TOWN OF MONUMENT

PAVEMENT DESIGN AND CONSTRUCTION STANDARDS

Original Approved Date: Feb 2 2012
# PAVEMENT DESIGN AND CONSTRUCTION STANDARDS

## SPECIFICATION REVISIONS

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<tr>
<th>Section</th>
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<tr>
<td>Subsection 5</td>
<td>3/20/2012</td>
<td>Addition of Recycled Asphalt Pvmnt Option</td>
</tr>
<tr>
<td>All</td>
<td>10/8/2013</td>
<td>Format Update</td>
</tr>
<tr>
<td>Sub 5: 1-D-6</td>
<td>10/10/2013</td>
<td>Revision of Recycled Asphalt Pvmnt Option</td>
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# TOWN OF MONUMENT PAVEMENT DESIGN AND CONSTRUCTION STANDARDS

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SUBSECTION 1

GENERAL INFORMATION

1.1 Authority

The administration of these standards, including interpretation, enforcement, revision, and waiver, is hereby delegated to the Director of Development Services. These standards are comprised of written standards of engineering practice, materials specifications, construction procedures, and publications generally acceptable within the construction industry. Interpretation of any discrepancies between sections of the specifications shall be made by the Director of Development Services.

1.2 Effective Date of Standards

These specifications shall be effective from the date they are approved by the Board of Trustees. The date shall be noted on the title sheet of the specifications. It shall be the responsibility of the holders of these standards to determine that the set in their possession is the current edition.

1.3 Revisions, Amendments, or Additions

These standards may be administratively revised, amended, or added to from time to time, and such revisions, additions, or amendments shall be binding and in full force and effect as of the date of their adoption.
SUBSECTION 2

TOWN CODE CHAPTER 16.48
Chapter 16.48  PAVEMENT DESIGN, CONSTRUCTION, AND MATERIALS SPECIFICATIONS

16.48.010  Purpose and Intent

This chapter covers the design, testing, construction, and material specifications for asphalt and concrete pavement, base course, and subgrade for public and private roads and streets, and privately owned parking areas, within the Town of Monument municipal boundaries. The intent of this chapter is to provide guidance to the development community in the preparation of design drawings, and in the construction of paved areas frequented by vehicular and pedestrian traffic, both within public right-of-way and on private property.

Since residents and visitors all use private streets and parking areas with as much frequency as public streets and roads, it is in the best interests of the Town to establish design and construction standards for privately owned streets and parking areas.

16.48.020  Governing Standards

A. Design and Construction of Public and Private Streets and Roads

Except as otherwise approved by the Department of Development Services, or modified or supplemented in this chapter, design, materials, equipment, details, and construction methods for asphalt and concrete pavement, base course, and subgrade for public and private roads and streets shall comply with the Pavement Design Criteria Manual of the City of Colorado Springs Engineering Department Engineering Criteria Manual, as amended from time to time. The Pavement Design Criteria Manual also references the Pikes Peak Region Asphalt Specifications (Version 2) by the Colorado Asphalt Pavement Association (C.A.P.A), City of Colorado Springs, and El Paso County Department of Transportation (April 2008). Both of these documents are hereby incorporated into this chapter by reference, with “Development Services Department” replacing “City Engineering” and “Development Services Director” replacing “City Engineer” wherever mentioned in the Pavement Design Criteria Manual.

Additionally, the following revisions and substitutions are incorporated into the Pikes Peak Region Asphalt Specifications:

1. In Table 1.002.1 – Aggregate Properties, the Town reserves the right to require the percentage of coarse aggregate retained on a #4 sieve to be 35% maximum, dependent upon conditions particular to the site and/or project.
2. In Table 1.004.4 – Testing Responsibilities, for Capital Projects and Overlays, the Town reserves the right to hire its own independent AMRL approved testing laboratory for quality assurance. For all development projects, the Town will allow the developer to decide whether he wants to have the
contractor hire the testing laboratory, or hire his own laboratory. All laboratories must be AMRL approved.

3. In Section 1.004 Hot Mix Asphalt Pavement Construction, subsection N. Testing and Inspection, subsection 4. Testing Frequencies and Tolerances, a sentence is to be added to the end of subsection 4 which reads, “Penalties for test failures may be assessed by the Town, including but not limited to an extension of the pavement warranty for up to one year.

4. In Section 1.004 Hot Mix Asphalt Pavement Construction, subsection N. Testing and Inspection, subsection 5. Contractor’s Quality Control Program, subsection a. Testing Laboratory add “AMRL certified” as a requirement for the independent testing laboratory in the first sentence.

B. Design and Construction of Privately Owned Parking Areas

Technical specifications and requirements for the design and construction of privately owned parking areas are to be found in the Town of Monument Pavement Design and Construction Standards, which are hereby incorporated into this Code by reference.

C. Concrete Sidewalk

Refer to the Town of Monument Roadway Standards for specifications and requirements for concrete sidewalk pavement design, construction, and materials.

16.48.030 Porous Asphalt Pavement

A. Purpose

The Town will allow porous asphalt pavement, also referred to in the industry as an open-graded friction course, to be used on a case-by-case basis as a means of reducing the impact of paved surfaces on existing and proposed stormwater systems, and ultimately on streams, creeks, and other estuaries. Porous asphalt pavement has been shown to reduce ponding and standing water on pavement surfaces, resulting in a safer drainage surface during, and immediately after, rainstorms. It has also been determined to reduce the amount of sedimentation exiting a site due to its permeable nature, which results in improved water quality associated with runoff. Further, the reduction in size and, in some cases elimination, of stormwater detention basins, can have a beneficial effect on both the Town’s stormwater quality management efforts and on private development, since a potentially greater portion of a site can be used for improvements.

B. Evaluation Criteria

A private development site may be eligible for the use of porous asphalt pavement if the following conditions are present:
1. Permeability of existing (in situ) soils on the site is 0.50 inches per hour or greater based on a standard percolation test. This is required so that the porous system will infiltrate into the existing soil at an adequate rate to minimize runoff and ponding.

2. The proposed porous asphalt pavement area can be protected from heavy traffic during construction that could over-compact the area.

3. The existing soil is proven to be capable of sustaining normal vehicular traffic loads without being compacted to the density usually required for subgrades underneath parking lots and roadways.

4. The minimum depth to an impervious subsurface layer, or high water table, is two feet.

5. The bottom of the infiltration bed can be designed and constructed to be flat.

6. The maximum slope of the porous asphalt surface can be designed to be no greater than 5 percent.

7. Runoff from adjacent areas on site can be routed to the infiltration bed, with maximum ratio of impervious to pervious area being five to one (5:1).

C. General Design Criteria

1. The cross-section of the pavement infiltration bed, and subgrade should generally follow the guidelines in Figure 1 below:

   ![FIGURE 1](PAVEMENT SURFACE (MIN. SLOPE 2%)

<table>
<thead>
<tr>
<th>PAVEMENT SURFACE</th>
<th>(MIN. SLOPE 2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POROUS ASPHALT</td>
<td>4&quot; MIN. OPEN GRADED (16% VOIDS MINIMUM)</td>
</tr>
<tr>
<td>TOP COURSE</td>
<td>HOT MIX ASPHALT (HMA)</td>
</tr>
<tr>
<td>FILTER COURSE</td>
<td>2&quot; THICK LAYER OF ½-INCH CRUSHED STONE/AGGREGATE</td>
</tr>
<tr>
<td>RESERVOIR COURSE</td>
<td>8&quot;-9&quot; CRUSHED STONE (40% VOIDS)</td>
</tr>
</tbody>
</table>

   FILTER FABRIC ___________________________________________ FROST DEPTH

   UNCOMPACTED, UNDISTURBED SUBGRADE SOIL


   PAVEMENT DESIGN AND CONSTRUCTION STANDARDS
D. Construction of Porous Asphalt Pavement

Specific construction methods, materials specifications, and installation techniques are all contained in NAPA’s Information Series 131 publication.

E. Post-Construction and Maintenance Considerations

Since asphalt permeability is a key factor in the long-term effectiveness of porous asphalt pavement systems, it is imperative that a maintenance program be established by the owner of the property. This maintenance program shall be submitted to the Department of Development Services for review, and approval of the program shall be issued by the Department prior to release of a certificate of occupancy for the intended use. At a minimum, the program shall address:

1. Regular inspection intervals by the owner and the Town.
2. Inspections following large storms, major snowfalls, and other events that may result in clogging of the porous asphalt surfaces, filter course, or reservoir course.
3. Regular cleaning, sweeping, and/or washing of the asphalt surfaces to keep the porosity at its optimum level. Frequency of the cleaning program must be included.

Sec. 16.48.040 Finishing of Paved Surfaces

After the pavement and shoulders have been completed, the contractor shall place in acceptable condition any portion of the right-of-way that has been distributed by his or her operations.

Sec. 16.48.050 Restriction of Traffic

The contractor shall arrange the work in such a manner as to cause a minimum of inconvenience to the traveling public and abutting property owners. The Town retains the authority to order the contractor to reschedule operations should traffic considerations become paramount. Any and all traffic barricades, warning signs, and flagmen will be provided by the contractor as required by the U.S. Department of Transportation Manual for Uniform Traffic Control Devices, as a minimum. More may be required depending on the construction site and conditions. The contractor shall verify that all heavy equipment utilized during construction will not damage existing roadways. Any damage that occurs as a result of the contractor’s operations shall be repaired to the satisfaction of the Town at the expense of the contractor.
Sec. 16.48.060 Cooperation

All adjacent driveways and access to business areas within the limits of each project shall be kept open at all times, said access to be maintained by the contractor, and the excavated area shall be kept under close dust control.
SECTION II

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1.0 General

The structural design of a pavement system must be done with a clear understanding of the factors that affect the life and serviceability of the pavement. There are multiple factors in design and construction of a pavement system. This Pavement Design Criteria Manual addresses those factors having a significant effect on the pavement life and serviceability. The objective is to obtain the best quality pavement system considering factors such as: subgrade, traffic loads, pavement material, future maintenance and special considerations such as swelling or collapse prone soils, slope instabilities and frost susceptible soils. The design must be founded upon a sound theoretical and experience base since public monies are at risk and a direct fiduciary responsibility exists. This design manual assumes that all of the parts of the pavement section and subgrade, trench backfill, hot mix asphalt, aggregate base course, etc. are constructed in accordance with the City Engineering Standard Engineering Specifications and the Pikes Peak Region Asphalt Paving Specifications.

This design methodology is prescriptive in nature and represents the minimum requirements of a design. The philosophy is to provide a design system which is easy to understand and use, and allows the Design Engineer flexibility to investigate alternatives. Alternatives, when proposed, must meet minimum design requirements and have sufficient data and analyses to allow City Engineering to evaluate the alternatives. The acceptance of any design is solely up to City Engineering. In the event City Engineering rejects a design, reasons for the rejection will be provided to the Design Engineer.

Pavement design reports and recommendations for new subdivision streets are submitted to the Engineering Development Review Division of City Engineering. Pavement design reports and recommendations for City Engineering capital projects are submitted to City Engineering’s project engineer.

The design basis presented in this document is based upon the 1993 American Association of State Highway and Transportation Officials (AASHTO) Design Guide. The objective is to provide design parameters for local materials and conditions, and to provide guidance on the use of AASHTO equations. The pavement designs obtained from this procedure should have equal life and serviceability provided the minimum material specifications are met, construction recommendations are followed, and proper maintenance is provided. The design methodology presented is not meant to prevent the use of alternative methods as technology changes and additional pavement systems develop. Furthermore, with City Engineering discretion and approval, the Colorado Department of Transportation 2010 Pavement Design Manual, or most current version, shall be considered for accepted design solutions for methods not contained in this Pavement Design Criteria Manual. Throughout this manual, ASTM and applicable AASHTO, or CDOT test standards apply interchangeably.
1.1 Design Report

The Design Report is to consider the conditions after design of the pavement alignment and elevation, and after the street is cut to utility grade (utility grade, or “rough” grade, is defined as within +/-0.2’ of final grade). The nature of subgrade soils which expand or collapse due to wetting provide unique design problems which are best addressed during rough grading operations. A Preliminary Geotechnical Investigation of the street alignment is appropriate when expansive or collapsible soil conditions are present, and when over-excavation, moisture treatment and re-compaction of the subgrade during mass site grading is expected to be appropriate. The preliminary investigation borings must be located in both cut and fill areas, and must be properly surveyed for both horizontal and vertical location. Borings must extend below finish subgrade elevations per boring depths as discussed in Section 2.0.
2.0 Field Investigation

The field investigation should be designed to evaluate subgrade soil types, determine ground water levels that may impact pavement performance, and investigate support conditions along the alignment. As a minimum:

1. Borings shall be made at not greater than 250-foot horizontal intervals for 2-lane roadways; and not greater than 250-foot intervals in each direction for roadways with multiple lanes in each direction.

2. Additional borings shall be made to investigate conditions such as filled drainage ways, obvious deflecting subgrade, subgrade material color changes, unusual adjoining vegetation or other observable conditions which could affect pavement performance.

3. Borings are to be a minimum of 4 feet in depth below design subgrade, with every fourth (minimum of one) boring 9 feet in depth below rough roadway subgrade elevation.

4. All borings shall be sampled using “California” or thin wall Shelby tube type samplers at depths of 1 foot and 4 feet below rough cut subgrade elevation for each boring, and at a depth of 9 feet at every fourth boring. The blows per foot or Shelby pushed length and recovery, boring number, and sample description shall be documented. Bulk samples of materials found in the upper 4 feet of the subgrade shall be obtained from each boring. Should varying materials be found in the upper 4 feet, samples of each material type shall be obtained for classification.

5. Boring logs shall include a description of soil types encountered, depths at which and types of samples taken, blow counts, moisture conditions, free water and anomalous conditions.

6. If circumstances warrant, test pits are allowed provided that the engineer can provide adequate analysis for pavement design purposes meeting City Engineering criteria.
Laboratory Testing

The purpose of the laboratory testing program is to classify subgrade material and evaluate support properties and moisture sensitivity (heave, collapse, softening) that can affect long-term pavement performance. Testing programs consist of classification testing (i.e., gradation analysis, Atterberg Limits and sulfate tests) and engineering properties testing (i.e., swell Consolidation, R-value, unconfined compressive strength, California Bearing Ratio, and Resilient Modulus Tests).

Soil Classification

All samples of the subgrade soils obtained shall be tested to evaluate classification using the AASHTO system. The minimum requirements are shown in Table 1.

<table>
<thead>
<tr>
<th>Subgrade Classification Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO Soil Classification, AASHTO M 145</td>
</tr>
<tr>
<td>Group Index Number</td>
</tr>
<tr>
<td>Natural Moisture/Density, AASHTO T 265</td>
</tr>
<tr>
<td>&amp; AASHTO T 204</td>
</tr>
<tr>
<td>Maximum Dry Density and Optimum Moisture Content T99 / 180</td>
</tr>
<tr>
<td>Liquid Limit, AASHTO T 89</td>
</tr>
<tr>
<td>Plastic Limit, AASHTO T 90</td>
</tr>
<tr>
<td>Percent Passing No. 200, AASHTO T 11</td>
</tr>
<tr>
<td>Gradation Analysis, AASHTO T 27</td>
</tr>
<tr>
<td>Sulfate Tests, CDOT, CPL 2103</td>
</tr>
</tbody>
</table>

Soils shall be grouped based upon the AASHTO classification system for each bulk material found in the upper 4 feet and the Group Index calculated. When a greater than 7 point disparity in Group Index is noted, the subgrade soil groups shall be subdivided into two or more groups. The content of soil groups shall be plotted on a project drawing. Soils which govern the design shall be those having the highest AASHTO soil classification (i.e., A-7-6 to A-2-4), lowest subgrade support or highest Group Index, within the design length of the roadway. Roadway design can be subdivided based upon the extent of subgrade materials found along the roadway length.
3.2 Swell/Consolidation Tests

Cohesive materials (A-4, A-5, A-6 and A-7) shall be tested to determine swell or consolidation potential. Tests shall be run on “California” or thin wall Shelby tube samples collected from 1 foot below the utility grade or subgrade in accordance with ASTM D 4546 at a vertical pressure of 200 psf. Testing frequency for these materials shall be in accordance with Table 2.

**Table 2**

<table>
<thead>
<tr>
<th>Number of Borings</th>
<th>Testing Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 5</td>
<td>Each boring</td>
</tr>
<tr>
<td>5 - 25</td>
<td>Minimum 5 samples</td>
</tr>
<tr>
<td>Greater than 25</td>
<td>Minimum 7 samples or 1 per 5 borings</td>
</tr>
</tbody>
</table>

The test results shall be plotted and the percent swell/consolidation and swell pressure (psf) shall be determined and reported. Test results which are suspected of being not representative of “typical” conditions shall not be considered in the design of the pavement but shall be reported. Any deletion of data shall be justified in the written report. The swell/consolidation potential for a given soil group shall be the calculated average of the group.

3.3 Subgrade Support Evaluation

For the material groups which govern the design (as determined in Section 3.1) of the pavement system, compaction and strength testing shall be performed on composite samples constructed using equal amounts of bulk sampled materials with the same classification and Group Index range specification in accordance with Table 3.

**Table 3**

<table>
<thead>
<tr>
<th>Subgrade Compaction and Strength Testing</th>
<th>For groups classified as A-2-6, A-6, and A-7 For all groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconfined Compressive Strength Test on remolded sample, compacted at 2% above Proctor optimum moisture content in accordance with AASHTO T 99, or California Bearing Ratio on remolded sample (AASHTO T 193) compacted at 2% above Proctor optimum moisture content. or Hveem Stabilometer (R-value), AASHTO T 190</td>
<td>For all groups Classified as A-2-6, A-6, and A-7 For all groups</td>
</tr>
</tbody>
</table>
The design soil support value shall be determined to be the lowest value obtained from the testing. In the event the Design Engineer elects to remove and replace the lowest support value to a minimum depth of 2 feet below finish subgrade, the support value of the replacement fill can be used. Technical justification (calculations) for the removal and replacement shall be provided in the report.
4.0 Pavement Design

The design methodology is based upon the 1993 AASHTO Design Guide equations and considers Traffic and Subgrade Resilient Modulus as the primary variables. Traffic loading requirements are presented in Section 4.1. The Subgrade Resilient Modulus and swell/consolidation analysis shall be determined in accordance with Section 4.2. The design equations for flexible and rigid pavements are presented in Section 4.3 and 4.4. Alternatives will be considered with advances in pavement design methods and paving material changes. Any deviation from guidelines presented in this document must be technically justified and approved by City Engineering.

4.1 Equivalent Single Axle Load (ESAL)

One of the factors used in pavement design is the loading of traffic on the roadway. This is a combination of the volume of traffic and the weight of the vehicles on the street. This factor is described in terms of 18,000-pound Equivalent Single Axle Loads or ESAL's. The calculation of ESAL's is based on the following information:

- ADT
- Lane distribution
- Truck volumes
- Truck weights and axle configurations

Since this information is not readily available for all streets, this manual provides default ESAL values for City street classifications and City-wide truck volume estimates. The ESAL values to be used for street classifications are shown in Table 4.

Pavement design can be completed using a roadway specific ESAL value. ESAL can be calculated using the technique described in the Colorado Department of Transportation (CDOT) most recent Pavement Design manual. The calculations, input data, and any assumptions must be reviewed and accepted by City Engineering.

Table 4

<table>
<thead>
<tr>
<th>City Street Classification</th>
<th>20-year ESAL Flexible Pavement</th>
<th>20-year ESAL Rigid Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway/ Expressway</td>
<td>8,000,000</td>
<td>11,000,000</td>
</tr>
<tr>
<td>Major Arterial</td>
<td>4,500,000</td>
<td>6,250,000</td>
</tr>
<tr>
<td>Minor Arterial</td>
<td>2,500,000</td>
<td>3,250,000</td>
</tr>
<tr>
<td>Industrial Street/Commercial Frontage</td>
<td>1,250,000</td>
<td>1,750,000</td>
</tr>
<tr>
<td>Major/Minor Collector</td>
<td>200,000</td>
<td>200,000</td>
</tr>
<tr>
<td>Local</td>
<td>50,000</td>
<td>50,000</td>
</tr>
</tbody>
</table>

*These are one-directional and per-lane ESAL values which may not be reduced for directional travel or lane distribution.*
Subgrade Support Characterization

Subgrade characterization consists of evaluating subgrade and long-term support values. The degree of moisture sensitivity and deflection sensitivity is used to evaluate the depth of moisture treatment appropriate to reduce the deflection at the surface of the completed pavement system. The support value is expressed in the form of a Resilient Modulus as determined from unconfined compressive strength, R-value, or CBR testing.

1. **Expansive Subgrade** - Tests performed to determine swell (expansion) potential in accordance with Section 3.2 shall be averaged for each soil group. For the highest average swell, the depth of moisture treatment shall be determined in accordance with Table 5. Using engineering judgment, locally differing values shall be addressed in the text of the report under the appropriate subgrade discussion section.

   **Table 5**

   **Depth Of Moisture Treatment For Expansive Soils**

<table>
<thead>
<tr>
<th>Swell % at 200 psf Subgrade Soil Liner Samples</th>
<th>Depth of Moisture Treatment (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Arterials</td>
<td>Arterials</td>
</tr>
<tr>
<td>&lt; 2</td>
<td>--</td>
</tr>
<tr>
<td>2 to 3</td>
<td>--</td>
</tr>
<tr>
<td>3 to 4</td>
<td>--</td>
</tr>
<tr>
<td>4 to 5</td>
<td>2</td>
</tr>
<tr>
<td>5 to 6</td>
<td>3</td>
</tr>
<tr>
<td>6 to 8</td>
<td>4</td>
</tr>
<tr>
<td>8 to 10</td>
<td>5</td>
</tr>
<tr>
<td>Greater than 10</td>
<td>6</td>
</tr>
</tbody>
</table>

   Moisture treatment is the process of removing the soil, adding moisture until the soil moisture content is between 1 and 3 percent above optimum as determined by AASHTO T 99 (ASTM D 698), and compacted to at least 95 percent of maximum Standard Proctor density. Soils requiring moisture treatment per Table 5 will require a stabilized subgrade per Section 4.2.2. Moisture treatment shall extend to the back of curb as a minimum.

2. **Subgrade Stabilization** - Subgrade soils treated to have high moisture contents typically have low support values and will be soft and yielding during paving. Stabilization of at least the upper 12 inches by chemical or mechanical methods will be necessary. This depth includes any approved Chemically Treated Subgrade section (CTS). The depth of treatment has to be determined by the design engineer in the design report, or as an addendum to the report, based upon the actual field conditions. Subgrade stabilization shall extend to the back of curb as a minimum.
a. Chemical Stabilization - Chemical stabilizing agents include lime, fly ash, combinations of lime/fly ash, and lime/Portland cement. Other agents or combinations can be used with approval by City Engineering and provided the mix design requirements are satisfied. Laboratory mix designs shall meet the following criteria:

1. For Lime treatment the pH shall be equal to or higher than 12.3 before compaction (not required where swell is less than 4 percent)
2. Unconfined Compressive Strength between 160 psi and 700 psi (ASTM 2166)
3. Swell less than one percent at 200 psf (ASTM D 4546)

When lime is used, Plasticity Index is to be reported from initial to final construction to all interested parties (e.g., Stabilization Contractor, Geotechnical Engineer and City Inspector) and shall not be used for acceptance purposes. The design stabilizing agent percentage as determined by the designer shall be increased by 1.0 percent in the field to account for waste, inert materials, and construction variability.

