements may be reinforced with joints, unreinforced with joints or continuously reinforced with no joints. The steel reinforcement is used to control transverse cracking.

Joint spacing is particularly important in the performance of plain jointed pavement. The spacing is usually much closer than in reinforced pavements to control cracks due to temperature and moisture enduced stresses. The slab spacing selected must also minimize joint movement thus protecting the aggregate interlock value of the joint. DelDOT has a standard spacing of 20 feet [6 m] for 12 inch [305 mm] Portland cement concrete pavement. (See the Standard Construction Details.)

9.5 STRUCTURAL DESIGN FOR FLEXIBLE PAVEMENTS

A flexible pavement structure may consist of three layers, designated as a subbase course, a base course, and a surface course. A flexible pavement system distributes the load by particle-to-particle-contact by interlocking, friction, and cohesion through its thickness. The surface

course usually consists of a binder course and a surface course.

The concept of all pavement design procedures is to determine the required structural thickness based on the projected traffic loading. Using this as a basis, the most economical and constructable combination of materials is determined. For flexible pavements, this consists of determining the required thickness of the pavement's subbase, base, and surface courses.

9.5.1 SUBBASE COURSE

The subbase course is the portion of the flexible pavement structure between the subgrade and the base course. The subbase insulates the base and surface courses from frost penetration, provides a drainage medium, and a layer resistant to erosion and erosion of fine material into the subgrade. The subbase usually consists of a compacted layer of granular material, which may be either treated or untreated. Subbase materials are either a Soil Cement Base Course, Graded Aggregate Base Coarse or Borrow Type A.

This course has a less stringent specification requirement for strength, plasticity, and gradation. If roadbed materials are of high quality, the pavement design report may recommend that the subbase layer be omitted. If the roadbed materials are relatively poor quality, the design procedure will indicate that a substantial thickness of pavement is required. In this case, alternate designs are usually provided with and without the use of a subbase. The selection of an alternate may then be made on the basis of availability and relative costs of materials suitable for the base and subbase. By using less expensive materials in the lower layer of a flexible pavement structure, the use of a subbase course is often the most economical solution to construction of pavements over poor roadbeds.

9.5.2 BASE COURSE

The base course is the portion of the flexible pavement structure immediately beneath the surface course. The base course is the primary load-spreading layer. It has to be strong enough to withstand the shear stresses produced by the wheel loads, and be incompressible and rigid enough to distribute the load over the underlying materials.

Base course material typically consists of a Graded Aggregate Base Course or Bituminous Concrete Base Course. A graded aggregate base course may be crushed stone, crushed slag, crushed or uncrushed gravel and sand, or other combinations of these materials. These materials may also be used treated with suitable stabilizing admixtures such as Portland cement or asphalt. Base course specifications are generally more stringent than for subbase materials in requirements for strength, plasticity, and gradation.

9.5.3 SURFACE COURSE

The surface course of a flexible pavement consists of a wearing course and a binder course which are mixtures of mineral aggregates and bituminous materials, placed as the upper courses and usually constructed on a base course. In addition to providing a portion of the pavement structural support, the surface course must also be designed to resist the abrasive forces of traffic and weather. They are designed to be dense enough to minimize surface water penetrating the pavement. The proper aggregate selection will provide a non-polishing-skid-resistant surface, resist rutting and provide a smooth and uniform riding surface. The success of a surface course depends to a considerable degree on obtaining a laboratory mixture with the optimum gradation of aggregate and percent of bituminous binder. Open graded mixtures that provide good surface drainage and skid-resistance are available for use on high-speed, high-traffic facilities.

9.5.4 STRUCTURAL NUMBER (SN)

The structural number is an abstract number expressing the structural strength of pavement required for a given combination of the effective resilient modulus, M_R, of the roadbed soils, the total equivalent 18-kip [80 kN] single-axle loads (ESALS), the design serviceability loss, and the standard deviation and reliability factors. The AASHTO Guide provides a nomograph for determining this value. The required SN must be converted to an actual thickness of surfacing, base and subbase by means of appropriate layer coefficients representing the relative strength of the material to be used for each layer.

A design equation is used to solve for the total required SN for the entire pavement structure. By solving the equation with the effective resilient modulus value representative of the roadbed soil, an SN for the entire pavement structure is obtained represented by the general equation:

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

Where:

a_1, a_2, a_3 = layer coefficients representatives of surface, base, and subbase course, respectively;

D_1, D_2, D_3 = actual thickness, in inches [mm], of surface, base and subbase courses, respectively (Open-graded surface courses are excluded from this calculation.) and,

m_2, m_3 = drainage factors modifying base and subbase layer coefficients.

The nomograph allows the pavement designer to determine the SN and provides a means through assigning a reliability factor (R) to incorporate some degree of certainty into the validity of the design process. In addition, it allows for assigning a standard deviation factor, which accounts for the variance in the projected traffic capacities and their reliability.

The SN equation does not have a single solution since many combinations of layer thickness will satisfy the equation. However, the pavement designer must use past experience, consider cost effectiveness and construction and maintenance constraints in order to avoid an impractical design.

The design procedure allows for doing a life cycle cost analysis based upon planned rehabilitation. This allows the designer to analyze the tradeoffs between thickness designs of the initial pavement structure and any subsequent overlays.

The procedure allows for considering the adverse effects of changing environmental conditions. The objective is to perform an iterative process to determine when the combined serviceability loss due to traffic and environment reaches the terminal level.

9.5.5 LAYER COEFFICIENTS

The layer coefficient expresses the empirical relationship between the SN and thickness, and is a measure of the relative ability of the material to function as a structural component of the total pavement structure.

To design a flexible alternative, the structural number over the roadbed soil is computed. Then, the structural numbers for the subbase and the base layers are determined. Using the differences between these values, the maximum thickness of any layer can be computed.

The SN for any combination of courses is determined with the design equation, the layer coefficients and the proposed thickness of each course. Alternate designs can be prepared by varying the thickness. The computed SN should equal or exceed the required SN determined from the nomographs in the AASHTO Guide.