If water soluble sulfate contents exceed 0.2 percent, the treatment shall be accomplished using a double application method. A double application method consists of an initial treatment of Lime and allowing it to mellow for a minimum period of 7 days (with constant wetting). After the mellow period, the subgrade should be mechanically mixed prior to applying the remaining percentage of chemical stabilizer (Lime, Fly Ash or Cement). This shall be presented and discussed in the design report. All chemical stabilization shall be performed in accordance with Section 6.5.

b. Mechanical Stabilization - Soft, yielding soils may be stabilized mechanically using geogrids in conjunction with aggregate base course or recycled concrete to provide a stable construction platform. All mechanical stabilization shall be performed in accordance with Section 6.6.

3. Resilient Modulus - Subgrade support characteristics using the 1993 AASHTO design methodology consider the Resilient Modulus (Mr). Equipment to directly determine the Resilient Modulus may not be available to some local firms. A series of correlations and alternative equations are provided to aid firms that do not have the appropriate equipment to estimate the design Mr. equations to estimate values using R-value for non-cohesive subgrade materials, a modified unconfined compressive strength procedure or CBR for cohesive subgrade materials are included with this document. The subgrade strength characteristics shall be evaluated in accordance with the requirements of Section 3.0 Laboratory Testing. These values can be converted into Resilient Modulus using the following equations:
Unconfined Compressive Strength

- (A-2-6 soils) \( M_r = 2.23 \text{ (qu) } (.75) \)
- (A-6 soils) \( M_r = 2.15 \text{ (qu) } (.75) \)
- (A-7-6 soils) \( M_r = 3.13 \text{ (qu) } (.75) \)
- (Claystone) \( M_r = 1.68 \text{ (qu) } (.75) \)

Where qu = unconfined compressive strength in psf

California Bearing Ratio

\( M_r = (\text{CBR}) \times 1500 \)

Hveem Stabilometer (R Value)

\( M_r = \frac{S + 18.72}{6.24} \)

Where \( S = \frac{(\text{R-value} - 5)}{11.29} + 3 \)

4.3 Flexible Pavement Structural Section

The thickness of the pavement section shall be determined using the design traffic 20-year, 18-kip ESAL's obtained from Section 4.1, the Resilient Modulus obtained from Section 4.2.3 and the depth of moisture treatment and stabilization obtained from Section 4.2.1 and 4.2.2.

The Structural Number (SN) shall be determined using the AASHTO 1993 design methodology or using the design nomographs provided in Figure 1 with the input parameters presented in Table 6. Using strength coefficients provided in Table 7, calculate the thickness of the various pavement layers by the following formula:

\[
\text{SN} = a_1(D_1) + a_2(D_2) + \ldots + a_n(D_n)
\]

Where:
- \( a_1 = \text{Strength coefficient for HMA} \)
- \( a_2, a_3, a_4 \ldots a_n = \text{Strength coefficient for lower layers} \)
- \( D_1 = \text{Thickness of HMA} \)
- \( D_2, D_3, D_4 \ldots D_n = \text{Thickness of additional layers} \)
### Table 6

**Material Strength Coefficients**

<table>
<thead>
<tr>
<th>Material</th>
<th>Coefficient ((a))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Mix Asphalt (HMA)</td>
<td>0.44</td>
</tr>
<tr>
<td>Existing Hot Mix Asphalt</td>
<td>0.24</td>
</tr>
<tr>
<td>Aggregate Base Course/Recycled Concrete Base</td>
<td>0.12</td>
</tr>
<tr>
<td>Existing Aggregate Base Course/Recycled Concrete Base</td>
<td>0.10</td>
</tr>
<tr>
<td>Granular Sub-base ((R = 50+, CBR = 15+))</td>
<td>0.07</td>
</tr>
<tr>
<td>Chemically Treated Subgrade (constructed in accordance with Section 6.5)</td>
<td>0.14</td>
</tr>
</tbody>
</table>

*Note 1: Maximum value unless supported by testing*

### Table 7

**Flexible Pavement Design Parameters**

<table>
<thead>
<tr>
<th>Input</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability ((R))</td>
<td>95% for arterials and all commercial frontage and industrial roadways</td>
</tr>
<tr>
<td></td>
<td>90% for collectors</td>
</tr>
<tr>
<td></td>
<td>85% for local roadways</td>
</tr>
<tr>
<td></td>
<td>80% for cul-de-sacs</td>
</tr>
<tr>
<td>Standard Deviation ((S_o))</td>
<td>0.44 for flexible pavements</td>
</tr>
<tr>
<td>Initial Serviceability =4.5</td>
<td>2.5 Locals, collectors, private drives, parking lots and public alleys</td>
</tr>
<tr>
<td>Serviceability Loss ((\Delta PSI))</td>
<td>2.0 Arterials and all commercial frontage and industrial roadways</td>
</tr>
</tbody>
</table>

### 4.4 Rigid Pavement Structural Section

The thickness of the pavement section shall be determined using the traffic ESAL’s obtained from Section 4.1, a k-value, the depth of moisture treatment, and stabilization obtained from Section 4.2.1 and 4.2.2. For rigid pavement design, the Resilient Modulus (Mr in psi) must be converted to a Modulus of Subgrade Reaction (k-Value in pci) using the following formula.

\[
k\text{-value (pci)} = \frac{\text{Resilient Modulus (psi)}}{19.4}
\]

The effective k-value can be determined by correcting for Loss of Support (LS) (Figure 1) with the following assumptions:

- \(LS = 0\) for concrete over an existing pavement
- \(LS = 1.0\) for Chemically Treated Subgrades
- \(LS = 2.0 – 2.5\) for Natural Subgrade Materials
The design thickness shall be determined using the AASHTO 1993 design methodology or using the design nomographs provided in Figure 3 and 4 with the input parameters presented in Table 8.

### Table 8

<table>
<thead>
<tr>
<th>Input</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability (R)</td>
<td>95% for arterials and all commercial frontage and industrial roadways</td>
</tr>
<tr>
<td></td>
<td>90% for collectors</td>
</tr>
<tr>
<td></td>
<td>85% for local roadways</td>
</tr>
<tr>
<td></td>
<td>80% for cul-de-sacs</td>
</tr>
<tr>
<td>Standard Deviation (So)</td>
<td>0.34 for rigid pavements</td>
</tr>
<tr>
<td>Concrete Elastic Modulus (Ec)</td>
<td>3,500,000 psi</td>
</tr>
<tr>
<td>Concrete Modulus of Rupture (S’c)</td>
<td>650 psi</td>
</tr>
<tr>
<td>Load Transfer Coefficient (J)</td>
<td>2.8 full reinforcement</td>
</tr>
<tr>
<td></td>
<td>3.6 if tied into curb &amp; gutter</td>
</tr>
<tr>
<td></td>
<td>4.2 no reinforcement</td>
</tr>
<tr>
<td>Initial Serviceability =4.5</td>
<td></td>
</tr>
<tr>
<td>Serviceability Loss (ΔPSI)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5 Local, collectors, private drives, parking lots and public alleys</td>
</tr>
<tr>
<td></td>
<td>2.0 Arterials and all commercial frontage and industrial roadways</td>
</tr>
</tbody>
</table>

Joint spacing, doweling and tie bars shall be in accordance with American Concrete Pavement Association recommendations contained in Design and Construction of Joints for Concrete Streets. Dowels are required for industrial and arterial streets for longitudinal and expansion joints.

### Minimum Pavement Sections

If the calculated pavement sections indicate sections thinner than the Minimum Pavement Sections shown below in Table 4.5.1, the Minimum Pavement Sections shall govern. The City Engineer prefers the use of flexible pavement designed as a composite section of hot mix asphalt over aggregate base course. Full depth pavement sections (flexible or rigid) are allowed subject to sufficient justification over chemically treated subgrade, or suitable subgrade as defined herein. Full depth pavement is not allowed over mechanically stabilized subgrade. Certain very sandy subgrade conditions may require applying a non-structural covering of aggregate base course for constructability to support the paving equipment. The City Engineer may increase the minimum pavement section at any location if conditions warrant. Following in Table 9 are the minimum pavement thicknesses required by City Engineering:
### Table 9

**Minimum Pavement Thicknesses (inches)**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Flexible Pavement</th>
<th>Rigid Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HMA + ABC³</td>
<td>HMA + CTS²</td>
</tr>
<tr>
<td>Major Arterial</td>
<td>5” + 12”</td>
<td>5” + 12”</td>
</tr>
<tr>
<td>Minor Arterial</td>
<td>4 + 12”</td>
<td>4” + 12”</td>
</tr>
<tr>
<td>Major Residential Collector (4 lane)</td>
<td>4” + 8”</td>
<td>4” + 8”</td>
</tr>
<tr>
<td>Major Residential Collector (2 lane)</td>
<td>4” + 8”</td>
<td>4” + 8”</td>
</tr>
<tr>
<td>Minor Residential Collector</td>
<td>4” + 6”</td>
<td>4” + 6”</td>
</tr>
<tr>
<td>Residential</td>
<td>4” + 6”</td>
<td>4” + 6”</td>
</tr>
<tr>
<td>Minor Residential</td>
<td>4” + 6”</td>
<td>4” + 6”</td>
</tr>
<tr>
<td>Hillside Minor Residential</td>
<td>4” + 6”</td>
<td>4” + 6”</td>
</tr>
<tr>
<td>Industrial/Commercial (4 lane)</td>
<td>4” + 12”</td>
<td>4” + 12”</td>
</tr>
<tr>
<td>Industrial/Commercial (2 lane)</td>
<td>4” + 12”</td>
<td>4” + 12”</td>
</tr>
<tr>
<td>Frontage Road</td>
<td>4” + 6”</td>
<td>4” + 6”</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Full depth pavement (asphaltic concrete) is only allowed over chemically treated or suitable subgrade.
2. Full depth pavement is not allowed over mechanically stabilized expansive subgrade. See section 4.5.
3. The minimum thickness of ABC shall be six inches in any application.

**ABBREVIATIONS:**
- HMA = Hot Mix Asphalt
- ABC = Aggregate Base Course
- CTS = Chemically Treated Subgrade
- PCCP = Portland Cement Concrete Pavement

### 4.6 Alternate Pavement Designs

City Engineering understands the need to consider emerging technologies in pavement design. In light of this, any alternate pavement design will be reviewed and considered with respect to the following criteria:

- Initial construction cost
- Life cycle cost
- Construction delay and impact
- Facility maintenance and ease of repair
- Pavement noise, smoothness
- Industry capacity and local contractor capability
- Special design provisions such as edge drains behind the curbs¹ to intercept moisture from adjoining development and prevent it from adversely affecting the road subgrade and paving section.
City Engineering reserves the right to make the pavement type selection using these and/or other criteria on City funded projects.

Special Drainage Considerations: The design engineer should anticipate the future developed condition of the land adjacent to the roadway when making the paving design recommendations. Even when no shallow groundwater is present in the pre-developed condition it is expected that certain land uses such as single family homes and projects with irrigated landscaping present the possibility of water entering the road subgrade and adversely affecting the performance and longevity of the pavement. City forces have to install retrofit underdrain systems in many streets to mitigate these kinds of problems. Appropriate recommendations and design features to stop water from infiltrating into the pavement section will receive positive response from City Engineering.
5.0 Pavement Design Report

All pavement design reports shall be prepared by or under the supervision of, and stamped and signed by, a Professional Engineer licensed in the State of Colorado and practicing as a Geotechnical Engineer.

5.1 Report Submittal

Design reports shall be submitted to City Engineering. Pavement design reports for new subdivision streets are submitted to the Engineering Development Review Division of City Engineering. Pavement design reports for City Engineering capital projects are submitted to City Engineering’s project engineer. All reports shall contain the following items:

- Description of the area of the project including the location land use, surface conditions, topography, site grading, extent of site development at the time of investigation, vegetation, and any unusual surface features.
- Listing of the sampling and testing techniques and appropriate AASHTO or ASTM designations.
- Table showing AASHTO, USCS and Group Index of the individual subgrade samples found within the drilling depths and of the groups which govern the pavement design.
- Subgrade support testing sections shall include graphs of moisture/density relation tests, R-values, CBR tests, unconfined compressive strength, swell/consolidation tests and other tests deemed to be applicable for the conditions found performed. The subgrade-support test results shall be shown along with the resulting calculated Resilient Modulus or k-Value and the equations used to determine the value.
- Where moisture sensitive subgrade soils occur, the depth of moisture treatment and subgrade stabilization other than the depth determined from Section 4.2.1 shall be discussed and the analysis shown.
- Where treatment is required due to expansive soils (Section 4.2.1), a stabilized subgrade is required (Section 4.2.2) and a report shall determine the stabilizing agent to be used. Any stabilizing agents not listed must be pre-approved by City Engineering. Special stabilization techniques required due to high water soluble sulfate contents or other conditions shall be presented. Where soils contain soluble sulfates in concentrations greater than 0.2 percent, a discussion on a double application method and sulfate resistant concrete shall be presented. Should any of these soils be stabilized, special construction precautions shall be presented (i.e., staged construction).
- The design traffic in terms of ESAL’s shall be presented on a figure and discussed in the design report, including the source of traffic information.
- Design pavement thicknesses including hot mix asphalt, Portland cement concrete or composite sections shall be shown on a figure for the various street sections. If computer software is used to develop solutions, the print out from the software shall be included in the report. If nomographs are used, they shall be included in the design report for each soil group and traffic loading condition.

- A discussion of design and construction concerns shall be presented, followed by specific recommendations to mitigate the concerns. Factors such as, but not limited to, swelling heave, frost heave, collapsing soils, difficult excavations, steeply dipping bedrock, organic soils, high water table, median landscaping, low density, collapse prone soils, or utility trench settlement effects must be presented, discussed, and mitigation recommendations presented.

- Where two minor arterial or higher classification streets intersect, the design should consider the combined traffic volumes. The use of Portland Cement Concrete Pavement at high traffic volume intersections may be deemed necessary by City Engineering. High volume asphaltic concrete may also be appropriate. City Engineering will determine the extent of the “high volume” intersection treatments.

- The report shall include a discussion of material requirements to meet the design assumptions. The report shall refer to appropriate City of Colorado Springs and Pikes Peak Region material and construction specifications. Hot mix asphalt design recommendations, in accordance with the City of Colorado Springs and the Pikes Peak Region Asphalt Paving Specifications, shall also be included. CDOT requirements may also apply for high traffic intersections.

- Additional concerns with respect to design, construction, maintenance, and other project aspects should be presented and discussed.

- For subdivision streets, any issues identified in the Geologic Hazard Study relating to soil stability or special design requirements must be discussed.

- Reference List

5.2 Figures

To evaluate the design, figures are necessary to present information and design data. All reports must have the following:

1. **Project location including:**
   a. A vicinity figure showing the project location using existing landmarks, roadways.
   b. Location of exploratory borings and the estimated extent of subgrade soil types by soil groups and AASHTO classifications.

2. **Graphical representation of exploratory borings:**
   a. Graphical boring logs shall be represented using AASHTO classifications for materials. Bedrock shall be represented in accordance with local practice, i.e., sandstone, claystone, interbedded bedrock, weathered claystone.
   b. The boring logs shall also provide the following:
1. Sampling depths and length, including blow count, push depth, and recovery
2. Moisture content, dry density, percent swell/consolidation – under a 200 psf pressure
3. Atterberg Limits (liquid limit, plasticity index)
4. Percent passing the No. 200 sieve
c. Figures showing swell/consolidation, moisture/density relations, unconfined compressive strength, and results of Hveem/stabilization or CBR testing.
d. Design pavement section alternatives and special alternatives

3. **Recommended Pavement System:**
   a. The design alternatives, based upon engineering, shall be presented on a “Recommended Pavement Alternatives” figure, illustrating the extent of each alternative pavement section along with a legend describing each pavement alternative, the design ESAL, and the subgrade group used for the design.
b. Special considerations such as soft soils, organic materials, treatments shall be presented on the “Recommended Pavement Alternatives” figure.
c. Structures such as bridges, box culverts, interchanges, and turn lanes shall be shown on all site figures.
d. Where lanes have different pavement sections, the variations shall be clearly shown on the “Recommended Pavement Alternatives” figure.
Design chart for flexible pavements

Figure 1

Example:

\[ W_a = 5 \times 10^4 \]

\[ R = 95\% \]

\[ S_e = 0.35 \]

\[ M = 5000 \text{ psi} \]

\[ \Delta \text{PSI} = 18 \]

Solution:

\[ SN = 5.0 \]
CORRECTION OF EFFECTIVE MODULUS OF SUBGRADE REACTION FOR LOSS OF SUPPORT

Effective Modulus of Subgrade Reaction, k (pci)
(Corrected for Potential Loss of Support)

Design Chart for Rigid Pavements

FIGURE 2
Design chart for rigid pavements
Figure 4

Design chart for rigid pavements

NOTE: Application of reliability in this chart requires the use of mean values for all the input variables.

NOTE: FROM AASHTO GUIDE FOR DESIGN OF PAVEMENT STRUCTURES (1993)

Design Chart for Rigid Pavements (Segment 2)
6.0 Construction And Material Specifications

The intent is to specify materials, equipment, methods and standards to be used for the construction of pavement systems as indicated on the plans. The design intent is to construct a pavement with adequate thickness and quality to provide a serviceable life of at least 20 years. All workmanship and materials shall be in accordance with the requirements of these specifications and special provisions, and in conformity with the lines, grades, quantities and typical cross sections shown on the plans or as directed by City Engineering.

6.1 Hot Mix Asphalt

All hot mix asphalt must meet the material specifications and construction standards presented in the current version of the Pikes Peak Region Asphalt Paving Specifications.

6.2 Portland Cement Concrete

All Portland cement concrete must meet the material specifications and construction standards presented in the current version of the City of Colorado Springs City Engineering Standard Specifications Manual.

6.3 Subgrade and Aggregate Base Course

All prepared subgrade and aggregate base course, including recycled concrete, must meet the material specifications and construction standards presented in the current version of the City of Colorado Springs City Engineering Standard Specifications Manual. Aggregate base course shall extend to the back of curb as a minimum.

6.4 Moisture Treatment for Expansive Soils

This work consists of removing, moisture conditioning, replacing, compaction, and shaping the existing expansive subgrade with moisture and density control to the extent shown on the plans. The purpose is to provide a zone of low swelling, strain absorbing material between the expansive subgrade and the pavement section. Moisture treatment shall extend to the back of curb as a minimum. The depth of removal and replacement with moisture treated subgrade shall be consistent with the plans regardless of cut, fill or backfill.
1. **Equipment** - The contractor shall provide equipment in good operating condition that is specifically designed and manufactured for the purpose of excavating, hauling, mixing, watering, leveling and compacting subgrade materials. Mixing and watering equipment shall be capable of achieving a uniform moisture content without wet or dry zones. Compaction equipment shall be adequately designed to obtain compaction requirements without adverse shoving, rutting, displacement or loosening of subgrade material. The equipment shall be available to perform the work specified within the time frames required and to be coordinated with other activities. The equipment shall be operated by skilled workman at a normal production rate for the specified type of work. All equipment and machinery shall be kept in good working order, free of leaks and properly muffled. All taxes, licenses and fees shall have been paid and proper licenses and permits shall be posted as required by law.

2. **Construction Methods**

   a. **Compaction** - The existing subgrade shall be removed, uniformly moisture treated, mixed, replaced, and compacted. Each layer shall be compacted to at least 95 percent Standard Proctor density as determined by AASHTO T 99 at 1 to 3 percent above optimum moisture content. The thickness of layers, prior to compactions, shall depend upon the type of sprinkling, mixing and compacting equipment used. Moisture/density tests should be performed every 250 linear feet, alternating lanes, to verify subgrade density meets specifications.

   After each layer of fill is complete, tests must be made to confirm moisture content and required compaction. When the material fails to meet the compaction or moisture requirements or should the material lose the required compaction or moisture or finish before the next course is placed or the project is accepted, the layer shall be processed. Reprocessing shall be done at the contractor’s expense.

   The contractor may be required to excavate an area of the layer in order to facilitate the taking of density tests. Replacement and compaction of the removed material in the area shall be at the contractor’s expense.

   b. **Subgrade Stabilization** - Moisture treatment will leave a soft yielding subgrade unsuitable for paving. Stabilization in accordance with Item 4.2.2, Subgrade Stabilization, shall be performed to the depths and limits shown on the plans.

3. **Tolerances**

   a. **Grade Tolerances** - Any deviation in excess of 1/2 inch in cross section and 1/2 inch in 10 feet measured longitudinally shall be corrected by loosening, adding or removing the material, reshaping and re-compacting by sprinkling and rolling. Deviations in excess of this tolerance shall be corrected by the contractor, at the contractor’s expense, in a manner satisfactory to City Engineering.

   b. **Compaction Tolerances** - Compaction below the specified minimum shall be corrected by re-compaction. Inadequate compaction shall be corrected by the contractor, at the contractor’s expense.
c. Moisture Tolerances - Any loss of moisture below the set limits shall be corrected by moisture conditioning and re-compaction. Loss of moisture shall be corrected by the contractor, at the contractor’s expense.

4. **Testing and Inspection**
   
a. Testing of moisture treated soils shall be performed in accordance with Table 10.

   **Schedule for Minimum Materials Sampling and Testing**
   **(Moisture Treated Soils)**

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Test Standard</th>
<th>Minimum Frequency of Tests</th>
</tr>
</thead>
</table>
   | In Place Soil Density And Moisture Content | AASHTO T 191  
AASHTO T 238  
AASHTO T 239  
ASTM D 2167  
ASTM D 2216  
ASTM D 2216 | One test for each 250 lane feet (not less than one test per day). |
   | Liquid Limit                  | AASHTO T 89                     | One test per soil type                      |
   | Plastic Limit               | AASHTO T 90                     | One test per soil type                      |
   | Moisture-Density Relationships | AASHTO T 99  
AASHTO T 180 | One test per soil type                      |

### 6.5 Chemically Stabilized Subgrade

This work consists of the contractor constructing one or more courses of a mixture of subgrade soil, approved stabilizing agent and water in substantial conformity with the design line, grades, thicknesses, and typical cross sections shown on the approved plans and the approved pavement thickness design. **Purpose** - The purpose of the work shall be to provide a structural section on which paving materials can be placed and to meet design specifications, while at the same time, protecting the underlying moisture-treated subgrade soils. Subgrade stabilization shall extend to the back of curb as a minimum. This specification can also be applied to achieve a stabilized paving platform without structural benefits.