The layer coefficients per 1 in [25 mm] of material have been established for various types and classes of flexible pavement, base course, and subbase.

Figure 9-2
Layer Coefficients

Material Type	Layer Coefficient
Type C Surface Mix	0.40
Type B Binder Course	0.40
Bituminous Concrete Base Course	0.32
Soil Cement	0.20
Graded Aggregate Base Course	0.14
Select Borrow	0.08

9.5.6 MINIMUM LIFT THICKNESS

Although the equations allow for a great number of thickness variations, there are the practicalities of constructing and maintaining a facility, which must be considered. Depending upon the material being placed, there are minimum and maximum limits in the placement depth that are practical for the available equipment to compact and are economical.

Minimum lift thickness for hot-mix is recommended to be three times the nominal aggregate size in the mix. Figure 9-3 shows the practical maximum and minimum lift thickness (compacted) that are to be applied to the materials normally used in constructing a flexible pavement section.

9.5.7 TEMPORARY PAVEMENTS

It is not practical to attempt to follow the formalized AASHTO procedures for design of temporary pavements such as needed for detours during construction. Variations in speed and ease of placement as well as the anticipated required service life of the detour significantly affect the economic justification for the structural design.

When temporary pavements are needed designers should closely coordinate with the M&R Section in the development of a practical pavement design based on knowledge of local conditions and engineering judgment.

Figure 9-3
Lift Thickness

Type of Material	Minimum Lift Thickness	Maximum Lift Thickness
Type C Surface Mix (9.5 mm)	1-¼ inches [30 mm]	2 inches [50 mm]
Type B Binder/Base	2-¼ inches [60 mm]	3 inches [75 mm]
Bituminous Concrete Base Course	3 inches [75 mm]	6 inches [150 mm]
Graded Aggregate Base Course	4 inches [100 mm]	8 inches [200 mm]
Soil Cement	4 inches [100 mm]	6 inches [150 mm]
Select Borrow	4 inches [100 mm]	8 inches [200 mm]
Open Graded	1 inch [25 mm]	1 inch [25 mm]

9.6 DESIGN FOR RIGID PAVEMENTS

Rigid pavements consist of a Portland cement concrete slab on a subbase course. The design procedure consists of developing an effective modulus of subgrade reaction based on subbase treatment and thickness, determine the slab thickness, allowing for any stage construction, adjusting for adverse environmental conditions, determining type of joints, joint sealant, and the required reinforcement.

9.6.1 SUBBASE—EFFECTIVE MODULUS OF SUBGRADE REACTION

Before the slab thickness can be determined, it is necessary to determine the strength (modulus), of the material on which the slab will be supported. This is done by determining an effective modulus of subgrade reaction (k), of the soilbed and subbase.

The effective k-value is dependent upon several factors including the roadbed soil resilient modulus, the type of subbase, the thickness of subbase, the potential of loss of support due to erosion of the subgrade and in northern New Castle County whether there is rock underlying the proposed pavement.

The subbase used in a rigid pavement structure consists of one or more compacted layers of granular material, graded aggregate or a stabilized material such as bituminous concrete. This material is placed between the subgrade and the rigid pavement. The subbase provides several very important functions:

* Provides uniform, stable and permanent support,
* Increases the effective modulus of subgrade reaction (k),
* Prevents pumping of fine-grained soils at joints, cracks and edges of the pavement,
* Reduces cracking and faulting, and
* Provides a working platform for construction equipment, especially the paver.

9.6.2 PAVEMENT SLAB THICKNESS

After developing the effective k-value the process of selecting the optimum slab and subbase thickness can begin. Past experience, economics, equipment limitations, ease of construction, and other subjective factors influence the final recommended section(s).

The AASHTO Guide provides a nomograph which provides the slab thickness based on inputting the k-value, the estimated future traffic, the reliability factor to be achieved, the standard deviation, the design serviceability loss, the concrete elastic modulus, the concrete modulus of rupture, the load transfer coefficient, and the drainage coefficient.

9.6.3 JOINTS

Joints are a very important part in assuring a rigid pavement will perform as intended. They allow for the stresses created by the expansion and contraction of the concrete during curing and during seasonal temperature changes. They also are used to facilitate construction.

The Department's Standard Construction Details for Construction provide details for locating and constructing the required rigid pavement joints. The following is a general discussion on the need, use and treatment of joints.

9.6.3.1 JOINT TYPES

The three types of joints used in constructing a rigid pavement are expansion, contraction and construction. Expansion joints provide space for the pavement to expand, preventing buckling of the slabs.

Contraction or weakened plane (dummy) joints provide relief for the tensile stresses caused by the effects of temperature, moisture and friction. Without these joints to control cracking, the slabs would crack randomly.

Construction joints are required to facilitate construction. Although used at the end of a day's pour, they are particularly dictated by the width of the paving machine and the pavement thickness.

Joints may be developed by sawing, forming, or with inserts. When sawing joints, timing is very important to prevent uncontrolled cracking and will vary during the day depending upon the slab temperature, curing conditions, and the concrete mix.

9.6.3.2 JOINT GEOMETRY

Joint geometry refers to the spacing and layout of the joints.

Transverse and longitudinal contraction joint spacing is dependent upon local conditions of materials (coarse aggregate type) and the environment, whereas expansion and construction joints are dependent on layout and construction methods.

Contraction joints are spaced to prevent intermediate natural cracking due to thermal changes and subbase friction created by the movement of the slabs. The type of joint sealant and slab thickness affects their spacing.

Expansion joints are usually used at structures and where pavement types change. They are expensive, complex to construct, and have not performed well in the past. Therefore, they are used only where absolutely necessary.

The spacing of construction joints is a function of the daily construction activities and equipment. They are used when equipment breaks down and at the end of the day's pour. Longitudinal construction joints are placed at lane edges to maximize pavement smoothness and minimize load transfer problems

The width of the joint is a function of the slab length, movement due to opening and closing by temperature cycles and concrete shrinkage. More movement expected at the joint affects the quality and cost of the joint sealant used.

The depth of a joint is selected to ensure that the slab will crack where intended.

9.6.4 REINFORCEMENT DESIGN

Concrete pavements inherently crack. Depending upon the slab length and depth selected, it may be necessary to provide steel reinforcement within the pavement slab. The purpose of the reinforcement is not to prevent cracking but to control the crack width. Excessive cracking allows for moisture intrusion into the subgrade which is the leading cause for distress in the slab.

Stresses leading to cracking are temperature and moisture related contraction of the slab. These stresses are resisted by the subbase as friction and shear between it and the slab. The result is tensile stresses that are minimum at the mid-point of the slab. To resist these stresses and limit the crack width, reinforcement is installed. The AASHTO Guide provides methods for designing the necessary reinforcement for both jointed reinforced concrete pavement and continuously reinforced concrete pavements.

9.7 PAVEMENT DESIGN FOR REHABILITATION OF EXISTING PAVEMENTS

9.7.1 REHABILITATION CONCEPTS

Bituminous concrete pavements deteriorate because of climatic conditions, age, and traffic. Transverse and longitudinal shrinkage stresses occur due to temperature changes. Over time, material problems can develop causing surface problems with stripping, raveling, weathering and bleeding of the asphalt. Repeated traffic loadings eventually cause fatigue cracking allowing moisture into the subbase causing loss of subgrade support leading to pavement cracking or failure.

For composite pavements with both concrete and asphalt as components of the pavement structure, the most prominent problem is reflective cracking from joints and cracks in the concrete base. This is caused by a combination of underlying slab movement due to temperature changes and heavy loads crossing the joints and cracks. The primary resulting distress is spalling of the asphalt as well of the concrete if severe enough.

Concrete pavements react differently depending whether or not they are reinforced. Over time and load applications each reacts different-

ly. The only reinforcement in non-reinforced pavements is tie bars across the longitudinal joints to keep the slab from separating and dowels at the transverse joints to transfer loads across the joints. If dowels are not used, the design depends only upon aggregate interlock to transfer these loads. With loss of subgrade support, cracking of the slab can occur at almost any location. However, more common problems occur at joints. Once the joints are no longer free to move, spalling, buckling, and random slab cracking can result. If joint sealant is lost, aggregate interlock is lost, or cracks become too wide, pumping of the subgrade within the travel lane and the shoulder can occur. This leads to erosion of support material and faulting and cracking

Reinforced concrete pavements perform much like non-reinforced pavements. They usually have longer joint spacing and internal reinforcement to resist the larger tensile stresses. There are fewer joints to relieve stresses; when their free movement is restricted, rapid faulting of the pavement can occur. In addition, normal shrinkage, thermal curl, and load applications cause cracks in the slab that over time grow in width, allowing moisture and road salt to infiltrate. Corrosion of the reinforcing mesh occurs. As the loads are repeated, pumping begins leading to faulting and spalling of the pavement.

Continuously reinforced concrete pavements deteriorate under heavy truck loading and are also adversely affect by moisture under the slab. This type of pavement is more complicated to construct and deterioration will occur due to inadequate consolidation, poor vertical steel placement, and inadequate steel overlap.

Because of the need to maintain the pavement systems now in place, several rehabilitation strategies have been developed to address the various problems that may affect a pavement's performance. The objective is to extend the pavement’s service life. The alternative methods of rehabilitating a pavement range from a simple overlay to complete removal and replacement. When developing a rehabilitation strategy a combination of the following alternatives are considered:

1. Resurfacing to provide structural capacity and/or serviceability either using concrete or asphalt,
2. Replacing or restoring malfunctioning joints,
3. Pavement subsealing prior to resurfacing or as a part of concrete restoration,
4. Grinding rigid pavements to restore smoothness.
5. Removing and replacing deteriorated materials,
6. Reworking or strengthening bases and subases,
7. Recycling existing material,
8. Improving the subdrainage or adding underdrains,
9. Joint and crack sealing,
10. Full depth pavement repair,
11. Partial depth pavement repair, and
12. Cracking and seating.

M&R and other team members develop the most effective strategy through a detailed pavement evaluation. This evaluation is normally prepared as a part of the Department’s long term pavement rehabilitation program and will be a part of the project initiation data. The three steps for determining the preferred strategy are to (1) determine the cause of the pavement distress, (2) develop a list of possible solutions that cure and hopefully prevent reoccurrence, and (3) recommend the preferred solution. The preferred solution includes an analysis of funding, traffic control problems, minimum desirable service life, utility conflicts, clearances to overhead structures, available materials and equipment, contructibility, future maintenance and reliability based on past performance.

9.7.2 TYPES OF DISTRESS

Although furnished at the project initiation stage, each project usually will have a project scoping meeting and preliminary field review prior to beginning detailed design. The field review will include checking the pavement for condition and any damage that may have occurred since the last pavement survey to confirm the proposed strategy is still valid. The following discussion is a brief description of the various conditions the designer may observe depending upon the type of pavement being evaluated.

9.7.2.1 ASPHALT PAVEMENTS

Asphalt pavements usually have the following major distress conditions: (1) alligator or fatigue cracking, (2) longitudinal and transverse cracking, (3) depressions, and (4) rutting.

Alligator or fatigue cracking is caused by repeated traffic loadings. They are a series of interconnecting cracks caused by fatigue failure of the bituminous concrete surface. The crack starts at the bottom of the asphalt surface or the stabilized base due to high tensile stresses and propagates to the surface as a longitudinal crack. After repeated load applications, a network of these cracks form that look like chicken wire or the skin of an alligator. This type of cracking does not occur in asphalt overlays over concrete—only in high load areas and is considered a major structural distress. Pattern cracking not in high load areas is called block cracking.

Longitudinal cracks are parallel to the pavement's centerline or paving laydown direction. They may be caused by: (1) a poorly constructed paving lane joint; (2) shrinkage of the bituminous concrete surface due to low temperatures or hardening of the asphalt; or (3) a reflective crack caused by cracks beneath the surface course, including cracks in Portland cement concrete. Transverse cracks are perpendicular to the pavement's centerline; they are caused by (2) or (3) above and are not usually load-related.