1. **Materials**
   
a. Stabilizing Agents - The pre-approved stabilizing agents are listed in Table 11. Various combinations of these materials may also be used, subject to a suitable mix design. Other agents may be used with prior written approval of City Engineering.
Approved Chemical Stabilizing Agents

Table 11

<table>
<thead>
<tr>
<th>Agents</th>
<th>Must conform to requirements of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>ASTM C 977, C 110</td>
</tr>
<tr>
<td>Fly Ash (C and F)</td>
<td>ASTM C 618</td>
</tr>
<tr>
<td>Cement Kiln Dust</td>
<td>ASTM D 5050</td>
</tr>
<tr>
<td>Portland Cement</td>
<td>ASTM C 114</td>
</tr>
</tbody>
</table>

High-calcium quicklime shall conform to the requirements of ASTM C 977 and rate of slaking test shall produce a temperature rise of 20°C in 30 seconds and 35°C in 3 minutes per ASTM C110. Dolomitic quicklime, magnesia quicklime with magnesium oxide contents in excess of 4 percent or carbonated hydrated lime, shall not be used. High-calcium quicklime must be applied in slurry.

Fly ash may consist of Class C or Class F. Class F fly ash shall only be allowed in conjunction with lime or other cementitious stabilizing agents.

All stabilizing agents shall come from the same source as used in the design. If the source is changed, a new design must be submitted to City Engineering for approval. Each lot of stabilizing agent furnished shall have the supplier’s certificate of compliance.

b. Water - Water used for mixing or curing should be from a potable source. In the event potable water is not used, non-potable water shall be tested in accordance with and meet the requirements of AASHTO T 26 and used in the mix design.

c. Subgrade - The subgrade material to be stabilized shall be free of roots, sod, weeds, wood, construction debris, ice, snow, or other frozen materials, deleterious matter, and stones larger than 3 inches in size. Material in the stabilized zone shall have a water soluble sulfate content of less than 0.2 percent as per CPL 2103, Method B. If the subgrade soils have a soluble sulfate content exceeding 0.2 percent, the mix design shall address the specific methodology used to prevent adverse effects of sulfate reactions (e.g. heaving subgrade, cracked pavement).

2. Equipment - All equipment shall be subject to approval by City Engineering. All equipment and machinery shall be kept in good working order, free of leaks and properly muffled.

a. Dry Application Equipment - Equipment for spreading dry stabilizing agent shall be of an approved screw-type spreader box, mixer, or other semi-enclosed equipment which is equipped with a metering device. Spreading of stabilizing agents by aggregate spreaders or motor-graders will not be allowed.

b. Slurry Application Equipment - A distributor or truck applicator shall be used and be capable of continuous agitation to keep the slurry mixture uniform. The applicator shall be capable of uniformly metering the stabilizing agent during application.
c. Mixing Equipment - Mixing equipment shall be of sufficient size to adequately mix the stabilizing agent into the soil and to pulverize the mixture. The size of the mixer shall be adequate to mix and pulverize the mixture to a minimum depth of 12 inches in a single pass. Blades, discs, and similar equipment are not allowed without prior written approval of City Engineering.

d. Compaction Equipment - Compaction equipment shall be in good working order and of sufficient size and effective force to achieve the required compactive effort.

3. Construction Submittals - At least 15 days prior to commencing stabilization work, the contractor shall furnish the following information to City Engineering:

- The source and supplier of stabilizing agent and certifications, including purity of stabilizing agent, from the manufacturer's testing agency indicating that the stabilizing agent meets the appropriate requirements.
- Description of the proposed construction equipment, construction methods, expected production rates and planned sequence of construction.
- A mix design giving the Water Soluble Sulfate test results percentage of stabilizing agent, source of the agent, properties and any special considerations.

For each day's work, the contractor shall furnish the following information to the City Engineering Inspector by the following day:

- Certified truck weight tickets of stabilizing agent, delivered or used at the site.
- A summary of the amount of stabilizing agent used each day, areas stabilized and first mixed, areas second mixed and compacted, and areas with curing completed.
- Prior to paving, final in place soil properties per Table 6.5.11.

4. Stabilized Mix Design

Mix designs shall be performed under the supervision of and signed by a Professional Engineer licensed to practice in the State of Colorado practicing as a geotechnical engineer. Mix design shall comply with the requirements of Table 12

<table>
<thead>
<tr>
<th>Stabilization Agent</th>
<th>Minimum pH (Notes 1 &amp; 2)</th>
<th>Maximum Swell Potential (%) (Note 3)</th>
<th>Minimum Unconfined Compressive Strength (psi) (Note 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>12.0</td>
<td>1.0</td>
<td>160</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>N/A</td>
<td>1.0</td>
<td>160</td>
</tr>
<tr>
<td>Cement Kiln Dust</td>
<td>N/A</td>
<td>1.0</td>
<td>160</td>
</tr>
<tr>
<td>Portland Cement</td>
<td>N/A</td>
<td>1.0</td>
<td>160</td>
</tr>
<tr>
<td>Lime-Fly Ash</td>
<td>12.3</td>
<td>1.0</td>
<td>160</td>
</tr>
</tbody>
</table>
Notes:

1. When lime is used, the pH should be no less than 12.0 as measured after completion of initial mixing with stabilizing agent and at ambient temperature.
2. Testing of pH is to be done in accordance with Eades-Grim pH test method (ASTM D 6276).
3. Swell Potential to be less than 1.0 percent at 200 psf, ASTM D 4546.
4. Minimum of 160 psi (Mr > 34,800 psi, where Mr = 10,000 + 124qU) in five (5) days of moist curing at 100°F (38°C) or ambient (72°F) for seven (7) days. Testing is in accordance with ASTM D 1633 Method A for pozzolanic agents and ASTM D 5102 Procedure B for Hydrated Lime.

When lime is used, Plasticity Index is to be reported from initial to final construction to all interested parties and shall not be used for acceptance purposes. The design stabilizing agent percentage as determined by the designer shall be increased by 1.0 percent in the field to account for waste, inert materials, and construction variability.

5. Processing Materials - It is the primary requirement of this specification to secure a completed subgrade structural section containing a uniform stabilized mixture. The mixture is to have a uniform density and moisture content, free from loose or segregated areas, well bound for its full depth, well cured, and with a surface suitable for placing subsequent courses. It shall be the responsibility of the contractor to regulate the sequence of their work, to use the proper amount of stabilizing agent, maintain the work, and rework the courses, as necessary, to meet the requirements.

a. Application - The subgrade shall not be treated when the ambient air temperature falls below 40°, or when the subgrade material is frozen, or when weather predictions suggest that subgrade material temperature may fall below freezing within 24 hours, unless prior written approval of City Engineering has been issued. Prior to beginning any treatment, the subgrade shall also be constructed and finished to a smooth and uniform surface that is in conformity to the grade and typical section specified. Variation from the subgrade plan elevation specified shall not be more than ± 0.08 ft. The in-place density shall be at least 95% of maximum dry density as determined by ASTM D 698, Standard Proctor Density, and within 0 to 3% of optimum moisture content for fly ash or cement treated soils. For lime treated materials, the moisture content shall be at least 3% above optimum. Stabilizing agent shall be applied at the minimum rate specified by the mix design for the depth of stabilized subgrade shown on the plans. The rate shall be determined from a design using the on-site soils and shall meet the requirements found in Section 4.2.2. Rate of application shall be verified using area/quantity calculations or testing of stabilized subgrade. Stabilizing agent shall be spread only on that area where the first mixing operations can be completed during the same working day. Lime slurry shall not be left exposed to the air for more than four hours without initial mixing. City Engineering reserves the right to require variation of the rate of application of stabilizing agent from the mix design application rates during the progress of construction as necessary to maintain the desired characteristics of the stabilized subgrade.

Stabilizing agent shall be applied using the following methods:
1. Slurry Placement - The distribution of stabilizing agent shall be attained by successive applications over a measured section of subgrade until the proper amount of agent has been spread. The amount spread shall be the amount required for mixing to the specified depth, which will result in the percentage determined in the design. When quicklime is used in place of hydrated lime the amount of quicklime used will be determined by the certified lime purity for each load supplied as follows:

\[ \text{Quicklime delivered } \times \text{ purity } \times 1.32 = A \]

\[ \text{Quicklime delivered } \times \text{ inert material } = B \]

\[ A + B = \text{total hydrated lime available} \]

**Note:** When a double treatment of lime is required, the first 50 percent of the agent shall be placed, moisture treated and allowed to mellow or cure for up to three weeks, as determined by the Design Engineer. The last half of the lime shall then be applied.

2. Dry Placement (This method can only be used for Fly Ash, cement kiln dust, and Portland cement) - The amount of stabilizing agent spread shall be the amount required for mixing to the specified depth, which will result in the percentage specified by the design. The stabilizing agent shall be distributed in such a manner that scattering by wind will be minimal. Agents shall not be applied when wind conditions, in the opinion of City Engineering's inspector, are detrimental to a proper application. The blended material shall be sprinkled or watered until moisture content is as specified in subgrade stabilization design. The combination of stabilizing agent, soil and water shall be called the "mixture." After spreading of stabilizing agent and during mixing, water shall be added to hydrate the agent and for dust control.

b. High Sulfate Treatment - Where sulfates are over 0.2 percent the designer must address the method of treatment.

c. Mixing - No stabilization shall take place when precipitation may cause damage to the subgrade. Mixing shall be continuous. The full depth of the treated subgrade material shall be mixed with an approved mixing machine to the specified depth below the bottom of the pavement structure and/or curb. The mixing machine shall make a sufficient number of passes to adequately achieve 100 percent of the material passing the one-inch sieve and 60 percent passing the 1/4-inch sieve. Water shall be added to the subgrade during mixing to provide a moisture content of at least 3 percent above the optimum moisture of the mixture or as specified in subgrade stabilization design. Mixing and remixing will be performed, as necessary, to assist the stabilizing agent-soil reaction and produce a homogeneous mixture. Mixing and remixing shall continue until the combination of stabilizing agent and subgrade material is free of streaks or pockets of stabilizing agent.
d. Mellowing (Lime or Lime/Fly Ash Only) - The moisture content of the subgrade mixture shall be maintained above optimum for a minimum of 2 days and until the subgrade stabilization design criteria is met. Remixing will be done as necessary to assist the reaction, as determined by the design engineer. Application of water shall be performed as necessary during the mellowing period; the material shall maintain a moisture content of at least 3 percent above optimum. The stabilized material shall not be subjected to traffic. If during the mellowing period the material is not in a semi-loose state, the chemical reaction process may slow and, therefore, require additional time and/or mixing as determined by the design engineer.

e. Final Mixing (Lime or Lime/Fly Ash Only) - Final mixing of the treated subgrade shall not occur if the temperature of the soil to be stabilized is below 40°F. The treated subgrade shall be maintained at a temperature of 40°F or above until the treated material has been compacted. The material shall be uniformly mixed by an approved method to meet the following requirements when tested dry by laboratory sieves:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Minimum Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-inch sieve</td>
<td>100</td>
</tr>
<tr>
<td>No. 4 sieve</td>
<td>60</td>
</tr>
</tbody>
</table>

6. Compaction - Compaction of the mixture, for the full depth of the stabilized subgrade shown on the plans, shall begin as soon as practical after final mixing. Stabilized subgrade with cementitious stabilization agent shall be completed within 90 minutes of the time the cementitious stabilization agent and water are mixed. The field density of the compacted mixture shall be at least 95 percent of the maximum dry density of laboratory specimens prepared from samples taken from the treated subgrade material immediately prior to compacting. The specimens shall be compacted and tested in accordance with ASTM D 698 or ASTM D 558, as specified in the subgrade stabilization mix design. The in-place field density shall be determined in accordance with ASTM D 1556, ASTM D 2167 or ASTM D 2922. The moisture content of the mixture of shall be between 0 to 3 percent above the optimum moisture content. The optimum moisture content shall be determined in accordance with ASTM D 698 or ASTM D 558, as specified in subgrade stabilization design. Initial compaction shall be done by means of a sheepfoot or segmented wheel roller. Final compaction shall be by means of a smooth wheel or pneumatic tired roller. Areas inaccessible to a mechanical roller shall be compacted to the required density by other means acceptable to the design engineer. All irregularities, depressions, or weak spots which develop shall be corrected immediately by scarifying the areas affected, adding or removing materials as required, and reshaping and re-compacting by moisture conditioning and rolling. Adding additional stabilized material to an initial cured section, resulting in lamination and potential slip plane, is not allowed. The surface of the course shall be maintained in a smooth condition, free from
undulations and ruts, until other work is placed thereon or the work is accepted. Should the material, due to any reason or cause, lose the required stability, density, and finish before the next course or pavement is placed, it shall be corrected and refinished at the sole expense of the contractor, as directed by City Engineering.

7. **Finishing and Curing** - After the final layer of stabilized subgrade has been compacted, the shape of the surface shall be achieved by blading. The surface shall be smooth and conform to the required lines, sections, and grades, in accordance with the plans and thoroughly cured, or to within a minimum of 0.1 foot above the finished subgrade elevation to allow for trimming to final grade prior to placement of surface coarse. The completed section shall then be finished by rolling with suitable pneumatic tired equipment with sufficiently light effort to prevent hairline cracking. Curing may be accomplished by periodic water application to maintain moisture content preventing sloughing or cracking of the surface of the stabilized subgrade to a depth no greater than 0.1 foot, or by the utilization of a bituminous seal. When bituminous seal is utilized, the minimum application will be at the rate of 0.12 gallons per square yard, as directed and approved by the design engineer. The completed section shall be cured for a minimum of 5 days before further courses are added or any traffic is permitted, unless otherwise permitted by the design engineer. The moisture cure duration may be reduced if a non-yielding surface is obtained to support construction traffic and either the next layer of stabilized soils are placed or the pavement layer is constructed, as approved by the Engineer. If the surface of the finished layer is above the approved plan elevation tolerance specified in this section, the excess material shall be trimmed, removed, and disposed of. Any low areas will be replaced with the subsequent surface courses. No loose material shall be left in place after trimming. After trimming the stabilized subgrade surface shall be rolled again with a steel wheel or pneumatic tired roller to seal the surface.

8. **Tolerances**

   a. **Thickness** - Stabilized zone thickness shall be verified by the use of phenolphthalein and shall be performed at intervals of approximately 500 feet in each lane. When the measurement of the thickness is deficient by more than 1 inch from the plan thickness, two additional locations shall be measured randomly within the deficient area and used in determining the average thickness. When the average thickness is deficient by more than 1 inch, the entire area shall be reprocessed to meet the design parameters or the roadway design section must be re-evaluated.

   b. **Grade** - Prior to placement of surface course, any deviation in excess of 1/2 inch in cross-section and 1/2 inch in 10 feet measured longitudinally shall be corrected. Variations in excess of this tolerance shall be corrected by the contractor, at the contractor’s expense, in a manner satisfactory to City Engineering. Thickness requirements shall be met in areas corrected for grade.
c. **Strength** - The stabilized subgrade must develop a laboratory compressive strength of at least 160 psi at 5 days in accordance with Table 6.5.4. Samples shall be molded from stabilized soil within 1.5 hours of final mixing with the material compacted per ASTM D 558 or ASTM D 698, as specified in subgrade stabilization design, at the field moisture content.

9. **Conformity with Plans and Specifications** - When thickness and/or strength criteria fail to meet design parameters, even after all possible attempts have been made to correct said deviations, remediation will be required as listed in Table 13. Evaluation of the roadway pavement section will be made by the Design Engineer with written approval of City Engineering. The pavement structural section shall be adjusted to compensate for any deficiency in the stabilized subgrade thickness and strength, at the contractor’s expense. Placement of subsequent surface course will not occur until the stabilized subgrade has been accepted in writing by City Engineering.

<table>
<thead>
<tr>
<th>Deficiency</th>
<th>Remediation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 25% of design thickness</td>
<td>Evaluate roadway design section</td>
</tr>
<tr>
<td>Greater than 25% of design thickness</td>
<td>Remove and replace</td>
</tr>
<tr>
<td>Less than 25% of required strength</td>
<td>Evaluate roadway design section</td>
</tr>
<tr>
<td>Greater than 25% of required strength</td>
<td>Remove and replace</td>
</tr>
</tbody>
</table>

10. **Measurement** - The area of stabilized subgrade shall be measured by the plan quantities completed, in place, and accepted. No separate measurement of depth or area, except as required for thickness testing shall be performed. The quantity of stabilizing agent accepted and used shall be measured by the ton of fly ash, Portland cement, cement kiln dust, or hydrated lime used (or the calculated dry hydrated lime content of the lime slurry).

11. **Testing and Inspection** - Testing and inspection shall be performed in accordance with Table 14.
Table 14

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Test Standard</th>
<th>Minimum Frequency of Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling</td>
<td>AASHTO T 87</td>
<td>One per 2,500 square yards</td>
</tr>
<tr>
<td>Sample Preparation</td>
<td>ASTM D 3551</td>
<td>Hold one test per 2,500 square yards as directed by City Engineering</td>
</tr>
<tr>
<td>Maximum Dry Density and Optimum Moisture Content</td>
<td>ASTM D 698 (Lime) ASTM D 558 (Cement)</td>
<td>Hold minimum one test per soil type or as directed by City Engineering</td>
</tr>
</tbody>
</table>
| In Place Soil Density                         | ASTM D 1556 ASTM D 2167 ASTM D 6938   | One test for each 250 lane feet  

(not less than one test per day) |
| In Place Moisture Content                     | ASTM D 2216 ASTM D 6938               | Hold one test per 2,500 square yards                           |
| Ph                                            | ASTM D 6276                            | Hold one test per 2,500 square yards                           |
| Swell                                          | ASTM D 4546 Method B                   | Hold minimum one test per 2,500 square yards or as directed by City of Colorado Springs |
| Unconfined Compressive Strength (Lime)         | ASTM D 5102 (Procedure B)              | Hold one test per 2,500 square yards                           |
| Compressive Strength Cementitious Agents      | ASTM D 1633 (Method A)                 | Hold one test per 2,500 square yards                           |
| Atterberg Limits                               | AASHTO T 89 & T 90                     | Hold one test per 2,500 square yards                           |
| Stabilization Thickness                        | As directed by testing agency          | Hold one test every 500 feet per lane                          |

### 6.6 Mechanically Stabilized Subgrade

This work includes mechanically stabilized subgrade of base/subbase course and/or subgrade improvement in the construction of paved or unpaved roadways. Design details for geogrid reinforcement, such as geogrid type, fill thickness, pavement cross-section and associated details, shall be as shown on the project drawings. Purpose - The purpose of the work shall be to provide a stabilized paving platform section on which paving materials can be placed. Subgrade stabilization shall extend to the back of curb as a minimum. This item shall not be used to retain moisture in subgrades unless retaining moisture in the section can be assured. This specification shall be used for a construction platform and not as a means of mitigating swell.

1. **Materials**
   
   a. **Definitions**
      
      1. **Mechanically Reinforced** - Placement of a geogrid immediately over a soft subgrade soil in order to improve the bearing capacity and mitigate deformation of the subgrade soil. The goal of this application may be to reduce deeper excavation requirements, improve construction efficiency, reduce the amount of aggregate subbase/base material required, provide a stiff working platform for pavement construction, or combination of these.
2. **Geogrid** - A biaxial polymeric grid formed by a regular network of integrally connected tensile elements with apertures of sufficient size to allow interlocking with surrounding soil, rock, or earth to function primarily as reinforcement.

3. **Multi-Layer Geogrid** - A geogrid product consisting of multiple layers of grid which are not integrally connected throughout.

4. **Extruded Geogrid** – A geogrid product formed by extrusion of a polypropylene or polypropylene/polyethylene copolymer sheet followed by its perforation with a precise arrangement of holes and subsequent stretching, or drawing, into the finished product.

5. **Woven Geogrid** – A geogrid product formed by weaving discrete strips of polymer into a network. These geogrids usually require a protective coating to protect the polymer from pre-mature degradation.

6. **Minimum Average Roll Value (MARV)** - Value based on testing and determined in accordance with ASTM D4759-92.

7. **True Initial Modulus in Use** - The ratio of tensile strength to corresponding zero strain. The tensile strength is measured via ASTM D6637 at a strain rate of 10 percent per minute. Values shown are MARVs. For multi-layer geogrid products, rib tensile testing shall be performed on the multi-layer configurations, as prescribed by ASTM D6637.

8. **Junction Strength** - Breaking tensile strength of junctions when tested in accordance with GRI-GG2 as modified by AASHTO Standard Specification for Highway Bridges, 1997 Interim, using a single rib having the greater of 3 junctions or a minimum 8 inch machine direction sample and tested at a strain rate of 10 percent per minute based on this gauge length, values shown are MARVs. For multi-layer geogrid products, junction strength testing shall be performed across junctions from each layer of grid individually, and results shall not be assumed as additive from single layers to multiple layers.

9. **Flexural Stiffness** (also known as Flexural Rigidity) - Resistance to bending force measured via ASTM D1388-96, Option A, using specimen dimensions of 864 millimeters in length by 1 aperture in width, values shown are MARVs. For multi-layer geogrid products, flexural stiffness testing shall be performed directly on the multi-layer configuration without using any connecting elements other than those used continuously throughout the actual product, and results shall not be assumed as additive from testing performed on a single layer of the multi-layer product.

10. **Aperture Stability Modulus** (also known as Torsional Rigidity or Torsional Stiffness) - Resistance to in-plane rotational movement measured by applying a 20 kg-cm (2.0 m-N) moment to the central junction of a 9-inch by 9-inch specimen restrained at its perimeter, values shown are MARVs. For multi-layer geogrid products, torsional stiffness testing shall be performed on each layer of grid individually, and results shall not be assumed as additive from single layers to multiple layers.
11. **Granular Fill Material** – The preferred gradation for base reinforcement application is well-graded crushed aggregate fill with a maximum particle size (100 percent passing) of 1 ½ inches, and less than 10% fines (passing the #200 sieve). Recycled concrete may be used only with polypropylene geogrids in accordance with Federal Highway Administration (FHWA) 2001.

2. **Manufacturers**
   a. All manufacturers will be considered provided they meet the submittal process as per Table 6.6.3.

3. **Geogrid Material Properties**
   a. **Structural Soil Reinforcement Geogrid** – The geogrid shall be integrally formed and deployed as a single layer having the following characteristics according to Table 15 (all values are minimum average roll values unless a range or characteristic is indicated.)
   
   b. Geotextile materials shall not be considered as an alternate to geogrid materials for subgrade improvement or base/sub-base reinforcement applications. A geotextile may be used in the cross-section to provide separation, filtration or drainage; however, no structural contribution shall be attributed to the geotextile.