Depressions are localized pavement surface areas that are slightly lower than the surrounding pavement. Depressions are most noticeable during and after a rain. If deep and large enough, depressions may cause hydroplaning or an unpleasant ride. Depressions may be initially built into the pavement by the paving operation or as a result of settling of the surface support structure.

Rutting is a surface depression in the wheel paths. Usually, there is uplift along the sides of rutted areas. Rutting is the result of permanent consolidation or lateral movement of any of the pavement layers or subgrade due to traffic loads. Rutting may also occur because of plastic movement of the asphalt due to high temperatures, poor design mix or inadequate compaction during construction.

In addition to the major distresses, the pavement survey may indicate surface corrugation areas, joint reflection cracking, lane and shoulder drop off, lane and shoulder separation, patch deterioration, polished aggregate, potholes, raveling, and weathering.

If necessary, the M&R Section may determine that field observations are not adequate or need to be supplemented to identify underlying problems. In that case nondestructive testing (NDT) will be conducted. NDT is used to:

- Evaluate the in-situ (in-place) structural capacity of the pavement,
- Evaluate the capacity of joint and load transfer, and
- Detect the presence of voids under the pavement.

9.7.2.2 CONCRETE PAVEMENTS

Jointed concrete pavement may have the following distresses: (1) pumping, (2) longitudinal cracking, (3) spalling of transverse or longitudinal joints, or (4) Alkali-Silica-Reactivity (ASR).

Pumping is the ejection of material through joints or cracks, caused by the deflection of the slab under moving traffic. In some poorly drained pavements particularly in superelevated sections, water may bleed through the joints and cracks after a rain or continuously if large amounts of water are present.

Longitudinal cracks are caused by a combination of heavy load repetition, locking of load transfer devices, thermal and moisture stresses, and curing shrinkage stresses. Cracks that are spalling and/or faulting are considered a major structural problem.

Spalling of cracks and joints is the cracking, breaking or chipping of the slab edges within 2 ft (0.6 m) of the joint or crack. Spalling usually does not extend the full depth of the slab, but intersects the joint or crack at an angle. Spalling is a result of one or a combination of the following: (1) excessive stresses at poorly sealed or cleaned joints and cracks which allow incompressible material to accumulate preventing the pavement from expanding, (2) disintegration of the concrete, (3) weak concrete overstressed by repeated loading, and (4) a poorly designed or placed load transfer device.

Continuously reinforced concrete pavements usually show punchout and patch distress. Punchout is the loss of aggregate interlock between closely spaced cracks. The cracks fault, spall and under load applications the steel reinforcement ruptures causing concrete pieces to punch down. This type of distress is considered a major structural problem. Due to the difficulty in patching continuously reinforced pavements the failure of previously constructed patches can be anticipated.

ASR is another type of distress commonly found in Delaware. The pavements exhibiting the most severe ASR were generally constructed in the 1980's. ASR is the reaction between the alkalis (sodium and potassium) in Portland cement and certain siliceous aggregates. The product of this reaction is a thermodynamically metastable. The gel in the presence of water absorbs it, and causes expansion and cracking of the concrete. Once an ASR pavement has been identified, one possible solution is to apply lithium treatments. Lithium treatment will not repair the concrete, but will slow the further progression of ASR. Normally the pavement will have to be removed and replaced. Overlaying ASR concrete with a standard hot-mix overlay may trap moisture in the slab and accelerate the ASR causing premature failure of the overlay. However, hot-mix overlays with water proofing properties may minimize further deterioration for several years. M&R will recommend the most suitable solution when encountering ASR pavements.

In addition, other pavement distresses that may be observed in a field review are blow ups, corner cracks, depressions, durability "D" cracking, lane and shoulder drop-offs, lane and shoulder separation, patch deterioration, popouts, and staining of the pavement due to subgrade drainage problems.

Concrete pavements can also display roughness caused by irregularities in the pavement surface that adversely affect the ride quality, safety, and vehicle maintenance costs. Roughness is measurable based on the multi-frequency of waves, wavelengths and amplitudes. Roughness can be built into the pavement when constructed or develop over time due to traffic, climate, and other factors. Equipment is used to measure the roughness and a profile developed showing the vertical movement between the trailer axle and body. The results are reported in in/mile or m/km for the International Roughness Index (IRI). The roughness survey identifies areas where severe roughness exists and needs correction. Data provided can be used in developing a PSI which estimates the user's subjective assessment of the pavement condition. Surveys taken before and after a project can be used to document the benefits of the work to the traveling public.

9.7.3 DRAINAGE SURVEY

As emphasized throughout this chapter, the presence of moisture is a primary cause of distress or failure of all pavements. Therefore, a drainage survey is an important component of pavement evaluation. Moisture conditions are caused externally by the climatic conditions and internally by the properties of the materials composing the pavement structure. The severity of damage caused by excessive moisture will influence the decision on which rehabilitation strategy to select.

Since moisture problems can exist in any layer of the pavement structure, more than visual observations may be needed. Cores and even nondestructive deflection testing may have to be conducted. It is necessary to determine which material is responsible for the moisture-related damage and if an economical rehabilitation to correct the problem is to be initiated. Not identifying and correcting the problem could lead to a failed project. A valuable tool in this evaluation is the as-built plans.

In addition to determining if the pavement structure is freely draining and moisture resistant, the entire roadway section should be evaluated including:

1. Are the ditchlines free of standing water? If not, how high does it stand and will it infiltrate the pavement structure?
2. Are ditchlines and pavement edges clear of the type of growth that would indicate excessive moisture?
3. After a rain, is water standing in the joints or cracks. Is there pumping, is there standing water adjacent to the pavement or on the shoulder?
4. If there are drainage outlets including underdrains, are the outlets clear, at the proper elevation, and working?
5. Are drainage inlets clear and cross slopes adequate to remove the water from the pavement surface?
6. Are joint and crack sealants in good condition and preventing surface water infiltration?
7. Are there signs of pumping, such as pavement discoloration or the presence of fine material at joints or pavement edges?

Recommending drainage improvements to the pavement structure can be a very expensive item and should be carefully evaluated and documented.

9.7.4 RESTORATION

Restoration of a pavement includes the work required to return the pavement's level of serviceability for a designated time period. Frequently, some level of restoration is performed prior to an overlay or resurfacing. Work undertaken to restore pavements is quite varied and includes:

- Full-depth repair of jointed concrete pavement
- Full-depth repair of continuously reinforced concrete pavement,
- Patching with bituminous mixtures,
- Partial-depth spall repair,
- Slab stabilization and slab jacking,
- Diamond Grinding, grooving and cold milling,
- Pressure relief joints,
- Load transfer restoration,
- Joint and crack sealing,
- Surface treatments,
- Subdrainage, and
- Shoulder improvements.

9.7.4.1 FULL-DEPTH REPAIR

One of the most expensive restoration alternatives used on all types of pavements is full-depth repair. To limit the repair areas and the

potential of overruns, the specific distress or distresses to be addressed should be clearly established both during the design and construction phases. Depending upon the severity, distresses that may lend themselves to full-depth repair are blow-ups, corner breaks, durability "D" cracking, ASR, excessive spalling, and loss of load transfer. Intermediate working cracks may also have to be repaired by full-depth replacement or a working joint. Not addressing areas that need full-depth repair prior to an overlay could result in continued deterioration and premature failure of the overlay.

The major considerations to ensure satisfactory performance using this rehabilitation approach are:

1. Joint design,
2. Selection of the repair areas and their boundaries,
3. Preparation of the repair area,
4. Placement and finishing of the repair material,
5. Joint sealing material and its installation, and
6. Curing time and traffic control.

Usually the full-depth repair material is the same as the adjacent pavement. However, funding, traffic control or other reasons may require that concrete pavement be repaired with bituminous material. Using materials of different physical properties and characteristics can cause several problems. Differentials in expansion and contraction lead to pushing, shoving and humping requiring frequent milling to maintain rideability. The bituminous patch is more compressible and may allow excessive opening of remaining joints in the concrete pavement resulting in spalling, pumping, and faulting. In overlaying the patched pavement, there may be an increase in reflective cracking from the underlying joints The patch design may not have an equivalent structural strength. The difference in initial cost and possible future maintenance problems may not make using dissimilar materials the best solution.

9.7.4.2 PARTIAL-DEPTH REPAIR

Some distresses within the upper third of the slab in concrete pavements lend themselves to partial-depth repairs. Partial-depth repairs may or may not be more cost effective than full-depth depending upon the size, location, number, materials used, lane closure time and production limitations.

The distresses applicable to partial-depth repair are:

1. Spalls due the use of certain types of joint inserts,
2. Spalls caused by joint movement locking due to failed sealant and subsequent intrusion of incompressible material,
3. Spalls caused by misplaced dowels or other load transfer devices, and
4. Localized areas of scaling.

The M&R Section should be contacted for details on partial-depth patches as they require the use of better designs and construction techniques to be successful.

9.7.4.3 SLAB STABILIZATION AND SLAB JACKING

Although not that frequently used, voids under pavements can be filled, restoring the support strength of the pavement structure. The loss of support is caused by erosion of the subbase and/or subgrade by pumping or, in severe cases, movement of freely flowing water. Slab stabilization does not increase a pavement's structural strength, correct depressions or faulting and other distresses.

A slab that has settled may be raised through a process called slab jacking, also known as mudjacking. This procedure which injects water-soil-cement slurry (i.e. grout or mud) through holes drilled into the pavement slab under high pressure lifting the pavement back into its origi-

nal profile is also used infrequently. A process using expanding polyurethane foam may also be used. Another alternative is the injection of a flowable fill that consists of a mixture of fly ash and water that expands and hardens as it dries out. If not correctly done, all three of these methods can crack the slab.

9.7.4.4 DIAMOND GRINDING, GROOVING AND PAVEMENT MILLING

Diamond grinding is used to restore a concrete pavement's smoothness using closely spaced diamond-impregnated blades. Diamond grinding is effective in: (1) removing joint and crack faulting, (2) remove wheel path ruts, (3) correct joint unevenness caused by slab warpage, (4) removing areas of roughness and (5) restoring transverse drainage. Diamond grinding does not correct the problem that created the distress and may have to be use in conjunction with other rehabilitation techniques. Subsealing, slabjacking, full-depth, and partial depth repairs should be completed before grinding.

Grooving of concrete pavements is used to reduce hydroplaning by improving surface drainage and improving surface friction on curves or polished aggregate surfaces.

Pavement milling is used to remove asphalt surfaces as much as 3 to 4 inches [75 to 100 mm] in depth using carbide-cutting teeth mounted on a rotary drum. If used on concrete pavements, pavement milling leaves an extremely rough surface and spalled joints. Therefore, unless an overlay is included in the work, it should not be used on concrete.

Pavement milling is a very effective rehabilitation technique addressing several problems including:

1. Restoring the curb line of asphalt pavements,
2. Restoring cross slope and correcting inlet drainage problems,
3. Improving the friction resistance of asphalt pavements,
4. Removing asphalt overlays on concrete pavements,
5. Providing a good bonding surface on concrete for overlaying,
6. Removing material as part of a recycling project, and
7. Restoring pavement smoothness.

All three of these restoration techniques are cost effective, relatively quick and proven to perform well but do not improve the structural integrity of the pavement.

9.7.4.5 PRESSURE RELIEF JOINTS

As concrete pavement ages, there can be a net increase in its length. These increases can result from: poorly sealed joints and cracks filled with incompressible material, pumping of the base material into the joints and cracks, or the use of expansive or reactive aggregates in the initial mix.