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Units</th>
<th>Type 1</th>
<th>Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture Stability Modulus at 20 cm-kg (2.0 m-N)</td>
<td>Kinney (2001)</td>
<td>m-N/deg</td>
<td>0.32</td>
<td>0.65</td>
</tr>
<tr>
<td>Rib Shape</td>
<td>Observation</td>
<td>N/A</td>
<td>Rectangular or Square</td>
<td>Rectangular or Square</td>
</tr>
<tr>
<td>Rib Thickness</td>
<td>Calipered</td>
<td>In</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Nominal Aperture Size</td>
<td>I.D. Calipered</td>
<td>In</td>
<td>1.0 to 1.5</td>
<td>1.0 to 1.5</td>
</tr>
<tr>
<td>Junction Strength</td>
<td>GRI-GG2-2000 exception</td>
<td>ratio</td>
<td>Note ¹</td>
<td>Note ¹</td>
</tr>
<tr>
<td>Flexural Rigidity</td>
<td>ASTM D1388-96 Note ²</td>
<td>Mg-cm</td>
<td>250,000</td>
<td>750,000</td>
</tr>
<tr>
<td>Minimum Tensile Strength @ 2% Strain:</td>
<td>ASTM D6637-01 Note ³</td>
<td>Lb/ft</td>
<td>280</td>
<td>410</td>
</tr>
<tr>
<td>- MD³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- CMD³</td>
<td></td>
<td></td>
<td>450</td>
<td>620</td>
</tr>
<tr>
<td>Minimum Tensile Strength @ 5% Strain:</td>
<td>ASTM D6637-01 Note ⁴</td>
<td>Lb/ft</td>
<td>580</td>
<td>810</td>
</tr>
<tr>
<td>- MD³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- CMD³</td>
<td></td>
<td></td>
<td>920</td>
<td>1,340</td>
</tr>
</tbody>
</table>
NOTES:

1. The ratio of Junction Strength/Ultimate Tensile Strength must meet or exceed 75%.

2. Resistance to bending force measured via ASTM D-5732-95, using specimens of width two ribs wide, with transverse ribs cut flush with exterior edges of longitudinal ribs (as a “ladder”), and of length sufficiently long to enable measurement of the overhang dimension.

3. MD = machine direction (along roll length); CMD = cross-machine direction (across roll width).

4. True resistance to elongation when initially subjected to a load determined in accordance with ASTM D6637 without deforming test materials under load before measuring such resistance or employing “secant” or “offset” tangent methods of measurement so as to overstate tensile properties.

4. **Construction Platform Design**

   Construction platform design shall be performed under supervision of and signed by a Professional Engineer registered in the State of Colorado practicing as a geotechnical engineer. The recommended procedure shall be followed as outlined in AASHTO PP 46-01. Appropriate partial safety factors shall be applied to results obtained using geogrids having properties or characteristics outside the range of rigorous model validation (Giroud and Han, 2004). This method has been endorsed by numerous Department of Transportations and Government Agencies such as the Federal Highway Administration and Army Corps of Engineers. A piping ratio analysis (D15fill/D85subgrade) shall be performed to determine the need of a separation fabric. If the piping ratio is less than 5 then no separation fabric is required. If the piping ratio is greater than 5 then a separation fabric is required below the geogrid. Final determination of construction platform shall be approved by City Engineering.

5. **Utility Cuts**

   Repair of utility cuts in geogrid material shall be accomplished per manufacturer specifications.

6.7 **Proof Rolling**

   The Subgrade platform shall be thoroughly proof-rolled to the satisfaction of the City Inspector prior to placement of base course (or paving) and the base course shall be thoroughly proof-rolled to the satisfaction of the City inspector prior to paving. Reference Section 205 of the City’s Standard Specifications.

6.8 **Water Testing**

   As soon as practical upon final pavement construction the finished pavement surface shall be water-tested to the satisfaction of the City Engineering inspector to confirm positive surface drainage in all directions prior to acceptance of the street. Water shall be applied using a water truck spray bar or similar device at a rate adequate to demonstrate positive drainage flow across the crown and into the street gutters.
7.0 Definitions

AASHTO: American Association of State Highway and Transportation Officials

Adhesive Failure: Loss of bond between the joint sealant and the joint, or between the aggregate and the binder.

Agency: The jurisdiction or owner of the project and its representatives.

Aggregate Base (base course): Crushed stone or gravel, immediately under the surface course.

Aggregate Interlock: Interaction of aggregate particles across cracks and joints to transfer load.

Alligator Cracks: Interconnected cracks forming a series of small blocks resembling an alligator’s skin or chicken wire.

Analysis Period: The period of time for which the economic analysis is to be made; ordinarily will include at least one rehabilitation activity.

Asphalt Emulsion Slurry Seal: A mixture of emulsified asphalt, fine aggregate and mineral filler, with water added to produce slurry consistency. Seals are used as a preventative maintenance treatment to provide a new wearing surface and to fill small cracks.

Asphalt Leveling Course: A course (asphalt-aggregate mixture) of variable thickness used to eliminate irregularities in the contour of an existing surface prior to superimposed treatment or construction.

Asphalt Overlay: One or more courses of asphalt construction on an existing pavement. The overlay generally includes a leveling course, to correct the contour of the old pavement, followed by uniform course or courses to provide needed thickness.

Asphalt Tack Coat: A light application of emulsified asphalt applied to an existing asphalt or Portland cement concrete pavement surface. It is used to ensure a bond between the surface being paved and the overlying course. Typically 0.10 gals/yd2 of CSS1h.

ASTM: American Society for Testing Materials

Binder: Asphalt Cement used to hold stones together for paving.

Binder Course: The layer of asphalt cement concrete pavement underlying the surface course.

Bituminous: Like or from asphalt.

Bleeding or Flushing: The upward movement of asphalt in an asphalt pavement resulting in the formation of a film on the pavement surface. It creates a shiny, glass-like, reflective surface that may be tacky to the touch in warm weather.

Block Cracking: The occurrence of cracks that divide the asphalt surface into approximately rectangular pieces, typically one square foot or more in size.
California Bearing Ratio Test (CBR): An empirical measure of bearing capacity used for evaluating bases, subbases, and subgrades for pavement thickness design.

Centerline: The painted line separating opposing traffic lanes.

Channels: A ditch or canal adjacent the roadway.

Chipping: Breaking or cutting off small pieces from the surface.

Chip Seal: A thin layer of emulsified asphalt cement in which aggregate is embedded. The seal is placed to improve the texture of the pavement surface to increase skid resistance and decrease permeability of the surface.

City Street: A street whose traffic is predominantly local in character.

Cohesive Failure: The loss of a material's ability to bond to itself or its substrate. Results in the material splitting or tearing apart from itself or its substrate (i.e. joint sealant splitting).

Composite Pavement: A pavement structure composed of an asphalt cement concrete pavement wearing surface over aggregate base course or treated subgrade.

Contractor: The land developer or its agents involved in the construction of the project.

Corrugations (Washboarding): A form of plastic movement typified by ripples across the pavement surface. Most common in aggregate surficial pavements but occurs in asphalt cement concrete pavements as well.

Crack: Approximately vertical random cleavage of the pavement due to thermal or load action.

Crack Seal: An asphalt cement or similar material applied into a pavement crack to provide a non-permeable seal. The sealant must have adequate characteristics to provide bonding to each side of the crack.

CTS: Chemically Treated Subgrade

Deflection: The amount of downward vertical movement of a surface due to the application of a load to the surface.

- Rebound Deflection: The amount of vertical rebound of a surface that occurs when a load is removed from the surface.

- Representative Rebound Deflection: The mean value of measured rebound deflections in a test section plus two standard deviations, adjusted for temperature and most critical period of the year for pavement performance.

- Residual Deflection: The difference between original and final elevations of a surface resulting from the application to, and removal of one or more loads from, the surface.

Design ESAL: The total number of equivalent 80kN (18,000 lb) single-axle load applications expected during the Design Period.

Design Lane: The lane on which the greatest number of equivalent 80kN (18,000 lb) single-axle loads is expected. Normally this will be either lane of a two-lane roadway or the outside lane of a multi-lane highway.
**Design Period:** The number of years from initial construction or rehabilitation until terminal service life. This term should not be confused with pavement life or Analysis Period. By adding asphalt overlays as required, pavement life may be extended indefinitely, or until geometric considerations or other factors make the pavement obsolete.

**Disintegration:** The breaking up of a pavement into small, loose fragments due to traffic or weathering.

**Distortion:** Any change of a pavement surface from its original shape.

**Drainage Coefficients:** Factors used to modify layer coefficients in flexible pavements or stresses in rigid pavements as a function of how well the pavement structure can handle the adverse effect of water infiltration.

**Edge Cracking:** Fracture and materials loss in pavements without paved shoulders which occur along the pavement perimeter. Caused by soil movement beneath the pavement.

**Effective Thickness:** The thickness that a pavement would be if it could be converted to Full-Depth asphalt cement concrete pavement.

**Embankment (Embankment Soil):** The prepared or natural soil underlying the pavement structure.

**Embrittlement:** Premature (surficial) cracking of an asphalt concrete pavement due to oxidative aging of the asphalt cement.

**End Result Specifications:** Specifications that require the contractor to take the entire responsibility for supplying a product or an item of construction. The highway agency’s responsibility is to either accept or reject the final product or apply a price adjustment that compensates for the degree of compliance with the specifications. (End result specifications have the advantage of affording the contractor flexibility in exercising options for using new materials, techniques, and procedures to improve the quality and/or economy of the end product.)

**ESAL:** Equivalent Single Axel Load

**ESAL to Failure:** The number of design 18 kip (18,000 pound) axle load cycles required to produce approximately 40 percent fatigue cracking as calculated using AAMAS equations based on asphalt cement concrete pavement Resilient Modulus and tensile strain at the bottom of the ACCP layer.

**Equivalent 80kN (18,000 lb) Single-Axle Load (ESAL):** The effect on pavement performance of any combination of axle loads of varying magnitude equated to the number of 80kN (18,000 lb) single-axle loads required to produce an equivalent effect.

**Fatigue Cracking:** A series of small, jagged, interconnecting cracks caused by failure of the asphalt cement concrete pavement surface under repeated traffic loading (also called alligator cracking.)

**Fault:** Difference in elevation between opposing sides of a joint or crack.
**Flexible Pavement:** Pavement structures generally consisting of asphalt cement concrete pavement surfacing that maintains intimate contact with and distributes loads to the subbase or subgrade and depends upon aggregate interlock, particle friction, and cohesion for stability.

**Flowable Backfill:** A backfill material composed of a low-strength, self-leveling concrete material, composed of various combinations of cement fly ash, aggregate, water and chemical admixtures used to “flow” into areas requiring backfill that will provide density and strength without compaction.

**Fog Seal:** A thin layer of emulsified asphalt cement applied to the pavement surface. The seal is placed as a preventive treatment to rejuvenate the asphalt concrete pavement by improving flexibility and to decrease the permeability of the surface.

**Free Edge:** Pavement border that is able to move freely.

**Full-Depth Asphalt Pavement:** The term FULL-DEPTH (registered by the Asphalt Institute with the U.S. Patent Office) certifies that the pavement is one in which asphalt mixtures are employed for all courses above the subgrade or improved subgrade. A Full-Depth asphalt pavement is laid directly on the prepared subgrade.

**Functional Classification:** A method of separating and classifying streets according to their purpose or function in the network of streets, i.e. residential collectors, commercial collectors, residential locals.

**Grade Depressions:** Localized low areas of limited size which may or may not be accompanied by cracking.

**Hairline Crack:** A fracture that is very narrow in width, less than 3mm (0.12 in.).

**Heavy Trucks:** Two axle, six-tire trucks or larger. Pickup, panel and light four-tire trucks are not included. Trucks with heavy-duty, wide base tires are included.

**Hot Bituminous Pavement:** See Hot Mix Asphalt

**Hydroplaning:** The dangerous action of a vehicle being driven on a pavement over which a film of rain or other water has formed; on reaching a certain speed, the vehicle’s tires tend to ride upon the water surface rather than the pavement, drastically reducing the driver’s control of the vehicle.

**Hot Mix Asphalt:** High-quality, thoroughly-controlled hot mixture of asphalt cement and well-graded, high quality aggregate, thoroughly compacted into a uniform dense mass.

**Incentive/Disincentive Provision (for quality):** A pay adjustment schedule which functions to motivate the contractor to provide a high level of quality. (A pay adjustment schedule, even one which provides for pay increases, is not necessarily an incentive/disincentive provision, as individual pay increases/decreases may not be of sufficient magnitude to motivate the contractor toward high quality).

**Instability:** The lack of resistance to forces tending to cause movement or distortion of a pavement structure.

**Internal Vibration:** Vibration by means of vibrating units located within the specified thickness of pavement section and a minimum distance ahead of the screed equal to the pavement thickness.
**Lane Line:** Boundary between travel lanes, usually a painted stripe.

**Lane-to-Shoulder Drop-off:** The difference in elevation between the traffic lane and shoulder.

**Lane-to-Shoulder Separation:** Widening of the joint between the traffic lane and the shoulder.

**Layer Coefficient:** The empirical relationship between structural number (SN) and layer thickness which expresses the relative ability of a material to function as a structural component of the pavement.

**Lime Stabilized Subgrade:** A prepared and mechanically compacted mixture or lime, water and soil below the pavement system.

**Lime-Fly Ash Base:** A blend of mineral aggregate, lime, fly ash and water, combined in proper proportions which, when compacted, produces a dense mass.

**Lime-Fly Ash Stabilized Subgrade:** A prepared and mechanically compacted mixture of lime, fly ash, water and soil below the pavement system.

**Load Equivalency Factor (LF):** A factor used to convert applications of axle loads of any magnitude to an equivalent number of 80kN (18,000 lb) single axle loads.

**Longitudinal:** Parallel to the centerline of the pavement.

**Longitudinal Crack:** A crack that follows a course approximately parallel to the center line.

**Maintenance:** The preservation of the entire roadway, including surface, shoulders, roadsides, structures, and such traffic control devices as are necessary for its safe and efficient utilization.

**Materials/Methods Specifications:** Specifications that direct the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material.

**Method Specifications:** See Materials/Methods Specifications.

**Moisture Stabilized Subgrade:** Swelling soils which have been stabilized to low or nil swell by addition of moisture.

**Moisture Treatment:** Addition of moisture at 1 to 3 percent above standard Proctor optimum moisture content and compaction to 95 percent density.

**Parametric Analysis:** A study of a set of physical properties whose values determine the characteristics or behavior of something; used to isolate the significance of individual variables.

**Patch:** An area where the existing pavement has been removed and replaced with a new material.

**Patch Deterioration:** Distress occurring within a previously repaired area.

**Pavement Structure (Pavement):** A combination of subbase, base course, and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed.
Pavement Condition Indicator (PCI): A measure of the condition of an existing pavement section at a particular point in time, such as cracking measured in feet per mile, or faulting measured in inches of wheel path faulting per mile. When considered collectively, pavement condition indicators provide an estimate of the overall adequacy of a particular roadway.

Pavement Design (Design, Structure Design): The specifications for materials and thicknesses of the pavement components.

Pavement Distress Indicator: See Pavement Condition Indicator.

Pavement, Flexible: Pavement structures generally consisting of asphalt cement concrete pavement surfacing that maintains intimate contact with and distributes loads to the subbase or subgrade and depends upon aggregate interlock, particle friction, and cohesion for stability.

Pavement Performance: The trend of serviceability with load applications.

Pavement Rehabilitation: Work undertaken to extend the service life of an existing facility. This includes placement of additional surfacing material and/or other work necessary to return an existing roadway, including shoulders, to a condition of structural or functional adequacy. This could include the complete removal and replacement of the pavement structure.

Pavement, Rigid: A pavement structure consisting of Portland cement concrete pavement surfacing, with or without subbase.

Performance Period: See Design Period.

Performance Specifications: Specifications that describe how the finished product should perform over time. For highways, performance is typically described in terms of changes in physical condition of the surface and its response to load, or in terms of the cumulative traffic required bringing the pavement to a condition defined as “failure”. Specifications containing warranty/guarantee clauses are a form of performance specifications. (Other than the warranty/guarantee type, performance specifications have not been used for major highway pavement components (subgrades, bases, riding surfaces) because there have not been appropriate nondestructive tests to measure long-term performance immediately after construction. They have been used for some products (e.g., highway lighting, electrical components and joint sealant materials) for which there are tests of performance that can be rapidly conducted.)

Performance-Based Specifications: Specifications that describe the desired levels of fundamental engineering properties (e.g., Resilient Modulus, creep properties, and fatigue properties) that are predictors of performance and appear in primary prediction relationships (i.e., models that can be used to predict pavement stress, distress, or performance from combinations of predictors that represent traffic, environmental roadbed, and structural conditions.) [Because most fundamental engineering properties associated with pavements are currently not amenable to timely acceptance testing, performance-based specifications have not found application in highway construction].

Performance-Related Specifications: Specifications that describe the desired levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties that predict performance. These characteristics (for example, air voids in asphaltic pavements, and strength of concrete cores) are
amenable to acceptance testing at the time of construction. True performance-related specifications not only describe the desired levels of these quality characteristics, but also employ the quantified relationships containing the characteristics to predict subsequent pavement performance. They thus provide the basis for rational acceptance and/or price adjustment decisions.

**Planned Stage Construction:** The construction of roads and streets by applying successive layers of asphalt cement concrete pavement according to design and a predetermined time schedule.

**Plant-Mix Base:** A foundation course, produced in an asphalt mixing plant, which consists of a mineral aggregate uniformly coated with asphalt cement or emulsified asphalt.

**Portland Cement Concrete Pavement (PCCP):** High quality, thoroughly controlled mixture of portland cement, water, and well-graded, high quality aggregate, thoroughly mixed and placed as a uniform dense mass.

**Pothole:** A bowl-shaped depression of varying sizes in the pavement surface, resulting from localized disintegration.

**Prepared Roadbed:** In-place roadbed soils compacted or stabilized according to provisions of applicable specifications.

**Prescriptive Specifications:** See Materials/Methods Specifications.

**Present Serviceability:** The ability of a specific section of pavement to serve, for the use intended, mixed traffic on the day of rating.

**Present Serviceability Index (PSI):** A mathematical combination of values, obtained from certain physical measurements of a large number of pavements, so formulated as to predict, within prescribed limits, the Present Serviceability Rating (PSR) for those pavements.

**Present Serviceability Rating (PSR):** The mean of the individual ratings made by the members of a specific panel selected for the purpose.

**Proof Roll:** A test method for subgrade soils in which a loaded truck (18,000 pound axle weight) is driven over the subject area to delineate soft or yielding areas.

**QA/QC Specifications:** See Quality Assurance Specifications.

**QC/QA Specifications:** See Quality Assurance Specifications.

**Quality Assurance:** All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. Quality assurance addresses the overall problem of obtaining the quality of service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, quality assurance involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, and maintenance, and the interactions of these activities.

**Quality Assurance Specifications:** A combination of end result specifications and materials and methods specifications. The contractor is responsible for quality control (process control), and the Agency is responsible for acceptance of the product.
assurance specifications typically are statistically based specifications that use methods such as random sampling and lot-by-lot testing, which let the contractor know if his operations are producing an acceptable product.)

**Quality Control:** Those quality assurance actions and considerations necessary to assess production and construction processes so as to control the level of quality being produced in the end product. This concept of quality control includes sampling and testing to monitor the process but usually does not include acceptance sampling and testing.

**Raveling:** The wearing away of the pavement surface caused by the dislodging of aggregate particles.

**Recipe Specifications:** See Materials/Methods Specifications.

**Reflection Cracking:** Cracks in asphalt overlays that reflect the crack pattern in the pavement structure underneath.

**Resilient Modulus Test:** A measure of the modulus of elasticity of roadbed soil or other pavement material.

**Resistance Value (R-value):** A test for evaluating bases, subbases, and subgrades for pavement thickness design.

**Roadbed:** The graded portion of a highway between top and side slopes, prepared as a foundation for the pavement structure and shoulder.

**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.

**Roadway:** All facilities on which motor vehicles are intended to travel such as secondary roads, interstate highways, streets and parking lots.

**Roadway Land Use:** A classification based on the use of land adjacent or serviced by the street. The classification is used to separate streets for different volume assumptions.

**Roughometer:** A single-wheeled trailer instrumented to measure the roughness of a pavement surface in accumulated millimeters (inches) per mile.

**Rubberized Asphalt Cement:** Blend of asphalt cement and pre-vulcanized rubber.

**Rutting:** Longitudinal surface depressions in the wheel paths.

**Selected Material:** A suitable native material obtained from a specified source such as a particular roadway cut or borrow area, of a suitable material having specified characteristics to be used for a specific purpose.

**Serviceability:** The ability at time of observation of a pavement to serve traffic (autos and trucks) which use the facility.

**Shoving:** Permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic pushing against the pavement.

**Single Axle Load:** The total load transmitted by all wheels of a single axle extending the full width of the vehicle.
Skid Hazard: Any condition that might contribute to making a pavement slippery when wet.

Slippage Cracks: Cracks, sometimes crescent-shaped, that point in the direction of the thrust of wheels on the pavement surface.

SMA (Stone Matrix Asphalt, Split-Mastic Asphalt): An asphalt mix design composed of large stones creating a stone to stone matrix, often containing large percentages of asphalt cement and fillers.

Soil Cement Base: A hardened material formed by curing a mechanically compacted intimate mixture of pulverized soil, Portland cement and water, used as a layer in a pavement system to reinforce and protect the subgrade or subbase.

Stabilized Subgrade: A subgrade soil that has been altered by a chemical agent to make suitable for subgrade construction and pavement support.

Standard Deviation: The root-mean-square of the deviations about the arithmetic mean of a set of values.

Statistically Based Specifications: Specifications based on random sampling, and in which properties of the desired product or construction are described by appropriate statistical parameters.

Structural Number (SN): An index number derived from an analysis of traffic, roadbed soil conditions, and environment which may be converted to thickness of flexible pavement layers through the use of suitable layer coefficients related to the type of material being used in each layer of the pavement structure.

Subbase: The layer or layers of specified or selected material of designed thickness placed on a subgrade to support a base course.

Subbase (Subbase Course): The layer of graded sand-gravel or stabilized subgrade material between the surface of the embankment soil and the base course (and surfacing course when there is no base course).

Subgrade: The soil prepared to support a structure of a pavement system. It is the foundation for the pavement structure. The subgrade soil sometimes is called “basement soil” or “foundation soil”.

Subgrade, Improved: Any course or courses of select or improved material between the subgrade soil and the pavement structure.

Subgrade Resilient Modulus: The modulus of the subgrade determined by repeated load triaxial compression tests on soil samples. It is the ratio of the amplitude of the accepted axial stress to the amplitude of the resultant recoverable axial strain.

Surface (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 the “wearing course”.

Surface Thickness (Surfacing Thickness, Surface, Slab Thickness (Rigid)): The thickness of surfacing material, usually expressed in inches.
**Swell Potential:** The percent of volume changed expected for a soil sample when wetted, as measured through laboratory tests conducted using representative overburden pressures.

**Tandem Axle Load:** The total load transmitted to the road by two consecutive axles extending across the full width of the vehicle.

**Thermal Cracking:** Cracking occurring in pavement material introduced within the material resulting from a change in temperature.

**Traffic Equivalence Factor:** A numerical factor that expresses the relationship of a given axle load to another axle load in terms of their effect on the serviceability of a pavement structure.

**Transverse Crack:** A crack that follows a course approximately at right angles to the centerline.

**Triple (Tridem) Axle Load:** The total load transmitted to the road by three consecutive axles extending across the full width of the vehicle.

**Truck Factor:** The number of equivalent 80kN (18,000 lb) single-axle load applications contributed by one usage of a vehicle. Truck Factors can apply to vehicles of a single type or class or to a group of vehicles of different types.