Because pressure relief joints can adversely affect contraction joints, they are not usually installed unless there are major blow-up problems or the pavement has expanded to the point of shoving bridge abutments. These type of joints provide no load transfer and are also subject to closing through the intrusion of incompressibles, eventually becoming part of a pavement distress problem.

Pressure relief joints are full-depth and full-width saw cuts at mid-slab and are 2 to 4 inches [50 to 100 mm] in width. The joint must be cut across all lanes within the same time period to relieve the compressive stresses and is usually done at night under reduced traffic flow.

9.7.4.6 LOAD TRANSFER RESTORATION

Poor load transfer between joints can cause spalling, rocking, pumping, faulting, and corner breaks. Doweled joints are effective in providing

load transfer but under repeated load applications can work loose and lose this capability.

Whether or not joints and cracks have lost their load transfer ability, is determined through field observation and measurements conducted in the cooler parts of the year or day. The Falling Weight Deflectomator (FWD) may be used to test for load transfer capability at joints.

There are two techniques used to restore load transfer, both of which require the installation of dowels. Slots can be cut in the pavement, if the adjacent pavement is sound, and the dowels installed. More frequently and, usually a better alternative, load transfer is restored through full-depth repair.

9.7.4.7 JOINT AND CRACK SEALING

One of the easiest, cost effective and proven techniques in maintaining serviceability and restoring concrete and asphalt pavements is sealing and resealing joints and cracks. Inadequate or failed sealant allows free water and incompressibles to enter the pavement structure causing erosion of pavement support and blow-ups.

Joint sealants are constantly being improved and may be field poured—self-leveling, hot-poured, cold-poured, preformed compression seals, or field-poured—nonself-leveling sealants.

The performance of a sealant depends primarily upon the proper preparation of the joint to receive the sealant. The factors include the shape of the reservoir created for the sealant, the bonding ability of the sealant to the sidewalls, the surface preparation, the cleanliness of the surface, the dryness of the surface and the properties of the sealant. In addition, it is necessary to predict the amount of movement expected in the crack or joint to customize the type of sealant to fit the distresses encountered and techniques to be implemented.

Cracks occur randomly and are irregular in dimension and direction. Usually cracks do not experience the faulting and movement that happen at joints and sealing is not as tightly controlled. If the field survey indicates the width of cracks are large enough to cause large movements, then the cracks are sealed and treated similar to joints.

9.7.4.8 SURFACE TREATMENTS

The use of surface treatments or seal coats is a very effective way to rehabilitate. The technique is to apply asphalt and/or aggregate to a roadway surface at a depth of less than 1 inch [25 mm].

Surface treatments are classified by their composition and include:

Asphalt Chip Seal (Surface Treatment)—one or more applications of asphalt and stone chips.

Open-Graded Friction Course— the asphalt and aggregate mix is designed to be freely flowing to remove surface water thus reducing hydroplaning. In addition, it provides some improvement in skid resistance.

Micro Surfacing—a process using a moving pug mill which mixes latex rubber with an asphalt emulsion, aggregates and other additives that is placed on the surface.

Slurry Seal—a diluted emulsion mixed with a sand-size aggregate in a special mixer, and squeegeed onto the pavement. The thickness is usually less than one half inch [12 mm].

9.7.4.9 SUBDRAINAGE IMPROVEMENTS

The long-term presence of water within the pavement structure is largely responsible, directly and indirectly, for many of the distress and performance problems, which are found in the pavement systems. A pavement survey and evaluation includes a very detailed study of the drainage and subdrainage within the entire roadway cross section. Considerable design effort and cost are involved when correcting this

type of problem. Unless the rehabilitation program involves complete pavement reconstruction, improvements are limited to design and construction of longitudinal drains. Any modifications to or additions of transverse drains or drainage blankets would be limited to projects involving complete pavement replacement. However, the addition of longitudinal perforated underdrains to collect and outlet excess moisture in the pavement structure is a feasible and cost effective option.

9.7.4.10 SHOULDER IMPROVEMENTS

Shoulders are evaluated much like the mainline pavement and are include in the distress survey, drainage survey, traffic survey, structural evaluation, and subgrade and materials evaluation. Shoulders provide not only safer traffic flow but also give lateral support for the mainline pavement structure.

Shoulders can be rigid or flexible and distress similar to mainline pavements. Many of the same rehabilitation techniques are used. Reviewing the existing cross section can be very valuable. If the initial shoulder pavement design was not compatible with the mainline pavement structure, it may be a major contributor to its failure.

Two of the most common problems which occur are lane/shoulder joint separation which allows water into the subbase, and blockage of water draining out of the mainline subbase which is usually of more granular and higher quality. The material used in shoulder construction also may be of a different thickness. All of these affect the interaction between the two pavement structures.

Other distresses found in shoulders are pumping, fatigue cracking, lane/shoulder drop-off, frost heaving and differential shoulder support.

9.7.5 RECYCLING

Recycling is the term used to describe the process, which uses existing pavement materials to construct new pavements. The primary purpose is to conserve natural resources. In some cases, there may also be a net cost savings.

9.7.5.1 RECYCLING RIGID PAVEMENTS

Eventually, all pavements reach the end of their useful and/or structural life and must be reconstructed. This occurs when there is little or no structural life left due to extensive cracking, extensive slab settlement or heave, extensive joint deterioration requiring excessive full-depth repair, extensive concrete deterioration due to poor durability, and failure to meet geometric design standards.

Two methods of recycling are: to break the pavement slabs into smaller sections and leave them in place (rubblizing) as a base for resurfacing; or to break and remove the pavement slabs to an area for crushing and reuse. The crushed pavement material may be reused as aggregate in untreated dense graded aggregate bases for Portland cement concrete surfacing, asphalt concrete surfacing, fill, filter material, and as a drainage layer for edge drains.

Each method of recycling has its own cost and feasibility studies that need to be conducted before making a selection. Both methods involve the use of vibratory, hydraulic, pneumatic, or diesel chisels or hammers to demolish the existing pavement. Common factors to consider are: is the resulting recycled material actually reusable; are the underlying soils adequate to support an upgraded pavement; and are there shallow utilities (older gas, water or sewer lines such as vitrified clay or cast iron) that are sensitive to the equipment pounding and vibration and may rupture during the demolishing process.

The pavement may be demolished, removed, crushed and used for other construction purposes. This involves hauling the material to a crushing plant and having an electromagnet remove any reinforcement. The crushed material and salvaged steel would be available for reuse. The coarse-aggregate-sized particles resulting from the crushing process have a good shape and an-

gularity, high absorption and may have a lower specific gravity than virgin aggregates. For reuse of this material the concerns are the possible contaminants in the rubble including reinforcing steel, dowel bars and baskets, admixtures, chemical substances such as deicing salts, sea salt, oil, joint sealant material and soil.

9.7.5.1.1 RUBBLIZATION

Rubblization is initially the most expensive pavement recycling method, however, a selective use of it can be very effective in cost and construction time.

When rubblizing plain or reinforced concrete pavement, the rubble is leveled and left in place as the base for a new pavement. Maintaining traffic is a consideration as there must be enough area for the equipment to operate as well as a protective barrier. Even on a four lane facility this will require a median shoulder strong enough to temporarily carry full traffic loads or possibly a detour.

The rubblized surface essentially remains at the same elevation as the existing pavement. Therefore, matching existing curbs, drainage structures, intersecting roadways, and driveways is more complicated and time consuming. In addition, it may become difficult to meet height standards for guardrail and other appurtenances, as well as maintain vertical clearances for structures.

Rubblization is for total reconstruction. Rubblization reduces the structural value of a PCC pavement to a stone base. It requires a thick overlay, typically 11 inches [280 mm] of asphalt or 10 to 12 inches [255 to 305 mm] of concrete. It is a major reconstruction technique and therefore it should be used only when the pavement has reached the end if its service life, as indicated by severe deterioration, ASR, or severe freeze and thaw damages, etc.

Rubblization can be used when other concrete pavement restoration methods will not work. Thoroughly evaluate the existing condition of PCC pavements. Concrete pavement restoration (CPR) techniques, such as diamond grinding, patching or sealing, should be ruled out before the use of rubblization is specified. Pavement Management and M&R should be consulted in the selection of reconstruction/restoration technique.

Rubblization cannot be used over a subgrade demonstrating widespread instability or of poor condition. Many concrete distresses result from poor subgrade support conditions. Rubblizing a pavement destroys the concrete slab's bridging action, causing problems to become more pronounced. The poor support condition could be due to poor soils, poor drainage or high moisture content. If the problem is widespread, rubblization cannot be used. Thorough subgrade investigation is essential for the successful application. Contact M&R for subgrade investigation.

Treat rubblized PCC pavement as a subbase. Although rubblization provides the benefits of an in-place recycle opportunity and an interlocked stone base, it has challenges as well. As for all subbase materials, gradation and density are two important factors, but the control of these two factors is more difficult since it is in-place recycling.

The pavement breaker may be powerful, but as energy dissipates through the depth of the slab, it produces smaller pieces at the top and larger pieces at the bottom. A soft subgrade or the reinforcement in the slab only compounds the difference in sizes. The recommended requirement is for the top pieces to be 3" maximum and 12" maximum at the bottom. Acceptance of a larger size will increase the probability of future reflective cracking. A good density is achieved through the interlocking and good compaction.

With good control of gradation and density, it is reasonable to expect a good fatigue resistance performance of an asphalt overlay, which is a major controlling factor for a flexible pavement service life.

Rubblization is a balancing act. The size of rubblized concrete can be controlled. A larger size will provide a stronger support (thus a better structural value), but it increases the likelihood of reflective cracking (thus a reduced service life). The designer needs to balance these two in the pavement design. A long term performance evaluation to validate this design value may be necessary.

Install a drainage system. An adequate subgrade drainage system is essential for rubblization and future performance of the pavement. Rubblization cannot be successfully done over a wet subgrade. The drainage system should be in place at least two weeks prior to the rubblization. In a special case, if the drainage system cannot be installed prior to actual rubblization, then a time limit should be specified to have the drainage system installed immediately following rubblization.

Use a test section, not a second pass of the breaker. A second pass over a rubblized area does not enhance the quality of rubblization, and it could cause more damage. Test sections should be done to calibrate all rubblization variables (machine related-velocity, frequency, pressure or force, shoe size and conditions related-concrete condition or state of distress, thickness and subgrade conditions). The objective is to achieve the required sizes of rubblization both at the top and bottom of the PCC pavement for a good service life.

Selection of Rubblization Equipments and Production Rates - Among the different types of equipment for breaking the pavement, two frequently used types are resonant pavement breakers (a low impact, low-amplitude, high frequency vibration to the slab) and multiple head breakers (12 to 16 drop hammers mounted laterally in pairs with half of the hammers in a forward row and the remainder diagonally offset in a rear row). The multi-head breaker rubblizes a full lane width in a single pass with a production rate of about one lane mile per shift per day, while a resonant breaker may take up to 20 passes for a full lane width with a production rate of about ½ miles per shift per day.

The multi-head breaker may cause damages to the subgrade. the resonant breaker may produce concrete size too small at the top to meet the design requirement. Unless the equipment selection is specified on the plan, the specification will allow the use of either breaker.

A concrete overlay can be used. Rubblization was developed to eliminate reflective cracks in the asphalt overlay. Engineers still have an option of using concrete overlay, considering cost, service and construction time. Consult M&R for pavement design options.

Soft spots need to be repaired. Original PCC pavement could bridge the soft spot and this soft spot will show up after rubblization. Any depression one inch or greater in depth from the immediate surrounding area should be examined to see if it is due to poor underlying subgrade before the application of filler aggregate as required by the specification. A bearing capacity failure during rubblization could cause depression on one area and heave in other areas.

The repair of soft spots is necessary not only for a long term performance of the pavement but also for a good working platform for paving operations.

Pavements with delamination type cracks should not be rubblized. Horizontal cracks hinder the rubblization process by absorbing energy and decreasing the effective depth of rubblization.