**Twenty-Year ESAL:** (ESAL20) The Equivalent Single Axle Load application for a twenty-year design. The value is the product of the Load Equivalency factor for each vehicle type, the number of each particular vehicle per day, 365 days per year, and a twenty-year period.

**Upheaval:** The localized upward displacement of a pavement due to swelling of the subgrade or some portion of the pavement structure.

**USCS:** Unified Soil Classification System.

**Washboarding:** See Corrugations.

**Water Bleeding:** Seepage of water from joints or cracks.

**Weathering:** The wearing away of the pavement surface caused by the loss of asphalt binder.
SUBSECTION 4

PIKES PEAK REGION ASPHALT PAVING SPECIFICATIONS

(CAPA, COLORADO SPRINGS, EL PASO COUNTY)
# Pikes Peak Region
## Asphalt Paving Specifications

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Pikes Peak Region
Asphalt Paving Specifications

1.001 General Description. These specifications cover the requirements for the construction of Superpave Hot Mix Asphalt pavements. They include the general requirements for the construction of one or more lifts of Hot Mix Asphalt pavement on a prepared surface. The work shall consist of the preparation of the Hot Mix Asphalt (HMA) meeting the requirements herein, and the placement of the HMA to the lines, grades, thickness and typical cross sections shown on the plans or established by the Engineer. When more than one lift is required, each lift shall be compacted to the required density prior the placement of the next lift.

In these specifications the following terminology listed in Table 1.001.1 defines the traffic and volume levels for the different designations.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Volume and Loading Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>≤ 300,000 ESALs *</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt; 300,000 to ≤ 10,000,000 ESALs</td>
</tr>
<tr>
<td>High</td>
<td>&gt; 10,000,000 ESALs</td>
</tr>
<tr>
<td>Trails and Pathways</td>
<td>&lt; 100,000 ESALs - able to accommodate a 4,000 lb vehicle</td>
</tr>
<tr>
<td></td>
<td>for safety and maintenance purposes</td>
</tr>
<tr>
<td>Parking Lots</td>
<td>25% of volume used for entrance roadways</td>
</tr>
</tbody>
</table>

* Equivalent Single-Axle Loads

1.002 Materials. The HMA shall be composed of a mixture of aggregate, approved filler or additives, asphalt binder and reclaimed asphalt pavement (RAP), when permitted. The materials used in the manufacture of HMA shall meet the following requirements.

A. Aggregates. Aggregates shall be of uniform quality, clean, hard, durable particles of crushed stone, crushed gravel, natural gravel or crushed slag free from clay balls, vegetable matter or other deleterious materials meeting the requirements in Table 1.002.1 (page four).

The coarse and fine aggregates for the HMA mixture shall be graded and combined in such proportions that the resulting composite blend meets the grading requirements of the Job Mix Formula (JMF). The following Table 1.002.2 is for identification of material for bidding purposes only.

Aggregates meeting the requirements in Table 1.002.1 shall be used to develop the Job Mix Formula (JMF) for the HMA mixture. The aggregate should be composed of angular, coarse textured, cube shaped particles. Excess of fine material shall be wasted before crushing. Natural sand may be used to obtain gradation of the blended aggregate mixture but should not exceed 25%. If the percent of aggregate passing the #4 sieve is greater than 10% by weight of the individual aggregate sample, plasticity will be determined in accordance with AASHTO T 90. The gradation of the aggregates used in the mixture shall meet the criteria shown in the Aggregate Master Range Table 1.002.2, and shall not vary from the low limit on one sieve to the high limit on the adjacent sieve, or vice versa, but shall be well graded from coarse to fine. The nominal size aggregate used in the HMA mixture shall not be more than one-third the thickness of the uncompacted HMA lift being constructed.
TABLE 1.002.1 - AGGREGATE PROPERTIES

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Procedure</th>
<th>Coarse Retained on #4 Sieve</th>
<th>Fine Passing the #4 Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Aggregate Angularity&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic Level Low, Moderate, Trails and Pathways</td>
<td>CP&lt;sup&gt;1&lt;/sup&gt;-L5113 Method A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic Level 3 to 5 Moderate, High, Parking Lots</td>
<td></td>
<td>40% Minimum</td>
<td></td>
</tr>
<tr>
<td>Fractured Faces (minimum of 2)</td>
<td>CP-45</td>
<td>70% Minimum</td>
<td></td>
</tr>
<tr>
<td>LA Abrasion</td>
<td>AASHTO&lt;sup&gt;2&lt;/sup&gt; T 96</td>
<td>45% Maximum</td>
<td></td>
</tr>
<tr>
<td>Flat and Elongated Pieces</td>
<td>AASHTO M 283</td>
<td>10% Maximum</td>
<td></td>
</tr>
<tr>
<td>Sodium Sulfate Soundness</td>
<td>AASHTO T 104</td>
<td>Combined Coarse and Fine</td>
<td></td>
</tr>
<tr>
<td>Sand Equivalent&lt;sup&gt;3&lt;/sup&gt;</td>
<td>AASHTO T 176</td>
<td>45% Minimum</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>CP designates Colorado Department of Transportation material Testing Procedures.

<sup>2</sup>AASHTO designates American Association of State Highway and Transportation Officials Testing procedures.

<sup>3</sup>Tests are for the combined or blended samples.

TABLE 1.002.2 - AGGREGATE MASTER RANGE FOR HOT MIX ASPHALT MIXTURES

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent by Weight Passing Square Mesh Sieves</th>
<th>Grading S</th>
<th>Grading SX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot;</td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>¾&quot;</td>
<td>90 - 100</td>
<td></td>
<td>90 – 100</td>
</tr>
<tr>
<td>⅜&quot;</td>
<td>*</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>#4</td>
<td>*</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>#8</td>
<td>23 - 49</td>
<td>28 – 58</td>
<td></td>
</tr>
<tr>
<td>#30</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#200&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2 - 8</td>
<td>2 – 10</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>These additional screens will be established for the Contractor's Quality Control Testing using values from the Mix Design gradation.

B. Mineral Filler. If mineral filler is required to meet the JMF, it shall conform to the requirements of AASHTO M 17. It shall consist of rock dust, slag dust, hydrated lime, hydraulic cement, fly ash or other suitable mineral matter. Mineral filler shall have a plasticity index not greater than four (4) excluding hydrated lime and hydraulic cement. Mineral filler shall meet the grading limits shown in Table 1.002.3. The maximum amount of allowable hydrated lime or hydraulic cement shall not exceed 3% by weight of mix.

TABLE 1.002.3 - MINERAL FILLER GRADING LIMITS

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Mass Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>#30 (600 μm)</td>
<td>100</td>
</tr>
<tr>
<td>#50 (300 μm)</td>
<td>95 - 100</td>
</tr>
<tr>
<td>#200 (75 μm)</td>
<td>70 - 100</td>
</tr>
</tbody>
</table>
C. Additives. Additives to the mineral aggregate shall be added if the asphalt binder will not coat or stick to the aggregates. Additives shall be either Hydrated Lime, or other Anti-stripping Agents as approved by owner / agency engineers.

1. Hydrated Lime. Hydrated lime shall conform to ASTM C 207, Type N. The residue retained on a #200 (75μm) sieve shall not exceed 10% when determined in accordance with ASTM C 110.

2. Anti-stripping Agent. Liquid Anti-strip Agent shall be submitted for review and approval by owner.

D. Reclaimed Asphalt Pavement. Reclaimed Asphalt Pavement (RAP) shall be allowed in the HMA mixture. It shall be of uniform quality and gradation with a maximum size particle no greater than the maximum size allowed in the HMA mixture. HMA mixtures containing RAP shall meet the same gradation requirements as a virgin HMA mix. HMA pavements shall not contain more than 20% reclaimed asphalt pavement, unless approved by the owning agency’s engineer. In no case shall the RAP exceed 25%. The reclaimed asphalt pavement shall meet all the requirements for HMA pavement, as contained herein.

Reclaimed Asphalt Pavement (RAP) Material: The Engineer may require the contractor to maintain separate stockpiles for each type of RAP material. All processed material shall be free of foreign materials and segregation shall be minimized. Any RAP material that cannot be readily broken down in the mixing process, and/or affects the paving operation, shall be processed prior to mixing with the virgin material.

E. Asphalt Binder. Recommended Performance Graded asphalt binders are listed in Table 1.002.4, Binder Grades for HMA mixtures, and shall meet the requirements listed in Table 1.002.5, Properties for Performance Graded (PG) Binders. Any asphalt binder supplied must be from an approved source. An approved source for asphalt binders has to be certified by the Colorado Department of Transportation.

<table>
<thead>
<tr>
<th>Traffic Levels 1</th>
<th>Binder Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>(&lt; 300,000 ESALs)</td>
</tr>
<tr>
<td>Moderate</td>
<td>(300,000 to ≤ 10,000,000 ESALs)</td>
</tr>
<tr>
<td>High</td>
<td>(&gt; 10,000,000 ESALs)</td>
</tr>
<tr>
<td>Trails and Pathways</td>
<td>(&lt; 100,000 ESALs)</td>
</tr>
<tr>
<td>Parking Lots</td>
<td>(25 % of Roadways)</td>
</tr>
</tbody>
</table>

1 For 20-Year Designs.
2 For elevations approximately 7,000 feet or above, may use PG 58-28.
3 As specified by the Engineer.
### TABLE 1.002.5 - PROPERTIES OF PERFORMANCE GRADED BINDERS

<table>
<thead>
<tr>
<th>Property</th>
<th>PG Graded Binder Requirements</th>
<th>AASHTO Test No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>58-34¹</td>
<td>58-28</td>
</tr>
<tr>
<td><strong>Original Binder Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash Point Temperature, °C, minimum</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>Viscosity at 135 °C, Pa·s, maximum</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Dynamic Shear, Temperature °C, where G’/Sin @ 10 rad/sec ≥ 1.00 kPa</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>Ductility, 4°C (5cm/min) cm, minimum</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Toughness, joules, minimum</td>
<td>12.4</td>
<td></td>
</tr>
<tr>
<td>Tenacity, joules, minimum</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td><strong>RTOF Residue Properties</strong> AASHTO T 240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass Loss, percent maximum</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dynamic Shear, Temperature °C where G’/Sin @ 10 rads ≥ 2.20 kPa</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>Elastic Recovery, 25 °C, percent minimum</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Ductility, 4 °C (5 cm/min) cm, minimum</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td><strong>Pressure Aging Vessel Residue Properties, Aging Temperature 100 °C PP 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic Shear, Temperature °C where G’/Sin @ 10 rads ≤ 5000 kPa</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>Creep Stiffness, @ 60 s, test Temp. in °C</td>
<td>-24</td>
<td>-18</td>
</tr>
<tr>
<td>S, maximum, MPa</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>m-value, minimum</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Direct Tension, Temp. in °C, @ 1mm/min. where failure strain ≥ 1.0%</td>
<td>-24</td>
<td>-18</td>
</tr>
</tbody>
</table>

¹ Special grades used for unique loading or climate conditions.

² CDOT Test Method.

The Contractor shall provide to the Owner acceptable "Certification of Compliance" of each applicable asphalt binder grade that will be used on the project. Binder grades other than those shown above shall not be used unless the proposed binder and the mix design are approved by the Engineer.

1. **Mixture Binder Selection.** The binder to be used in the HMA mixture will depend on the local traffic level and traffic conditions. Binder grade selection for the HMA mixture for different traffic levels is shown in Table 1.002.4 Binder Grades for HMA Mixtures.

2. **Tack Coat Material Requirements.** Tack coat material shall be an Emulsified Asphalt conforming to AASHTO M 140 or M 208 for the designated grades.

F. **Material Acceptance.** Prior to the delivery of materials to the job site, the Contractor shall submit certification tests to the Engineer, for his approval, showing all materials to be used on the project meet the appropriate specification. The certification shall show the appropriate test(s) for each material, the test results and a statement that the materials meet the appropriate specification. If the Engineer requests samples of the materials for verification testing prior to and/or during the production of the HMA mixture, the Contractor shall deliver the requested materials to the owner's designated representative.
1.003 Hot Mix Asphalt Mixture Composition. The HMA mix shall be composed of well-graded aggregate, mineral filler, anti-stripping agent (if required and approved) and asphalt binder.

A. Mix Design. The Contractor shall submit the mix design (JMF) to the Engineer for approval seven (7) days prior to the beginning of paving operations. The mix design(s) of each mixture(s) to be used on the project shall be approved prior to the start of any paving operation. The mix design(s) shall be developed using the CDOT Superpave mix design procedures and shall be stamped (sealed) by an engineer licensed in the State of Colorado practicing in this field.

The Contractor shall submit as part of the mixture design the following items:

1. Source(s) of materials.
2. Aggregate gradation, specific gravity, source and description of individual aggregates and the final mixture blend.
3. Aggregate physical properties.
4. Source and grade of Performance Graded binder along with certification of binder.
5. Proposed JMF: aggregate and additive blending, final gradation shown on a 0.45 power graph, optimum binder content.
6. Mixing and compaction temperatures.
7. N_{ini} and N_{des} (N = number of gyrations).
8. Mixture properties determined at the minimum of four binder contents and interpolated at optimum and graphs showing mixture properties versus binder content.
10. Percent of RAP if used in the mixture.

The mix design(s) shall meet the requirements of Table 1.002.2 - Aggregate Master Range for Hot Mix Asphalt Mixtures, Table 1.002.4 - Binder Grades for HMA Mixtures, Table1.003.1 - Superpave Mixture Properties, and Table 1.003.2 - Voids in Mineral Aggregate. The HMA mixture(s) will be designed for the traffic level, nominal aggregate size and binder grade designated or as specified in the Special Provisions.

<table>
<thead>
<tr>
<th>TABLE 1.003.1 - SUPERPAVE MIXTURE PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Property</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Initial Gyrations, N_{ini} (information only)</td>
</tr>
<tr>
<td>Air Voids @ N_{ini}</td>
</tr>
<tr>
<td>Design Gyrations, N_{des}</td>
</tr>
<tr>
<td>Hveem Stability, CP-L 5106</td>
</tr>
<tr>
<td>Voids Filled w/Asphalt, VFA, MS-2</td>
</tr>
<tr>
<td>Lottman, Tensile Strength Ratio, % Retained CP-L 5109 (Optimum AC)</td>
</tr>
<tr>
<td>Lottman, Dry Tensile Strength, PSI, CP-L 5109</td>
</tr>
</tbody>
</table>

\(^1\) Unless otherwise specified by the Engineer.

\(^2\) Lottman requirement is 80 min. for mix design and 70 min. for field acceptance.
### TABLE 1.003.2 - VOIDS IN MINERAL AGGREGATE

<table>
<thead>
<tr>
<th>Nominal Maximum Particle Size *</th>
<th>Minimum VMA - %</th>
<th>Design Air Voids - %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>½&quot;</td>
<td>13.7</td>
<td>14.7</td>
</tr>
<tr>
<td>¾&quot;</td>
<td>12.7</td>
<td>13.7</td>
</tr>
<tr>
<td>1&quot;</td>
<td>11.7</td>
<td>12.7</td>
</tr>
</tbody>
</table>

* The nominal maximum particle size is one sieve size larger than the first sieve to retain more than 10%.

If the Contractor proposes to use RAP in the HMA mixture(s), the resulting mixture(s) must meet the same requirements as a mixture(s) that does (do) not contain RAP. The RAP shall be of uniform quality. The maximum size of the RAP shall be 1½" prior to the introduction into the mixer. The maximum aggregate size contained in the combination of RAP and new aggregate shall not exceed the maximum specified in Table 1.002.2.

### B. Plant Mix Production Verification

Mixture(s) being produced by the plant shall be verified prior to the start of the placement of the mixture(s). Verification shall be performed by a LabCAT Level C certified technician(s) to verify the volumetric properties of the mixture(s). Verification shall consist of three (3) consecutive tests, each test representing a separate production run, that have met all the requirements of Table 1.003.3. If the mixture(s) has been produced for another project within the last 90 days, verification results from that project can be submitted for this verification. Superpave mix design volumetric tolerances for the approved HMA mixture(s) shall be within the limits shown in Table 1.003.3.

### TABLE 1.003.3 - HMA MIXTURE DESIGN VERIFICATION TOLERANCES

<table>
<thead>
<tr>
<th>Property</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids</td>
<td>± 1.2%</td>
</tr>
<tr>
<td>VMA</td>
<td>± 1.2%</td>
</tr>
<tr>
<td>Asphalt Binder Content</td>
<td>± 0.4%</td>
</tr>
<tr>
<td>Stability</td>
<td>Applicable minimum</td>
</tr>
</tbody>
</table>

### 1.004 Hot Mix Asphalt Pavement Construction.

#### A. Pre-paving Meeting

Prior to the start of the paving season, project or operation, all key parties involved in the supply, haul, placement, compaction, inspection and quality control and quality assurance (QC/QA) of the HMA pavement shall attend a pre-paving meeting to go over procedures and acceptance of the HMA pavement. The layout and QC for joints shall also be discussed. The meeting may be scheduled by the Engineer. Areas of responsibility and contact names and phone numbers will be shared. Refer to the Guideline for Pre-Paving Meetings, Appendix A.
B. Paving Schedule. The Contractor shall arrange the work in such a manner as to cause a minimum of inconvenience to the traveling public and the abutting property owners. The Contractor shall submit to the Engineer a plan of this operation. In general, the Contractor shall be allowed to proceed as he proposes. However, the Engineer retains the authority to order the Contractor to schedule the proposed operation in another manner if such a change in schedule is to the benefit of the owner and beneficial to the interests of a good project. The Contractor shall arrange to have the haul vehicles operate over roads that will not be damaged by such vehicles. The Contractor shall provide all necessary Traffic Control in conformity with the current MUTCD requirements. Traffic Control shall be paid for as specified in the contract documents.

C. Weather Restrictions. The HMA mixture shall be placed only on properly constructed surfaces that are dry, unfrozen surfaces and only when weather conditions allow for proper handling and compacting of the mixture. The HMA shall be placed in accordance with the temperature limits shown in Table 1.004.1 and only when weather conditions permit the pavement to be properly placed and compacted as determined by the Engineer. Placement and compaction of the HMA may be accomplished at temperatures less than that that shown in Table 1.004.1 when meeting the compaction requirements stated herein and obtaining approval from the controlling governmental agency.

<table>
<thead>
<tr>
<th>Paving Course</th>
<th>Thickness</th>
<th>Minimum Surface and Air Temperature °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>All</td>
<td>50 *</td>
</tr>
<tr>
<td>Subsurface</td>
<td>&lt; 3&quot;</td>
<td>40</td>
</tr>
<tr>
<td>Subsurface</td>
<td>≥ 3&quot;</td>
<td>35</td>
</tr>
</tbody>
</table>

*Polymer modified asphalt binder HMA surface mixes. Other asphalt binder HMA may be placed at a minimum of 40 °F temperature and rising. Air temperature is to be taken in the shade. Surface is defined as the existing base on which the new pavement is to be placed.

D. HMA Production Facilities. The HMA plant used to produce the asphalt aggregate mixture shall meet the requirements of AASHTO M 156 and shall have adequate capacity and be maintained in good mechanical condition. The plant shall control dust, smoke, or other contaminants such that it meets the Colorado Air Quality Control Act, Title 25, Article 7, Colorado Revised Statutes (CRS) and all regulations promulgated thereunder.

1. Truck Scales. The HMA mixture shall be weighed on approved scales furnished by the Contractor or on public scales at the Contractor's expense. Such scales shall be inspected and sealed as often as the Engineer deems necessary to assure their accuracy.

2. Inspection of Plant. The Engineer or authorized representative shall have access, at all times, to all areas of the plant for checking the adequacy of the equipment; inspecting the operation of the plant; verifying weights, proportions and material properties and checking the temperatures maintained in the preparation of the mixtures.
3. **Storage Bins and Surge Bins.** HMA mix may be stored provided that any and all characteristics of the mixture are not altered by such storage.

If the Engineer determines that there is an excessive amount of heat loss, segregation or oxidation of the mixture or other adverse effects on the quality of the finished product due to the temporary storage, corrective action shall be taken. Unsuitable mixture shall be disposed of at the Contractor's expense. In no case shall HMA mix be stored more than 60 hours.

E. **Hauling Equipment.** Trucks used for hauling HMA mixtures shall have tight, clean and smooth metal beds. To prevent the mixture from adhering to them, the truck beds shall be lightly coated with a minimum amount of paraffin oil, lime solution or other approved release agent material. Petroleum distillates such as kerosene or fuel oil will not be permitted. Each truck shall have a cover of canvas or suitable cover to protect the mixture from adverse weather and to maintain temperature of the mixture. When necessary, to ensure that the mixture will be delivered to the site at the specified temperature, truck beds shall be insulated or heated and covers shall be securely fastened.

F. **Placement Equipment.** Pavers shall be self-propelled, with activated screed assemblies, heated as necessary, to spread and finish the HMA mixture to the specified width, thickness, smoothness and grade shown. The pavers shall have sufficient power to propel themselves and the hauling equipment without adversely affecting the finished pavement surface.

The receiving hopper of the paver shall have sufficient capacity to permit a uniform spreading operation. The hopper shall be equipped with a distribution system to place the mixture uniformly in front of the screed without segregation. The screed shall effectively produce a finished surface of the required evenness and texture without tearing, shoving or gouging the mixture.

The paver shall be capable of operating at consistent speeds to apply the mixture in an even, continuous layer avoiding stop and go operations. If an automatic grade and slope control device is used, the paver shall be equipped with a control system capable of automatically maintaining the specified screed elevation. The control system shall be automatically actuated from a reference line or through a system of mechanical sensors or sensor-directed mechanisms, which will maintain the paver screed at a predetermined transverse slope and at the proper elevation to obtain the required surface. The transverse slope controller shall be capable of maintaining the screed at the desired slope within ± 0.1%.

If the contractor fails to obtain and maintain the specified surface tolerances, the paving operations shall be suspended until satisfactory corrections, repairs, or equipment replacements are made.

G. **Compaction Equipment.** All compaction equipment used on the project for obtaining the required density of the HMA pavement shall be self propelled vibratory, steel wheel or pneumatic tire type capable of obtaining 94% (± 2%) of the maximum theoretical density without crushing the aggregate. They shall be in good condition and capable of operating at slow speeds to avoid displacement and tearing of the HMA mixture. Vibratory rollers shall be equipped with separate energy and propulsion controls. The number, type and weight of rollers shall be sufficient to compact the mixture to the required density while it is still in a workable condition. The use of equipment, which causes excessive crushing of the aggregate, will not be permitted.
H. Hot Mix Asphalt Mixture Production. The HMA mixture shall be produced in a plant meeting the requirements of Section 1.004 D. The dried aggregates and asphalt binder shall be combined in the plant in the quantities required to meet the Job Mix Formula (JMF).

1. Preparation of the Asphalt Binder. The asphalt binder shall be heated in a manner that will avoid local overheating and provide a continuous supply of the binder material to the plant at a uniform temperature. The temperature of the asphalt binder delivered to the mixer shall be sufficient to provide a suitable viscosity for adequate coating of the aggregate particles but shall not exceed the maximum temperature prescribed by the asphalt refiner.

2. Preparation of the Aggregate. The aggregate for the mixture shall be dried, and the temperature and rate of heating shall be such that no damage occurs to the aggregates. The temperature of the aggregate and mineral filler shall not exceed 350 °F when the asphalt is added. Particular care shall be taken that aggregates high in calcium or magnesium content are not damaged by overheating. The temperature shall not be lower than is required to obtain complete coating and uniform distribution on the aggregate particles and to provide a mixture of satisfactory workability. When hydrated lime is required to achieve complete and uniform coating of the aggregate by the asphalt binder, it shall be added to the aggregate in either a slurry or a dry form and then thoroughly mixed in an approved pug mill. The slurry shall contain a minimum of 70% water by weight. If dry hydrated lime is used, it shall be added to the wet aggregate at a minimum of 2% above saturated surface dry and then mixed thoroughly in an approved pug mill. Care should be taken to not add more moisture to the aggregate than required to insure proper coating.

3. Preparation of the Hot Mix Asphalt Mixture. The heated and dried aggregates and the asphalt binder shall be combined by weight in the mixer in the amount specified by the Job Mix Formula. The materials shall be mixed until the aggregate is completely and uniformly coated, and the asphalt cement is uniformly distributed throughout the aggregate. Baghouse fines shall be fed back to the mixing plant in a uniform and continuous manner to maintain uniformity in the mixture. The baghouse, fines feeder, auger, and related equipment shall be in good working condition and operated in accordance with manufacturer's recommendation. If the Engineer determines that non-uniform operation of the equipment is detrimental to the mixture paving operations may be suspended until the Contractor takes appropriate action.

The temperature of the HMA mixture, for different asphalt binder grades, when discharged from the plant, shall be within the maximum and minimum limits shown in Table 1.004.2. The HMA mixture shall be produced at the lowest temperature within the specified temperature range that produces a workable mix and provides for uniform coating of aggregates (95% minimum in accordance with AASHTO T 195), and allows the required compaction to be achieved.
TABLE 1.004.2 - HMA MIXTURE MIXING TEMPERATURE LIMITS

<table>
<thead>
<tr>
<th>Asphalt Grade</th>
<th>Minimum Mix Discharge Temperature, °F(^1)</th>
<th>Minimum Delivered Mix Temperature, °F(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 58 - 28</td>
<td>275</td>
<td>235</td>
</tr>
<tr>
<td>PG 64 - 22</td>
<td>290</td>
<td>235</td>
</tr>
<tr>
<td>PG 76-28</td>
<td>320</td>
<td>280</td>
</tr>
<tr>
<td>PG 64-28</td>
<td>320</td>
<td>280</td>
</tr>
<tr>
<td>PG 58-34</td>
<td>300</td>
<td>280</td>
</tr>
</tbody>
</table>

All temperatures shall be determined using a calibrated thermometer.

Reference the supplier’s recommendation for temperatures; varies from producer to producer and asphalt supplier; need to follow the viscosity charts provided by the asphalt supplier.

\(^1\) The maximum mix discharge temperature shall not exceed the minimum discharge temperature by more than 30 °F.

\(^2\) Delivered mix temperature shall be measured from the paver hopper.

I. Preparation of the Underlying Surface. The HMA mixture shall be placed on a prepared surface. Prior to the placing of the mixture, irregularities in the underlying surface shall be brought to uniform grade and cross section. The surface shall be cleaned of all dust and debris. A tack coat shall be applied as required by the contract or approved plans.

J. Tack Coat. This work consists of preparing and treating the surface that will be receiving the HMA mixture in accordance with these specifications and in conformity with the lines shown on the plans or established by the Engineer. Existing asphalt surfaces receiving an asphalt overlay, existing vertical concrete surfaces such as curb and gutter, crossspans and manholes, or the underlying courses of multi-course asphaltic pavement structure, shall receive a tack coat as required to ensure bonding of the new mat.

The asphaltic material for all tack coats shall meet the requirements of Section 1.002.E.2. The emulsified asphalt shall be diluted to not more than 1:1 with water and applied at a minimum of 0.10 ± 0.02 gallons per square yard of diluted material. The Engineer may direct other application rates to match the age and/or condition of the surface.

Before applying the tack coat, surfaces shall be thoroughly cleaned of all dirt and other debris to insure adequate bond between tack surface and asphaltic mat. Tack coats shall not be applied when the surface to receive the tack coat is wet or when weather conditions would prevent the proper construction of the tack coat. The surface shall be allowed to cure in order to permit drying and setting of the tack coat prior to the paving operation.

The Contractor shall provide equipment for heating and uniformly applying the tack coat material. The distributor or equipment for applying the tack coat shall be capable of uniformly spraying the material at even temperature and uniform pressure on variable widths of surface up to 15 feet in width at readily determined and controlled rates as required.

The tack coat shall be applied in a uniform and continuous spread. When traffic is maintained, sufficient width shall be left to adequately handle traffic. Care shall be taken so the application of the tack coat materials at the junctions of spreads is not in excess of the specified quantity. Excess material shall be removed or distributed as directed. Tack coat shall not be placed on any surface where traffic will travel on the freshly applied material.
K. **Patching.** Remove the backfill material to the depth and extent required by the owner/agency engineer. Prepare the subsurface with the required base course and/or Portland Cement concrete subsurface as specified by the owner/agency engineer. Depths and/or thickness of base course, Portland Cement concrete and/or asphalt pavement shall be as indicated on the drawings. The asphalt pavement shall be a minimum of four (4) inches or equal to the existing pavement thickness, whichever is greater. The backfill and base coarse material shall be thoroughly compacted to the densities as specified by the owner with a roller for large areas and smaller hand operated compactor for small patches.

Existing pavement may be rough cut initially in conjunction with trenching; however, a square even vertical cut shall be made in the existing HMA pavement after placement of backfill and prior to pavement replacement. The square vertical cut shall be made at a minimum of six (6) inches back from the trench line into good pavement. Before placement of the new pavement, the cut edges shall be thoroughly cleaned and a tack coat shall be uniformly and evenly applied to vertical faces. The patch shall be made with placement of a hot asphalt cement and aggregate mixture.

In large patches or whenever possible, a self-propelled paving machine shall be used to place the mixture. In small patches, the material shall be hand placed or placed with a spreader box without separation of the mixture. The material shall be placed to the grade and thickness required to allow for compaction after rolling. The hot mix material shall be compacted using the number, weight and type of rollers required to provide 94% (± 2%) of the maximum density of the mix (AASHTO T-209). Rolling shall continue until all roller marks are eliminated and no further compression is possible in the pavement. After rolling the surface, a straightedge or a string line shall be used to check grade and riding quality of the patch.

L. **Hauling of HMA Mixture.** Transporting the HMA mixture from the plant to the job site shall be done in vehicles meeting the requirements of Section 1.004.E. The Contractor shall have an adequate number of vehicles so delivery of the HMA mixture can be continuous with a minimum of interruptions of material to the paving equipment in order for a continued non-stop paving operation and before the temperature of the HMA material falls below 235 °F for non-modified material or not less than 275 °F for polymerized modified material. Deliveries shall be planned so the placing and compaction of all the mixture prepared for one day's operation can be completed during daylight, unless adequate artificial lighting is provided by the Contractor and approved by the Engineer. When the atmospheric temperature is less than 50 °Fahrenheit, all loads shall be delivered continuously in covered vehicles meeting the requirements in Section 1.004.E. Hauling over newly placed mixture shall not be permitted until the mixture has been compacted as specified and allowed to cool sufficiently so vehicular traffic does not damage or deform the final lift.

M. **Placing of HMA Mixture.** The HMA mixture shall be placed using equipment meeting the requirements in Section 1.004.F to the established grade and required thickness over the entire width or partial width as practicable.

The mixture shall be laid upon an approved surface, spread and struck off to obtain the required grade and elevation after compaction. The thickness of the mixture being placed should be such that after compaction is achieved, the finished mat will be even with the existing adjacent mat. Raking is discouraged and should not be allowed if it is causing segregation in the mat. Casting or raking that causes any segregation will not be permitted.
On areas where the use of mechanical spreading and finishing equipment is impracticable, the mixture shall be carefully dumped, spread, raked, screeded, and luted by hand tools to the required compacted thickness plus the amount necessary to achieve the required compacted thickness. Carefully move or minimally work the HMA mix with the use of rakes, lutes, or shovels to avoid segregation. Mixtures made with modified asphalt cement require more rapid completion of handwork areas than for normal mixtures. Hauling and placement sequences shall be coordinated so that the paver is in constant motion. Excessive starting and stopping should be avoided. If stopping and starting of the paving operation cannot be avoided, it should be done as rapidly as possible within reason. A construction joint shall be placed any time the paver stops, and the screed drops enough to cause a surface dip in violation of Section 1.004.M.1.b. or the mat temperature falls enough that the compaction can not be obtained as specified.

When echelon paving is permitted and approved by the Engineer, production of the mixture shall be maintained so pavers can be used in echelon to place the wearing course in adjacent lanes.

When material is shoveled, it shall be deposited by turning the shovel over above the desired area. No "slinging" of the shovel will be permitted. The hand placed material shall be smoothed and left higher than the machine laid material by about 1/4 inch per inch of depth prior to rolling. If the machine laid mixture has been rolled, then the hand laid mixture shall be smoothed and left higher than the rolled pavement by about 1/4 inch per inch depth. The majority of the raker's work shall be done with a lute rather than a tined rake.

1. Segregation. The HMA mixture shall be transported and placed on the roadway without segregation. If at any time, the Engineer observes segregated areas of pavement, s/he will notify the Contractor immediately. Further laydown operations will then be at the Contractor's risk. Any segregated areas behind the paver shall be removed upon verification. The segregated material shall be replaced with specification material.

After rolling, segregated areas will be delineated by the Engineer and evaluated as follows:

a. The Engineer will delineate the segregated areas to be evaluated and inform the Contractor of the location and extent of these areas within two calendar days, excluding weekends and holidays, of placement.

b. In each segregated area or group of areas to be evaluated, the Contractor shall take five 10 inch cores at random locations designated by the Engineer. In accordance with CP 75, the Contractor shall also take five 10 inch cores at random locations designated by the Engineer in non-segregated pavement adjacent to the segregated area. These cores shall be within 30 feet of the boundary of the segregated area and in the newly placed pavement. The coring shall be in the presence of the Engineer and the Engineer will take immediate possession of the cores. The Contractor may take additional cores at the Contractor's expense.

c. Gradation of the aggregate of the cores will be determined in accordance with CP 46.

d. The core aggregate gradations from the segregated area will be compared to the core aggregate gradations of the corresponding non-segregated area.
e. Two key sieves of the core gradations from the segregated area will be compared to the core gradations from the corresponding non-segregated area to determine the difference. If differences for both key sieves exceed the allowable difference specified in Table 1.004.3, the area is segregated.

<table>
<thead>
<tr>
<th>TABLE 1.004.3 - SEGREGATION DETERMINATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix Grading</td>
</tr>
<tr>
<td>SX</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>S</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

f. Segregated areas in the top lift shall be removed and replaced, full lane width, at the Contractor’s expense. The Engineer may approve a method equivalent to remove and replace that results in a non-segregated top lift. Segregated areas in lifts below the top lift, that are smaller than 50 square feet per 100 linear feet of lane width, will be corrected by the Contractor at the Contractor’s expense in a manner acceptable to the Engineer. Segregated areas larger than 50 square feet per 100 linear feet of lane width in any lift shall be removed and replaced, full lane width, by the Contractor at the Contractor’s expense.

If the area is determined to be segregated, the corings will be at the expense of the Contractor. If the area is determined to be non-segregated, the Engineer shall reimburse the Contractor the actual cost for obtaining the ten cores, not to exceed $2,000 total.

2. Lift Thickness. Each lift of compacted asphalt pavement shall be of uniform thickness. The minimum uncompacted lift thickness shall be three times the nominal aggregate size of the mixture. The maximum lift thickness shall be 3 inches unless the Contractor can demonstrate the ability to achieve required compaction of thicker lifts.

The final lift, when placed adjacent to guttering, shall extend ¼ to ½ inch above the lip of the gutter when compacted for a catch curb and gutter and shall be even with a spill curb and gutter at the time of construction.

The average compacted total pavement thickness shall be greater than or equal to the design specified on the construction drawings, with no single core thickness less than 90% of the specified thickness.

3. Joint Construction. The formation of all joints shall be made in such a manner as to ensure a continuous bond between the courses and to obtain the required density. All joints shall have the same texture and smoothness as other sections of the mat and shall meet the requirements for smoothness and grade.

The roller shall not pass over the unprotected end of the freshly laid mixture except when necessary to form a transverse joint. When necessary to form a transverse joint, it shall be made by means of placing a bulkhead or by tapering the course.

The free edge of the paved pass shall be laid as straight as possible and to the satisfaction of the Engineer. This joint shall be spray tack coated prior to placement of adjacent paving.
The new compacted mat shall overlap the adjacent previous placed mat no more than 1.5 inches. Excess overlap or thickness shall not be raked or cast onto the new mat, but shall be wasted by pulling back and removing. The hot edge shall be blocked or bumped in a smooth line consistent with the previous longitudinal edge. Minor raking will only be allowed to correct major grade problems or provide mix around manholes and meter covers.

**a. Longitudinal Joints.** The longitudinal joint in both a new pavement and an overlay pavement layer shall offset the joint in the layer immediately below by a minimum of 6 inches. In multiple lift (3 lifts or more) construction the joint in any succeeding lift shall not be placed in line of any of the previous lifts. The joints in any pavement layer shall not fall in a wheel path. The Contractor shall submit a longitudinal joint and pavement marking plan three days prior to the Pre-Paving Conference. The plan shall show the location and configuration of the proposed longitudinal joints and pavement markings, and shall detail the methods to be used in the field to establish a control line. The Contractor shall use a continuous string line to delineate every longitudinal joint during paving operations. All exposed string line shall be picked up and disposed of at the end of each day’s paving. Paving shall not commence until the plan has been approved in writing by the Engineer.

The joints in the top layer of pavement shall be located as follows unless otherwise approved in writing by the Engineer:

1. For two lane roadways, offset 6 to 12 inches from the center of pavement and from the outside edge of the travel lanes.

2. For roadways of more than 2 lanes, offset 6 to 12 inches from lane lines and outside edge of travel lanes.

Longitudinal joints shall not cross the centerline, lane lines or edge line unless approved by the Engineer.

Where paving operations are on the present traveled roadway, the Contractor shall arrange paving operations so there will be no exposed longitudinal joints between adjacent travel lanes longer than 25 feet at the end of a day’s run. With the approval of the Engineer, the Contractor may be permitted to:

1. Leave a vertical exposed longitudinal joint when the thickness of the pavement course being placed is 1.5 inches or less.

2. Leave an exposed longitudinal joint when the thickness of the pavement course being placed is greater than 2 inches provided that the top 1 inches of the longitudinal joint shall be vertical. The remainder of the joint, below 1-inch vertical portion, shall be tapered. The minimum width of the taper shall be two times the remaining thickness of the pavement course.

In the methods listed in paragraphs (1) and (2) above, all contact surfaces shall be given a tack coat of bituminous material before placing any fresh HMA mixture against the edge.
b. Transverse Joints. Along with the longitudinal joint plan, the Contractor shall submit a transverse joint plan showing the locations and the methods to be used to construct transverse joints. The Engineer must approve such plans prior to paving. Placing of the HMA mixture shall be continuous with a minimum of transverse joints.

Rollers shall not pass over the unprotected end of a freshly laid mixture. Transverse joints shall be formed by cutting back on the previous run to expose the full depth of the course. Tack coat material shall be applied to contact surfaces of all joints just before additional mixture is placed against the previously compacted material.

The end of transverse joints shall be located so they will be constructed with a full head of mix in front of the screed. When butt joints are constructed, runoff boards shall be used to support the roller on the downstream side of the joint. All tapered boards, rounded edges and segregated areas shall be removed to achieve a vertical face at the butt joint before paving is restarted.

When a tapered joint is required for traffic access, the ramp shall be removed back to a full depth before paving is restarted.

When restarting paving operations, the paver screed shall be placed on starter blocks on the completed side of the transverse joint. The starter blocks should be approximately 25% of the thickness of the existing completed mat, so that adequate grade and compaction can be achieved on starting the paving operation.

4. Compaction. The HMA shall be compacted by rolling. The number, weight, and type of rollers furnished shall be sufficient to obtain the required density while the mixture is in a workable condition. Compaction shall begin immediately after the mixture is placed and be continuous until the required density is obtained. When the mixture contains unmodified asphalt cement (PG 58-28 or PG 64-22) or modified (PG 58-34), and the surface temperature falls below 185 °F, further compaction effort shall not be applied unless approved. If the mixture contains modified asphalt cement (PG 76-28 or PG 64-28) and the surface temperature falls below 230 °F, further compaction effort shall not be applied unless approved.

All roller marks shall be removed with the finish rolling. Use of vibratory rollers with the vibrator on will not be permitted during surface course final rolling and will not be permitted on any bridge decks covered with waterproofing membrane.

Pavement shall be compacted to a density of 94% (± 2%) of the maximum theoretical density, determined according to CP 51. Field density determinations will be made in accordance with CP 44 or 81 (see Table 1.004.7). Core samples and compaction testing locations shall include a representative sampling (20% - 30%) of tests taken at 12 inches from visible joint lines for one lift paving and 18 inches from visible joint lines for multiple lift paving, for both longitudinal and transverse joints, in order to verify correlation between mat density and joint density. The joint density requirement shall be a minimum of 90% of the maximum theoretical density.

Along forms, curbs, headers, walls, and all other places not accessible to the rollers, the mixture shall be thoroughly compacted with mechanical tampers.

Any mixture that becomes loose and broken, mixed with dirt, or is in any way defective, shall be immediately removed and replaced with fresh hot mixture, and compacted to conform with the surrounding area.
N. Testing and Inspection.

1. Quality Control (QC). For the purposes of this Specification, QC is defined as the program employed by the HMA Supplier and Paving Contractor (“Contractor”) for controlling the production and installation of HMA pavements in compliance with this Specification and industry standards. QC of the work will be based on the implementation of the Contractor’s Quality Control Plan, on the results of QC testing, and on the following characteristics of the HMA mixture and the completed pavement:

- Binder Grade Certification
- Asphalt Binder Content
- Aggregate Gradation
- Air Voids
- Voids in the Mineral Aggregate (VMA)
- Mat Density
- Mat Thickness
- Mat Smoothness
- Lottman Tensile Strength

Quality Control (QC) testing shall typically be performed by the HMA Supplier/Paving Contractor using the HMA Supplier’s lab. QC testing shall include both the plant-produced materials as specified in Tables 1.004.5 and 1.004.6, and the field-placed material as specified in Table 1.004.7. Test results from each day’s production shall be completed and submitted as soon as possible to the Owner/Agency representative. Failing QC test results shall be reported within one business day.

Testing facilities shall conform to AASHTO requirements, including R-18. Personnel performing sampling and testing of HMA mixtures, in the lab and in the field, shall possess the appropriate and current LabCAT certification or combination of certifications, issued by the Rocky Mountain Asphalt Education Center for all sampling and testing performed.

2. Quality Assurance (QA). For the purposes of this Specification, QA is defined as the program employed by a City or County (“Owner/Agency”), for assuring compliance with this Specification and industry standards, for assuring that the Contractor’s QC program is functioning properly, and for accepting the finished HMA pavement product. Developers as interim owners provide the QA testing on development projects.

The Owner/Agency reserves the right to conduct Quality Assurance (QA) testing on any and all features of the HMA production and paving operations. The Owner/Agency will pay for passing QA tests on City/County contracts. The Developer will pay for passing QA tests on development projects. Failing tests and required retests and corrective actions will be paid for by the Contractor, provided that sampling and testing are performed in accordance with proper procedures. The cure for failed testing is at the discretion of the Owner/Agency Engineer, and may include removal and replacement, deductive change order, or extended warranty with financial assurance.

QA of the work will be primarily based on the following characteristics of the HMA mixture and the completed pavement:

- Asphalt Binder Content
- Aggregate Gradation
- Mat Density (Including Joints)
- Mat Thickness
- Mat Smoothness
VMA/volumetric QA testing will normally be reserved for larger jobs, and utilized at the discretion of the Owner/Agency by special provision.

QA tests will be performed by either an Independent Testing Lab or by an Owner/Agency Lab. Testing facilities shall conform to AASHTO requirements, including R-18, and testing personnel shall be LabCAT certified. Failing QA test results shall be provided to the Contractor/Developer and HMA Supplier within one business day.

3. Testing Responsibilities.

a. **Capital Projects and Overlays.** For capital projects, overlays and similar projects that are managed directly by contracts between the owning agency and general contractors, paving contractors and/or HMA suppliers, the testing responsibilities will be specified by the contract.

   (1) **QC.** In general, QC for overlays and capital projects will be managed by the HMA Supplier or Paving Contractor, primarily using the HMA Supplier’s lab.

   (2) **QA.** The Owner will augment the Contractor’s QC program by providing an Independent Testing Lab for the required testing frequencies as specified in Table 1.004.7 – “Field Acceptance Testing”, or as specified in the contract. Additional QA tests on both plant-produced materials and field-placed materials may be ordered by the Owner’s representative from an Independent Testing Lab at any time as deemed necessary by the Owner’s project manager.

b. **Development Projects.**

   (1) **QC.** For development projects, QC testing will be performed by the Contractor. The plant-produced HMA materials will be tested by the HMA Supplier’s lab as specified in Tables 1.004.5 and 1.004.6. The field-placed material shall be tested by the Contractor’s lab as specified in Table 1.004.7.