Survey and set a new profile. Although rubblization does not significantly change the existing grade, simply specifying a few inches over the existing grade may not be adequate. The existing PCC pavement may not have adequate cross slope, or it is distressed due to poor subgrade which might have resulted in an irregular profile. Comparing survey results with the original geometry could provide clues on distress or subgrade conditions.

The design service life should be 20 years or more; this should be noted on the plans. Rubblization with an overlay is major reconstruction. It should not be used as a short-term fix.

9.7.5.2 SURFACE RECYCLING OF BITUMINOUS PAVEMENTS

Surface recycling is the process that either reworks or removes and replaces a limited portion, usually about one inch [25 mm], of the asphalt surface. The distresses addressable through this process include: raveling, flushing or bleeding, low surface friction, weathering, poor drainage profile, shallow rutting, minor corrugations and block cracking. It may also be used to correct problems in the profile grade line.

The major advantage for selecting this rehabilitation method is the minimal amount of work involved. There are two processes. The first is hot surface recycling involving heating, scarifying, remixing, and repaving recycled material. Other surface recycling methods include hot pavement removal using a heater-planer or cold milling using a rotary drum equipped with closely spaced carbide teeth.

The material to be reused has a rejuvenating agent and soft asphalt added to restore the pavement consistency, viscosity or penetration. DelDOT does not typically use this method for recycling surface courses.

9.7.5.3 IN-PLACE RECYCLING OF BITUMINOUS PAVEMENTS

In-place recycling is a process in which the pavement surface is ripped up or pulverized to a depth greater than 1 inch [25 mm]. The material is cold worked and reused as an aggregate base. The recycled material may be further strengthened by the addition of admixtures such as asphalt, lime, cement or fly ash. The recycled material will perform similar to new stabilized material upgrading the structural capacity, correcting surface distresses and mixture problems in the asphalt pavement, and correcting base course problems such as gradation, moisture and density. Correction of profile grade problems can be made with this material.

9.7.5.4 HOT-MIX RECYCLING OF BITUMINOUS PAVEMENTS

Hot-mix recycling is the process in which all or some of the pavement structure is removed, reduced to the required size, and mixed hot with added asphalt cement at a central plant.

This process is used to correct surface roughness, cracking, rutting, surface friction, raveling, inadequate structure, and inadequate traffic capacity. It should be remembered that the underlying cause for structural inadequacy would not be corrected using this process.

9.7.6 RESURFACING

The most common type of rehabilitation for existing pavements is resurfacing. Resurfacing can correct many common distresses and add additional strength to the pavement structure.

Problems encountered with overlay projects include inadequate thickness to correct surface problems when the problem is actually structural, inadequate repair of the deteriorated areas, unanticipated increasing traffic loadings, and not addressing reflective cracking.

9.7.6.1 TYPES OF OVERLAYS AND THEIR FUNCTIONS

Overlays can be of asphalt or Portland cement concrete. There are several variations of these overlay techniques, which are designed for specific applications.

The most commonly used overlay is dense-graded, hot-mixed asphalt concrete, which may be used on existing asphalt or Portland cement concrete pavements.

Portland cement concrete overlays are designed specifically for the type of existing

pavement and may be unbonded, partially bonded or fully bonded.

In analyzing overlay alternatives, the designer should look at how extensive are the proposed pre-overlay repairs, structural adequacy of the existing pavement, subdrainage, existing distress conditions to be corrected, future traffic loadings, traffic control problems, clearances to overhead structures, and overall costs.

Asphalt overlays of rigid pavements are used both to correct surface problems and to improve the structural strength. Thicknesses greater than 2.5 inches [65 mm] are needed to provide improvements in strength. The greater the overlay thickness, the higher the possibility of rutting if compaction is not controlled but a significant reduction in reflective cracking can be expected.

Reflective cracking occurs in overlays due to thermal cracks in flexible pavements and joints in rigid pavements. Low temperatures, temperature cycles and traffic loads cause movement in the existing pavement leading to stresses reflecting through the overlay.

Another method to reduce reflective cracking in asphalt overlays of rigid pavements is to fracture the underlying slabs into pieces 2 to 3 feet [600 to 1000 mm] in size. After cracking the slab, a heavy roller is used to ensure the slabs are fully seated before the asphalt overlay is placed.

Reflective cracking leads to increased infiltration of water into the pavement structure that rapidly deteriorates the overlay. This creates potholes and other distresses. Treatments to minimize reflective cracking include the use of reinforcing fabrics, stress-relieving interlayers of rubber-asphalt with aggregate chips, crack-arresting interlayers of large aggregate bituminous material to blunt the cracks, and extensive pre-overlay repairs including determining existing joint and major crack locations, sealing them and saw cutting after paving.

Portland cement concrete overlays of existing rigid pavement may involve extensive pre-overlay repairs, are more difficult to construct and have added initial traffic control costs. These overlays may be fully bonded, partially bonded and unbonded.

Fully bonded concrete overlays require that the existing pavement be in good condition and that a complete and permanent bond be achieved. Fully bonded overlays are thinner and range from 2 to 4 inches [50 to 100 mm] in thickness.

Partially bonded concrete overlays require repair and/or replacement of damaged slabs. Surface cleaning by sweeping and either water blasting or sand blasting is necessary to achieve as much bond as possible. These overlays are usually between 5 to 7 inches [25 to 175 mm] in thickness.

Unbonded concrete overlays are used to improve the structural capacity of a rigid pavement in poor condition. A bond breaking and leveling course is placed between the existing pavement and overlay to assure there is no bonding and to absorb any movement in the base slab to prevent cracking of the overlay. Unbonded overlays are thicker and range from 8 to 10 inches [200 to 250 mm] in thickness.

All types of overlays normally require a fairly detailed design analysis. The analysis involves determining the initial construction and pavement information, a pavement distress survey, existing layer properties, future traffic analysis, existing pavement subgrade properties, overlay design properties, determining effective structural capacity, future overlay structural capacity, desired remaining service-life, and required overlay thickness design.