   (2) **QA.** The plant-produced and field-placed material shall also be tested by an Independent Testing Lab, as specified in Tables 1.004.4, 1.004.6 and 1.004.7, paid for by the Developer. The Developer may order additional testing as necessary to assure compliance with this Specification. Additional QA tests on both plant-produced materials and field-placed materials may also be ordered and paid for by the Owner/Agency’s representative from an Independent Testing Lab at any time deemed necessary by the Owner/Agency’s representative.

c. **Summary.** Table 1.004.4 – “Testing Responsibilities” (page 20) summarizes these requirements.
TABLE 1.004.4 – TESTING RESPONSIBILITIES

<table>
<thead>
<tr>
<th>SAMPLING LOCATION</th>
<th>TESTS</th>
<th>QC Capital Projects &amp; Overlays</th>
<th>Development Projects</th>
<th>QA Capital Projects &amp; Overlays</th>
<th>Development Projects ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLANT - PRODUCED MATERIALS</td>
<td>Asphalt Binder Grade Certification</td>
<td>Refinery</td>
<td>Refinery</td>
<td>N/A</td>
<td>Refinery</td>
</tr>
<tr>
<td></td>
<td>Asphalt Binder Content</td>
<td>HMA Supplier</td>
<td>HMA Supplier</td>
<td>Independent Testing Lab</td>
<td>Independent Testing Lab</td>
</tr>
<tr>
<td></td>
<td>Aggregate Gradation</td>
<td>HMA Supplier</td>
<td>HMA Supplier</td>
<td>Independent Testing Lab</td>
<td>Independent Testing Lab</td>
</tr>
<tr>
<td></td>
<td>Air Voids</td>
<td>HMA Supplier</td>
<td>HMA Supplier</td>
<td>Independent Testing Lab</td>
<td>Independent Testing Lab</td>
</tr>
<tr>
<td></td>
<td>Voids in Mineral Aggregate (VMA)</td>
<td>HMA Supplier</td>
<td>HMA Supplier</td>
<td>Independent Testing Lab</td>
<td>Independent Testing Lab</td>
</tr>
<tr>
<td></td>
<td>Lottman Tensile Strength</td>
<td>HMA Supplier</td>
<td>HMA Supplier</td>
<td>Independent Testing Lab</td>
<td>Independent Testing Lab</td>
</tr>
<tr>
<td>FIELD - PLACED MATERIALS</td>
<td>Asphalt Binder Content</td>
<td>HMA Supplier</td>
<td>HMA Supplier</td>
<td>Owner/Agency or Ind. Lab</td>
<td>Independent Testing Lab</td>
</tr>
<tr>
<td></td>
<td>Aggregate Gradation</td>
<td>HMA Supplier</td>
<td>HMA Supplier</td>
<td>Owner/Agency or Ind. Lab</td>
<td>Independent Testing Lab</td>
</tr>
<tr>
<td></td>
<td>Mat Density (% Compaction)</td>
<td>HMA Supplier</td>
<td>HMA Supplier</td>
<td>Owner/Agency or Ind. Lab</td>
<td>Independent Testing Lab</td>
</tr>
<tr>
<td></td>
<td>Mat Thickness</td>
<td>HMA Supplier</td>
<td>HMA Supplier</td>
<td>Owner/Agency or Ind. Lab</td>
<td>Independent Testing Lab</td>
</tr>
<tr>
<td></td>
<td>Mat Smoothness</td>
<td>Paving Contractor</td>
<td>Paving Contractor</td>
<td>Owner/Agency Inspector</td>
<td>Owner/Agency Inspector</td>
</tr>
</tbody>
</table>

¹ Independent Testing Lab hired by the Developer.

4. Testing Frequencies and Tolerances.

a. Plant-Produced Material. Sampling shall be at the plant. Sufficient material for preparation of test specimens shall be obtained by the Contractor in accordance with CP 41-98. When the Owner/Agency chooses to conduct QA testing through an Independent Testing Lab, samples shall be split with the supplier’s materials laboratory. One set of laboratory compacted specimens will be prepared for each at the number of gyrations required in Table 1.003.1. Each set of laboratory compacted specimens will consist of three test portions prepared from the same sample increment. The sample of HMA mixture may be placed in an oven in a covered metal container for not more than 30 minutes to maintain heat. The material shall be compacted at the temperature as specified in the Job Mix Formula.

The testing of plant-produced material shall be in accordance with Table 1.004.5 and 1.004.6. Two consecutive gradation tests falling outside the Action Limits, or one gradation test falling outside the Suspension Limits, will warrant corrective action and shall be subject to engineering review and possible removal and replacement of the represented day’s production.
The asphalt binder in the plant-produced material shall meet the specification in Table 1.002.5 – Properties of Performance Graded Binders, for the binder grade specified.

### TABLE 1.004.5 – PLANT QC TESTING FREQUENCIES AND TOLERANCES

<table>
<thead>
<tr>
<th>Test</th>
<th>Procedure</th>
<th>Specification Tolerance Limits</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Binder Content</td>
<td>AASHTO T 308-01 (CP-L 5120)</td>
<td>± 0.4%</td>
<td>1 per 1000 tons (^2) or 1 per day min.</td>
</tr>
<tr>
<td>Aggregate Gradation</td>
<td>AASHTO T 27-99 (CP 31A)</td>
<td>Table 1.004.6</td>
<td>1 per 1000 tons (^2) or 1 per day min.</td>
</tr>
<tr>
<td>Air Voids</td>
<td>AASHTO T 269-97</td>
<td>2.8% to 5.2%</td>
<td>1 per 1000 tons (^2,3) or 1 per day min.</td>
</tr>
<tr>
<td>Void in Mineral Aggregate</td>
<td>CP 48-95</td>
<td>Table 1.003.3</td>
<td>1 per 1000 tons (^2,3) or 1 per day min.</td>
</tr>
<tr>
<td>Lottman Tensile Strength</td>
<td>CP-L 5109</td>
<td>70 min.</td>
<td>1 per mix design in first month of production</td>
</tr>
</tbody>
</table>

1 Subject to owning agency engineer’s direction on a job by job basis.

2 The frequency of testing shall be based on cumulative tonnage of all projects using the approved Job Mix Formula. Representative tests for each mix design may be used for multiple jobs. Testing for less than 500 cumulative tons per day is not required.

3 Upon verification in accordance with Section 1.003, air voids and VMA testing frequency may be 1 per 10,000 tons or 1 per week minimum.

### TABLE 1.004.6 - CONTROL LIMITS FOR AGGREGATE GRADATION MEASUREMENTS

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Action Limit</th>
<th>Suspension Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in.</td>
<td>0 %</td>
<td>0 %</td>
</tr>
<tr>
<td>¾ in.</td>
<td>± 6 %</td>
<td>± 8 %</td>
</tr>
<tr>
<td>½ in.</td>
<td>± 6 %</td>
<td>± 8 %</td>
</tr>
<tr>
<td>⅜ in.</td>
<td>± 6 %</td>
<td>± 8 %</td>
</tr>
<tr>
<td>No. 4</td>
<td>± 5 %</td>
<td>± 7 %</td>
</tr>
<tr>
<td>No. 8</td>
<td>± 5 %</td>
<td>± 7 %</td>
</tr>
<tr>
<td>No. 30</td>
<td>± 4 %</td>
<td>± 6 %</td>
</tr>
<tr>
<td>No. 200</td>
<td>± 2%</td>
<td>± 3 %</td>
</tr>
</tbody>
</table>

b. Field-Placed Material. Sampling for Asphalt Binder Content and Aggregate Gradation shall be taken jointly by the QC and QA representatives, at the plant or at the job site, as designated by the Owner/Agency Representative. Job site samples will be taken from the truck or behind the paver. HMA pavement shall be tested in-place for acceptance in accordance with Table 1.004.7 (page 22). Densities shall be determined by core sampling in most cases and supplemented by nuclear gauge testing when allowed by the Owner/Agency representative.

Acceptance will be based on QC tests provided by the HMA Supplier/Paving Contractor, and verified by QA testing by Independent Testing Laboratories as required by this Specification and the Owner/Agency representative.
## TABLE 1.004.7 – FIELD ACCEPTANCE TESTING

<table>
<thead>
<tr>
<th>Test</th>
<th>Procedure</th>
<th>Specification Tolerance Limits</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Binder Content</td>
<td>AASHTO T 308-01 (CP-L 5120)</td>
<td>± 0.4 %</td>
<td>1 per 1,000 tons, or 1 per day minimum</td>
</tr>
<tr>
<td>Aggregate Gradation</td>
<td>AASHTO T 27-99 (CP 31A)</td>
<td>See Table 1.004.6</td>
<td>1 per 1,000 tons, or 1 per day minimum</td>
</tr>
<tr>
<td>Mat Density (% Compaction)</td>
<td>CP 51-98, or CP 81-01</td>
<td>94% ± 2%</td>
<td>1 per 500 tons, or portion thereof 1</td>
</tr>
<tr>
<td>Mat Thickness</td>
<td>CP 51-98</td>
<td>Design minus 10% on a single test. Job average must be ≥ design thickness.</td>
<td>1 per lane every 1,000 feet, or portion thereof 1</td>
</tr>
<tr>
<td>Mat Smoothness</td>
<td>10-ft Straightedge</td>
<td>≤ 3/16-inch</td>
<td>at Owner/Agency Inspector’s discretion</td>
</tr>
</tbody>
</table>

1 Longitudinal joints shall be tested at 20% - 30% of the total number of compaction tests taken, with a minimum of at least one per job.

When nuclear density measurements are allowed by the Owner/Agency representative for acceptance of field placed material, they shall be taken in accordance with CP 81-01. The nuclear density gauge shall be calibrated to a minimum of six cores taken from the same material. If nuclear density measurements indicate results outside the tolerance limits, cores shall be used to verify results. Size of the project should be taken into account when determining the basis for the density test correlation. Small quantities of HMA are not applicable to CP 81-01 procedure.

Core samples shall be neatly cut with a core drill or other approved equipment. The minimum diameter of the sample shall be four inches. Samples that are clearly defective, as a result of sampling, shall be discarded and another sample taken. Cores shall not be taken closer than one foot from a transverse or longitudinal joint. The Contractor installing the pavement shall furnish all tools, labor and materials for cutting samples and filling the cored pavement. The Contractor shall be responsible for supplying the Owner’s materials laboratory with the core samples. Cored holes shall be filled in a manner acceptable to the owner and within one day after sampling.

Test results of the percent of relative compaction (density) shall be determined by dividing the density reading of the nuclear density gauge or core by the maximum density of the product as determined by the approved Job Mix Formula (JMF). Testing frequency for Percent Relative Compaction shall be shall be in accordance with Table 1.004.7.

The required compacted HMA mat thickness shall be as specified on the construction plans and/or specified in the Special Conditions. Final mat thickness shall be determined from the same cores as are used to test for density. No single core thickness shall be less than ninety percent (<90%) of the specified thickness on the construction plans and/or Special Conditions. In addition, the average thickness for the job must be greater than or equal to the design thickness. When a single core thickness is less than ninety percent (<90%) of that specified, or when the job average is less than the specified design thickness, the Contractor shall correct the situation at his expense.
Surface Smoothness of the final riding surface of all pavements is subject to testing by the 10-foot straightedge method. The Contractor shall furnish an approved 10-foot straightedge and depth gauge and provide an operator to aid the Engineer in testing the finished pavement surface. Areas to be tested shall be determined by the Engineer or the Owner Agency Inspector. The variation between any two contacts with the surface shall not exceed 3/16-inch in 10 feet. Areas showing deviation of more than 3/16-inch shall be marked and corrected at the Contractor’s expense.

5. Contractors’ Quality Control Program. The Asphalt Producers and the Installing Contractors shall develop Quality Control (QC) Programs. The QC programs shall address all elements which affect the quality of the pavement including, but not limited to:

- Mix Design
- Aggregate Grading
- Quality of Materials
- Stockpile Management
- Proportioning
- Mixing and Transportation
- Placing and Finishing
- Asphalt Binder
- Air Voids
- Voids in Mineral Aggregate (VMA)
- Compaction
- Surface Smoothness

a. Testing Laboratory. The Contractor shall provide a fully equipped asphalt laboratory or shall hire an independent testing laboratory for quality control testing. Laboratory facilities shall be kept clean and all equipment shall be maintained in proper working condition. The Owner’s designated representative shall be permitted unrestricted access to inspect the Contractor’s laboratory facility and witness quality control activities. The Owner’s representative will advise the Contractor in writing of any noted deficiencies concerning the laboratory facility, equipment, supplies, testing personnel and testing procedures. When the deficiencies are serious enough to be adversely affecting test results, the incorporation of the materials into the work shall be suspended immediately and will not be permitted to resume until the deficiencies are satisfactorily corrected.

b. Quality Control Testing. The Contractor shall develop a quality control testing plan and perform all quality control tests necessary to control the production and construction processes applicable to these specifications. Quality control test results shall be submitted to the Engineer within 24 hours of sampling. Personnel performing sampling and testing of aggregates or HMA mixtures in the lab and in the field shall possess the appropriate LabCat certification or combination of certifications issued by the Rocky Mountain Asphalt Education Center for all sampling and testing performed.

Test procedures for QC testing are shown in Tables 1.004.5 and 1.004.7.

The quality control testing plan shall include, but not necessarily be limited to, the following tests:

1. **Asphalt Binder.** Asphalt content tests shall be performed for determination of binder content and shall be sampled at the same time as the VMA and air voids samples are obtained.

2. **Air Voids and VMA.** Air Voids and VMA shall be tested in accordance with AASHTO T 269-97 and CP 48-95, respectively, at a minimum frequency of 1 test
per 1,000 tons or 1 test per day. Upon verification in accordance with Section 1.003, Air Voids and VMA testing frequency may be reduced to 1 test per 10,000 tons or 1 test per week minimum.

(3) Gradation. Aggregate gradations shall be determined from mechanical analysis of extracted aggregate. When binder content is determined by a nuclear method, aggregate gradation shall be determined from the cold feed on drum mix or continuous mix plants or from hot bin samples on batch plants. The samples shall use actual batch weights to determine the combined aggregate gradation of the mixture.

(4) Lottman Tensile Strength. One sample per mix design during the first month of production, and as necessary for control thereafter.

(5) Moisture Content of Aggregate. The moisture content of the aggregate used for the production shall be determined in accordance with AASHTO T 255.

(6) Moisture Content of Mixture. The moisture content of the mixture shall be determined in accordance with AASHTO T 110 or CP42-90.

(7) Temperatures. Temperatures shall be checked, at least twice per day, at necessary locations to determine the temperatures of the dryer, the binder in the storage tank, the mixture at the plant and the mixture at the job site.

(8) In-Place Density Monitoring. The Contractor shall conduct testing to ensure that the specified density is being achieved during the construction of the HMA pavement.

(9) Additional Testing. Any additional testing that the Contractor deems necessary to control the process may be performed at the Contractor's option.

(10) Monitoring. The Engineer and/or the owner reserve the right to monitor any of the quality control tests listed above and to perform verification sampling and testing of all materials.

(11) Sampling. When directed by the Engineer, the Contractor shall sample and test any material that appears inconsistent with similar material being sampled, unless such material is voluntarily removed and replaced or deficiencies corrected by the Contractor. All sampling shall be in accordance with standard procedures specified.

(12) Control Charts. The Contractor shall maintain linear control charts both for individual measurements and ranges (i.e., difference between highest and lowest measurements) for aggregate gradation and asphalt content.

O. Method of Measurement. The accepted quantities of HMA pavement will be measured by the ton for the compacted thickness of pavement specified in each pay item. Batch mass (weights) will not be permitted as a method of measurement. The tonnage shall be the mass (weight) used in the accepted pavement.

HMA pavement courses measured by the square yard will be paid for at the contract unit price per square yard. This payment shall be full compensation for materials, tools, equipment and labor necessary to complete the work under this section in accordance with the plans and these specifications. The payment shall be full compensation for prime and/or tack coats applied in accordance with these specifications.
If there is no pay item for HMA pavement of the type specified, it will not be measured and paid for separately, but shall be included in the pay item most closely associated with the work.

**P. Basis of Payment.** The accepted quantities of HMA pavement will be paid for at the contract unit price for each pavement type and/or thickness listed in the bid schedule. The price will be full compensation for furnishing all materials, for preparation, mixing, placing and compaction of these materials and for all labor, equipment, tools and incidentals necessary to complete the work.

Payment for tack coat shall be a separate bid item and shall include all materials, tools, equipment and labor necessary to complete the work in accordance with the plans and specifications and as directed by the Engineer. Tack coat shall be paid for based on diluted gallons.
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Appendix A

HOT MIX ASPHALT PREPAVING CONFERENCE AGENDA

The items in the following agenda are minimum requirements that should be covered during the conference. The agenda may be used as is or as a base to develop a customized agenda.

<table>
<thead>
<tr>
<th>Project Number:</th>
<th>Owner’s Rep:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Code (SA):</td>
<td>Project Engineer:</td>
</tr>
<tr>
<td>Location:</td>
<td>Contractor:</td>
</tr>
<tr>
<td>Date:</td>
<td>Superintendent:</td>
</tr>
<tr>
<td>Time:</td>
<td>Foreman:</td>
</tr>
</tbody>
</table>

I. Attendance Roster

| Name: | Office Number: |
| Representing: | Fax Number: |
| Responsibilities: | Cell Number: |
| City, State, Zip: | Email Address: |

| Name: | Office Number: |
| Representing: | Fax Number: |
| Street Address: | Cell Number: |
| City, State, Zip: | Email Address: |

II. Project Organization and Status

A. OWNER/AGENCY Personnel:

1. Personnel in Charge at Paving Site:

| Name/Title: | Fax Number: |
| Office Number: | Home Number: |
| Mobile Number: | Email Address: |

2. Alternate Contact (when personnel identified in A.1 is not present):

| Name/Title: | Fax Number: |
| Office Number: | Home Number: |
| Mobile Number: | Email Address: |

3. Quality Assurance Supervisor:

| Name/Title: | Fax Number: |
| Office Number: | Home Number: |
| Mobile Number: | Email Address: |

4. Inspector/Duties:

| Name/Title: | Fax Number: |
| Office Number: | Home Number: |
| Mobile Number: | Email Address: |

5. Inspector/Duties:

| Name/Title: | Fax Number: |
| Office Number: | Home Number: |
| Mobile Number: | Email Address: |

Comments
B. CONTRACTOR / DEVELOPER Personnel:

1. Quality Control Supervisor:
   - Name/Title:  
   - Fax Number:  
   - Office Number:  
   - Mobile Number:  
   - Home Number:  
   - Email Address:  

2. Personnel to Notify at Paving Site:
   - Name/Title:  
   - Fax Number:  
   - Office Number:  
   - Mobile Number:  
   - Home Number:  
   - Email Address:  

3. Other:
   - Name/Title:  
   - Fax Number:  
   - Office Number:  
   - Mobile Number:  
   - Home Number:  
   - Email Address:  

Comments

C. Testing Information: (Compaction Test Results, acceptance tests to be performed, frequency)

1. Test locations determined by?

2. Frequency of tests to be performed?

3. Are Quality Assurance tests to be performed in addition to Quality Control tests?
   - If Yes how often, and who will be responsible to schedule the QA tests?

4. Turn around time of test results?
   - Preliminary?
   - Final?

5. Is the mix design(s) approved by the Owner/Agency?

D. Submittal and Notification of Test Results

1. What projects and affected owners/agencies will this JMF be provided to?

2. What process will be provided for submittal of test results?

3. Who should copies of the JMF be provided to?

4. Who will be responsible for QA testing?

III. Scheduling

A. Materials:
   Materials will be available for sampling on:

B. Asphalt Plant:
   The asphalt plant will be ready to be checked on:

C. Paving Equipment:
   The paving equipment will be set up and ready to be checked on:
### D. Paving Sequence:
1. The Contractor will commence paving on:
2. Hot Bituminous Pavement will be delivered at:
3. The Contractor proposes to work the following hours:
4. How many days per week does the Contractor intend to work?
5. What paving sequence will the Contractor follow?
6. Where will paving start?

### E. A quality control plan shall provide information to control the quality of the following:
1. Segregation:
2. Longitudinal Joint Construction:
3. Transverse Joint Construction:
4. Smoothness:
5. Other:

### F. Scales and Certified Weigher:
1. Scales shall be checked and sealed. Comments:
2. Weigh tickets shall contain information required by the owner. Comments:
3. Are truck weigh ticket required to be delivered on site? How will the weight tickets be collected? Comments:

### IV. Preparation

#### A. Method of Approval SubSurface Materials?

Comments:

#### B. Has the Subsurface Been Approved for Paving?

- Approved By Who?

#### C. Tack Coat:

1. Material type, Application Rate?

### V. Production and Placement

#### A. Compaction Test Section:

*The following procedures should be observed and documented:*

1. The Contractor must establish a roller pattern and carefully record the following information:
   a. Type, size, amplitude, frequency, and speed of roller:
HOT MIX ASPHALT PREPAVING CONFERENCE AGENDA (continued)

V. Production and Placement (continued)

<table>
<thead>
<tr>
<th>b. Tire pressure for rubber tire rollers and if the pass for vibratory rollers is vibratory or static:</th>
</tr>
</thead>
<tbody>
<tr>
<td>c. Surface temperature of mixture behind the laydown machine and subsequent temperatures and densities after each roller pass:</td>
</tr>
<tr>
<td>d. Sequence and distance from laydown machine for each roller and total number of passes of each roller to obtain specified density:</td>
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</tbody>
</table>

2. When the Compaction Test Section has been completed, the Contractor shall furnish a complete copy of this data to the person in charge (II.A.1) before continuing to pave. Comments:

3. When a successful Compaction Test Section has been completed, the Contractor is required to maintain the roller pattern established during the Compaction Test Section for the balance of the Hot Bituminous Pavement construction (i.e., the Contractor must use the same number and type of rollers and operate them at the same speed, frequency, and amplitude and in the same position, relative to the laydown machine, as was performed during the Compaction Test Section). If the Contractor wants to change the roller pattern that was established during the Compaction Test Section, the Contractor must construct a new Compaction Test Section and demonstrate that the density can be obtained with the new roller pattern before proceeding with the paving operation. Comments:

4. The Contractor is responsible for compaction testing of the Compaction Test Section. Comments:
V. Production and Placement (continued)

5. Cores are required to calibrate the nuclear density gauge. The Contractor can continue to pave under the following conditions:
   - The period that the Contractor continues to pave without test results from cores shall not exceed one working day.
   - Construction proceeds at the Contractor’s risk.

Comments:

6. A new Compaction Test Section will be required whenever there is a change in the compaction process. Comments:

7. Striping plan: Sub Contractor or contractor to do striping?
   When will striping occur?
   When will striping occur?
   Have Materials Data Sheets been submitted? Approved? If Not when?

B. Laydown Equipment:
1. Does the paving equipment meet the requirement detailed in the specifications? Comments:

VI. Traffic Control

A. Method of Handling Traffic:
Has the Method of Handling Traffic been submitted for the Mix Asphalt Pavement placement operation?
If not, when will it be submitted?
Is the traffic control plan approved?

VII. Follow Up Items

<table>
<thead>
<tr>
<th>Item for follow up</th>
<th>Who will follow up</th>
<th>Date of completion or response</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
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Appendix B

Mixture Design Requirements for Hot Mix Asphalt (HMA) Pavements

Agency: ___________________________  Project Number: ___________________________
Date: _______________  Project Name: __________________________

Project Special Provision Sheet for Hot Mix Asphalt (HMA) Pavements

This form is a **mandatory part of the bid documents**, and shall be filled out by the AGENCY for each mix specified. The Contractor shall include a copy of this form with each Mix Design submittal after the contract is awarded.

Street Classification: ____________________________
(examples: Residential, Collector, Arterial, Industrial, Parking Lot).

Construction Application:  
- Top Lift
- Intermediate Lift(s)
- Bottom Lift(s)
- Patching
- Other

Aggregate Gradation:  
- Grading SX
- Grading S
- Other

- < 2" thick lifts
- 2" to 3" thick lifts

RAP Quantity, Maximum:  
- 0%
- 20%
- Other

Mix Design Method & Compaction Level: (Chose one Method & one Traffic Level ⇒ Compaction Level).

<table>
<thead>
<tr>
<th>Superpave Gyratory, $N_{design}$</th>
<th>(See Table 1.003.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ N=75</td>
<td>☐ N=100</td>
</tr>
</tbody>
</table>

Asphalt Binder:

- PG 58-28
- PG 64-22
- PG 64-28
- Other

---

A completed Asphalt Mix Design Form shall supplement the Construction Specifications defining the contract specific requirements. Refer to the Specifications for details.

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SUBSECTION 5

DESIGN AND CONSTRUCTION OF PRIVATELY OWNED PARKING AREAS
DESIGN AND CONSTRUCTION OF PRIVATELY OWNED PARKING AREAS

The following standards are based upon information included in the Colorado Asphalt Pavement Association’s “Guideline to the Design and Construction of Asphalt Parking Lots in Colorado”.

A. Drainage Considerations

1. Irrigation systems should be designed to keep water away from the parking lot pavement subgrade as much as possible since saturation of subgrade soil tends to cause loss of strength and stability, which leads to more frequent and severe pavement failures.
2. Parking area surfaces should have a minimum slope of one-quarter inch per foot (2 percent).
3. Parking lots should be designed so that stormwater runoff collects in curb and gutter or crossspans and is routed to drainage inlets connected to a piped storm drain system with proper water quality controls and detention/retention mechanisms.

An exception to this criteria may be made for porous asphalt parking lots, which is contained in Section 16.48.040 of the Town Code.

B. Subgrade Preparation

1. Subgrade should be compacted to a uniform density of 95 percent of maximum density, using ASTM D698 (Standard Proctor) or ASTM D1557 (Modified Proctor).
2. Finished subgrade should not deviate from the required grade and cross-section by more than ½-inch in 10 feet.

C. Aggregate Base Course Construction

1. The aggregate base course should consist of one or more layers placed directly on the prepared subgrade, and should be spread and compacted with moisture control to the uniform thickness, density, and finished grade as required on the plans. The minimum thickness of the aggregate base course shall be 4 inches for nominal ¾-inch aggregate. For larger aggregate, the minimum base course thickness should be increased proportionately based upon the aggregate size.

D. Hot Mix Asphalt (HMA) Placement

1. Prime Coat

An asphalt emulsified primer (AEP) may be applied over the aggregate base before placement of the HMA base course.
2. Hot Mix Asphalt Base Course

The HMA base course should be placed directly on the aggregate base course, or subgrade for full-depth asphalt, and spread and compacted to the thickness indicated in the approved pavement design. The HMA base course material must meet the specifications for the mix type specified.

3. Tack Coat

Before placing successive pavement layers, the previous course must be cleaned and a tack coat of diluted emulsified asphalt should be applied. A tack coat can only be eliminated if the previous layer is freshly placed and thoroughly cleaned.

4. Hot Mix Asphalt Surface Course

The surface course must be placed in one or more lifts to the finished grades as indicated on the approved plans. The material must conform to specifications for Superpave hot mix asphalt. The finished surface may not vary from the established grades by more than ¼-inch in ten feet, when measured in any direction. As soon as the material can be compacted without displacement, rolling and compaction should take place until the surface is thoroughly compacted and no roller marks are visible.

5. Porous Asphalt Pavement Option

For areas where permeable subgrade material exists, porous asphalt pavement may be used to reduce stormwater runoff, and to reduce or eliminate the need for detention basins. A separate section of these specifications is devoted to the design and construction of porous asphalt pavement.

6. Recycled Asphalt Pavement Option

In addition to allowing the use of recycled asphalt pavement as detailed in the Pikes Peak Region Asphalt Specifications (C.A.P.A.), recycled asphalt pavement millings may be used as pavement material for new driveways for existing businesses and single-family residences that do not currently have a paved driveway, and for overflow parking lots for existing businesses with paved parking lots that do not contain enough parking spaces to accommodate the number of vehicles commonly parking in the existing lot.

Installation of recycled asphalt pavement millings must meet the following requirements:

- Subgrade must be free of vegetation and debris.
- A minimum of 4" of recycled asphalt pavement must be placed on well compacted subgrade.
• The pavement should consist of one or more layers placed directly on the prepared subgrade and should be spread and compacted to a uniform thickness.
• Pavement must be compacted using a smooth plate tamper or drum roller to a point where the pavement no longer exhibits signs of movement.
• Recycled asphalt pavement must be free of debris and vegetation.

E. Thickness Design

The thickness of the asphalt pavement section for parking lots must be determined by the engineer-of-record for the project, or a materials consultant qualified to determine the proper pavement thickness for the uses and types of vehicle loading expected for the developed site. Table 1 below provides suggested thickness for various levels of traffic and subgrade classes, for HMA over an aggregate base course and for full depth asphalt.

Table 1 shows suggested thicknesses of HMA pavement, full depth HMA design and also with aggregate base course, for various subgrade CBR values and traffic levels.

Table -1
Suggested Thickness Design -Parking Lots

<table>
<thead>
<tr>
<th>Traffic Level</th>
<th>Subgrade Class</th>
<th>Poor (CBR &lt; 5)</th>
<th>Fair (CBR 6-9)</th>
<th>Good (CBR 10-19)</th>
<th>Excellent (CBR&gt;20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Up to 10,000 ESALs</td>
<td>2.5/13.0</td>
<td>2.5/8.5</td>
<td>2.5/6.0</td>
<td>2.5/4.0</td>
<td></td>
</tr>
<tr>
<td>10-50,000 ESALs</td>
<td>3.3/16.0</td>
<td>3.5/11.0</td>
<td>3.6/6.0</td>
<td>3.5/6.0</td>
<td></td>
</tr>
<tr>
<td>50-100,000 ESALs</td>
<td>4.3/17.0</td>
<td>4.0/12.0</td>
<td>4.0/6.0</td>
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<tr>
<td>100-250,000 ESALs</td>
<td>5.3/18.0</td>
<td>4.5/13.0</td>
<td>4.5/6.0</td>
<td>4.5/6.0</td>
<td></td>
</tr>
<tr>
<td>250-500,000 ESALs</td>
<td>5.3/12.0</td>
<td>5.5/9.5</td>
<td>5.5/6.5</td>
<td>5.5/6.0</td>
<td></td>
</tr>
<tr>
<td>500-1,000,000 ESALs</td>
<td>6.3/23.0</td>
<td>6.0/15.5</td>
<td>6.0/7.0</td>
<td>6.0/6.0</td>
<td></td>
</tr>
<tr>
<td>Moderate Full Depth Asphalt, Inches</td>
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<td></td>
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</tr>
<tr>
<td>Light Up to 10,000 ESALs</td>
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<tr>
<td>10-50,000 ESALs</td>
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<td>5.5</td>
<td>4.5</td>
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</tr>
<tr>
<td>50-100,000 ESALs</td>
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<td>5.5</td>
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</tr>
<tr>
<td>100-250,000 ESALs</td>
<td>9.0</td>
<td>7.5</td>
<td>6.0</td>
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</tr>
<tr>
<td>250-500,000 ESALs</td>
<td>10.5</td>
<td>8.5</td>
<td>7.0</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>500-1,000,000 ESALs</td>
<td>11.5</td>
<td>9.5</td>
<td>7.5</td>
<td>6.5</td>
<td></td>
</tr>
</tbody>
</table>

Special truck lanes are sometimes required to expedite traffic to loading areas, trash dumpster sites, and equipment areas. Design thicknesses for these lanes or pavement areas should be increased to accommodate the expected loading. If a parking lot is small in size and has low traffic volume but has the weekly or bi-weekly trash truck, it would be more economical to construct the entire parking lot to handle the truck traffic than it would be to construct a heavy traffic lane just for trucks. A lot not constructed to handle heavy trucks will cost more in the long run because of continuing repairs to the pavement being destroyed by heavy trucks.

PAVEMENT DESIGN AND CONSTRUCTION STANDARDS
F. "Superpave" Mix Design

The “Superpave” Mix Design Method shall be used for all parking area asphalt pavement design, with the exception of parking areas using porous asphalt pavement.

1. For lower lifts, “SX” or “S” grading should be used, unless the parking area is expected to experience heavy traffic, in which case an “SG” grading is recommended for lower lifts.
2. For the top mat, “SX” grading should be used, although an “S” grading can be used for the top lift of parking areas expected to receive heavy traffic on a regular basis.

Non-Modified asphalt binders are recommended for use in all parking areas.

G. Placement of Asphalt Pavement

1. The thickness of an individual lift shall be limited to three times the nominal maximum aggregate size in the gradation.
2. The recommendations contained in the Construction Recommendations section of the Colorado Asphalt Pavement Association’s “A Guideline for the Design and Construction of Asphalt Parking Lots in Colorado” should be followed as closely as possible.
3. Hot mix asphalt (HMA) curb is not recommended for use in any applications. Permission to install HMA curb will only be granted in special cases when no other options are available.
SUBSECTION 6

“GUIDELINES TO THE DESIGN AND CONSTRUCTION OF ASPHALT PARKING LOTS IN COLORADO”

COLORADO ASPHALT PAVEMENT ASSOCIATION (CAPA)
A GUIDELINE FOR THE DESIGN AND CONSTRUCTION OF ASPHALT PARKING LOTS IN COLORADO
This document was developed by the Colorado Asphalt Pavement Association (CAPA). It is intended to be used as a resource in the design and construction of asphalt parking lots in Colorado. CAPA can not accept any responsibility for the inappropriate use of these documents. Engineering judgment and experience must be used to properly utilize the principles and guidelines contained in this document, taking into account available equipment, local materials and conditions. All reasonable care has been taken in the preparation of this guideline; however, the Colorado Asphalt Pavement Association can not accept any responsibility for the consequences of any inaccuracies which it may contain.

For more information, contact ..... 

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Centennial, Colorado 80112
P: (303) 741-6150   F: (303) 741-6146
e-mail:  office@co-asphalt.com
website:  www.co-asphalt.com
OVERVIEW

The parking lot is the first - and the last - part of a building complex to be viewed by the user. It is the gateway through which all customers, visitors, and employees pass. This first impression is very important to the overall feeling and atmosphere conveyed to the user.

Developers and property owners want their facilities to be attractive, well designed, and functional. Though many hours are spent on producing aesthetically pleasing building designs, the same design consideration for the parking area is often overlooked. Pavements in parking areas that are initially under-designed can experience excessive maintenance problems and a shortened service life. In addition, selecting the right materials for the asphalt pavement can assure a pleasing and attractive surface.

When properly designed and constructed, parking areas can be an attractive part of the facility that is also safe, and most important, usable to the maximum degree. Parking areas should be designed for low maintenance costs and easy modification for changes in use patterns.

This guide provides general information for proper parking area design and construction. This includes asphalt mixture and pavement design and guidance on selecting the right asphalt mixture. Also included is information on construction best practices and general guidance on facility layout.

The Superpave Hot Mix Asphalt (HMA) mixes that are used for paving parking lots can vary from fine graded mixes to coarse graded mixes. Each mix type requires that the paving contractor pay special attention to the plant produced mix properties and the methods that are used during placement and compaction. Two important components of this document are the section on controlling the volumetric properties of the mix during construction and the section on construction recommendations for HMA paving.

GENERAL PLANNING

In developing the parking area plan, several important details should be considered. First and foremost in the mind of the developer may be providing the maximum parking capacity in the available space while ensuring convenience and safety. On the other hand, the user will be concerned about sidewalk traffic flow, pedestrian visibility, obstructions and signs. Consideration must also be given to handicap parking. Additionally, areas need to be set aside for bicycle and motorcycle parking. When completed the parking area should be functional, fit into the overall theme for the building, and aesthetically pleasing in its overall appearance.
Criteria have been developed for optimizing parking area space. Among these are the following:

- Use rectangular areas where possible.
- Make the long sides of the parking areas parallel.
- Design so that parking stalls are located along the lot’s perimeter.
- Use traffic lanes that serve two rows of stalls.

Special attention should be given to the flow of traffic in and out of the parking lot as well as circulating routes inside the parking lot. Keep entrances far away from busy street intersections and from lines of vehicles stopped at a signal or stop sign. Be sure that the entering vehicles can move into the lot on an internal aisle, thereby avoiding entering congestion caused by involvement with turning vehicles. A pedestrian traffic-flow study is important to provide information about both safety and convenience.

Parking lot markings are a very important element of a good parking lot. The parking area should be clearly marked to designate parking spaces and to direct traffic flow. As specified in the Manual on Uniform Traffic Control Devices (MUTCD), parking on public streets should be marked out by using white traffic paint, except for dangerous areas, which should be marked in yellow. However, yellow lines are commonly used in off-street parking lots. All pavement striping should be four inches in width.

New asphalt surfaces can be marked with either traffic paint or cold-applied marking tape. For best results with paint application, allow the Hot Mix Asphalt (HMA) to cure for several days.

In areas where permeable subgrade material exists, Porous Asphalt pavement can offer a unique opportunity that reduces storm water runoff. This can eliminate the need for detention basins and, in most cases will perform better than detention basins in reducing the quality of runoff and pollutants. A properly designed porous asphalt pavement under the right conditions will provide one solution to stormwater runoff problems as well as groundwater table recharge. Because of the unique design and construction features of this product, information on Porous Asphalt Pavement is found toward the end of this document.

**PAVEMENT DESIGN CONSIDERATIONS**

Drainage Provisions ~ Drainage problems are frequently a major cause of parking area pavement failures. This is especially the case with irrigation sprinkler systems located in parking lot islands and medians. It is critical to keep water away from the subgrade soil. If the subgrade becomes saturated, it will lose strength and stability, making the overlying pavement structure susceptible to breakup under imposed loads.

Drainage provisions should be carefully designed and should be installed early in the construction process. As a general guideline, **parking area surfaces should have a minimum slope of 2 percent (2%) or 1/4 inch per foot.** This guideline may not be realistic when matching curb, gutter, v-pans, planters, ramps, etc. The parking lot should be designed to provide for positive drainage.
Pavement cross slopes of less than 2 percent are hard to construct without the formation of “bird baths”, slight depressions that pond water. They should also be constructed so water does not accumulate at the pavement edge. Runoff should be collected in curb and gutters and gutter pans and channeled off of the parking lot. Curb and gutter cross sections should be built so that water flows within the designed flow line and not along the interface between the asphalt pavement and curb face. Areas of high natural permeability may require an underdrain system to carry water away from the pavement substructure. Any soft or spongy area encountered during construction should be immediately evaluated for underdrain installation or for removal and replacement with suitable materials.

In saturated areas, the use of HMA base (compared to use of untreated aggregate base) will greatly reduce the potential for strength and stability problems.

**Subgrade Preparations** ~ All underground utilities should be protected or relocated before grading. All topsoil should be removed. Low-quality soil may be improved by adding granular materials, lime, asphalt, or other mixtures to stabilize the existing soils. Laboratory tests are recommended to evaluate the load-supporting characteristics of the subgrade soil. However, designs are sometimes selected after careful field evaluations based on experience and knowledge of local soil conditions.

The area to be paved should have all rock, debris, and vegetation removed. The area should be treated with a soil sterilant to inhibit future vegetative growth. Grading and compaction of the area should be completed so as to eliminate yielding or pumping of the soil.

The subgrade should be compacted to a uniform density of 95 percent of the maximum density. This should be determined in accordance with Standard or Modified Proctor density (ASTM D698 or ASTM D 1557) as appropriate to the soil type. When finished, the graded subgrade should not deviate from the required grade and cross section by more than one half inch in ten feet. If the subgrade is a fine-grained silt or clay, a separation fabric should be considered for use to prevent the finer material in the subgrade from inundating the more open-graded layers to be placed as a part of the pavement section.

**Untreated Aggregate Base Construction** ~ The untreated aggregate base course section based on the pavement design, should consist of one or more layers placed directly on the prepared subgrade, with or without a separation fabric, depending on soil type. It should be spread and compacted with moisture control to the uniform thickness, density and finished grade as required on the plans. The **minimum thickness of untreated aggregate base course is four inches** for Class 6 (3/4") material. The minimum thickness should be increased for larger (1½" or 3") material. The aggregate material should be of a type approved and suitable for this kind of application.

It should be noted that an untreated aggregate base might be sensitive to water in the subgrade. Pavement failures associated with water in the subgrade are accelerated if an untreated base allows water to enter the pavement structure. Grading should be done to promote natural drainage or other types of underdrain systems should be included in the design.
Prime Coat ~ An application of low viscosity liquid asphalt may be required over untreated aggregate base before placing the HMA surface course. A prime coat and its benefits differ with each application, and its use often can be eliminated. Discuss requirements with the paving contractor. If a prime coat is used, AEP (asphalt emulsified prime) should be specified as it is designed to penetrate the base material. The use of a tack coat is not recommended for use as prime coat.

Hot Mix Asphalt (HMA) Base Construction ~ The asphalt base course material should be placed directly on the prepared subgrade in one or more lifts. It should be spread and compacted to the thickness indicated on the plans. Compaction of this asphalt base is one of the most important construction operations contributing to the proper performance of the completed pavement. This is why it is so important to have a properly prepared and unyielding subgrade against which to compact. The HMA base material should meet the specifications for the mix type specified.

Tack Coat ~ Before placing successive pavement layers, the previous course should be cleaned and a tack coat of diluted emulsified asphalt should be applied if needed. The tack coat may be eliminated if the previous coat is freshly placed and thoroughly clean.

Hot Mix Asphalt (HMA) Surface Course ~ Material for the surface course should be an HMA mix placed in one or more lifts to the finished lines and grade as shown on the plans. The plant mix material should conform to specifications for Superpave hot mix asphalt.

For most applications, the HMA surface should not vary from established grade by more than one-quarter inch in ten feet when measured in any direction. This requirement may not be attainable when matching curb, gutter, and V-pan. Any irregularities in the surface of the pavement course should be corrected directly behind the paver. As soon as the material can be compacted without displacement, rolling and compaction should start and should continue until the surface is thoroughly compacted and roller marks disappear.

THICKNESS DESIGN FOR PARKING LOTS

The thickness of the asphalt pavement section for parking lots should be determined using the information presented in Chapters Two and Three of the *Guideline for the Design and Use of Asphalt Pavements for Colorado Roadways*, by the Colorado Asphalt Pavement Association. It is recommended that a qualified design consultant be used to design the pavement structure and layout of the parking lot. The design consultant can design the pavement structure using the methods discussed in Chapters Two and Three which would provide for the most economical pavement structural section.
Table 1 shows suggested thicknesses for HMA pavement, full depth HMA design and also with aggregate base course, for various subgrade CBR/R values and traffic levels.

### Table 1
Suggested Thickness Design - Parking Lots

<table>
<thead>
<tr>
<th>Traffic Level</th>
<th>Subgrade Class</th>
<th>Hot Mix Asphalt over Aggregate Base Course, inches</th>
<th>Full Depth Asphalt, inches a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor CBR &lt; 5</td>
<td>Fair CBR 6-9 R 33-41</td>
<td>Good CBR 10-19 R 43-52</td>
</tr>
<tr>
<td>Light</td>
<td>Up to 10,000 ESALs</td>
<td>2.5/13.0</td>
<td>2.5/8.5</td>
</tr>
<tr>
<td></td>
<td>10-50,000 ESALs</td>
<td>3.5/16.0</td>
<td>3.5/11.0</td>
</tr>
<tr>
<td>Moderate</td>
<td>50-100,000 ESALs</td>
<td>4.0/17.0</td>
<td>4.0/12.0</td>
</tr>
<tr>
<td></td>
<td>100-250,000 ESALs</td>
<td>5.0/18.0</td>
<td>4.5/13.0</td>
</tr>
<tr>
<td>Heavy</td>
<td>250-500,000 ESALs</td>
<td>5.5/12.0</td>
<td>5.5/9.5</td>
</tr>
<tr>
<td></td>
<td>500-1,000,000 ESALs</td>
<td>6.0/23.0</td>
<td>6.0/15.5</td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>6.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>10-50,000 ESALs</td>
<td>7.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Moderate</td>
<td>50-100,000 ESALs</td>
<td>8.0</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>100-250,000 ESALs</td>
<td>9.0</td>
<td>7.5</td>
</tr>
<tr>
<td>Heavy</td>
<td>250-500,000 ESALs</td>
<td>10.5</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>500-1,000,000 ESALs</td>
<td>11.5</td>
<td>9.5</td>
</tr>
</tbody>
</table>

1. Light- Passenger Cars  
2. Excellent subgrade conditions are ideal for full depth asphalt; However, a minimum of 100 (4 inches) of HMA is recommended. In some areas, aggregate is needed to provide material to fine grade and to provide a smooth surface to pave on. If needed, 100 mm (4 inches) of aggregate is recommended as a minimum thickness for this purpose.  
3. Full depth asphalt can be built on poor and fail soils only in dry conditions and when the subgrade soils may be brought up to optimum conditions and compacted to specified density.

Special truck lanes are sometimes required to expedite traffic to loading areas, trash dumpster sites, and equipment areas. Design thicknesses for these lanes or pavement areas should be increased to accommodate the expected loading. If a parking lot is small in size and has low traffic volume but has the weekly or bi-weekly trash truck, it would be more economical to construct the entire parking lot to handle the truck traffic than it would be to construct a heavy traffic lane just for trucks. A lot not constructed to handle heavy trucks will cost more in the long run because of continuing repairs to the pavement being destroyed by heavy trucks.
PLANNED STAGE CONSTRUCTION

Planned stage construction is a means of providing fully adequate pavements with the effective use of funds, materials, and energy. As defined, it is the construction of an HMA parking lot or roadway in two or more stages, separated by a predetermined interval of time. In many situations, building pavements by stages makes good economical sense. It is a technique long used by city and highway engineers.

Stage Construction is not maintenance. It is the placement of a minimum depth of pavement during initial construction, and a final surface course placed at a planned future date. HMA paving lends itself to this kind of construction.

As an example, for financial reasons, the owner of a new department store with a 350 space car parking lot decides to stage construct the six and one half inch, full-depth asphalt parking lot. Stage 1 is constructed at the time the store is built. A total depth of four and one half inches of HMA is placed. Stage Two, consisting of the final surface course of two inches, will be placed at a set time in the future. Consideration must be given to the nominal maximum size aggregate in the mix. The individual lift thickness for any one lift should be three times the nominal maximum size aggregate in the gradation. The truck loading zone and the dumpster-area are paved the full depth during initial construction.

Stage construction has the advantage of providing a thoroughly adequate, all weather pavement for the initial development of an area. Any damage to the Stage 1 pavement caused by traffic, settlements, or utility tear-ups can be repaired prior to placement of the final surface. With a proper asphalt tack coat where needed, the Stage Two pavement bonds to the old surface and becomes an integral part of the entire pavement structure.

Where stage construction is planned and there are curb and gutter sections drainage can be a problem. Not all the water from the lower paved area may be able to get into the drainage system. When this is a problem, means for the water to get into the drainage system will have to be constructed. Also, if asphalt curbs are used they are usually constructed on the paved surface. Careful planning is critical if stage construction is going to be used.

Note: The parking lot construction costs can be minimized by reducing the number of project mobilizations by the contractor. The more times the contractor has to move in and move out of a project the higher the cost. Therefore, it is important for the property owner or its representative to plan the work so as to minimize the number of project mobilizations by the contractor. Cautionary Notice to the designer: If using staged construction (or if the placement of the top lift will be delayed), the pavement section placed should be established so adequate depth of asphalt is provided for construction traffic.
ASPHALT MAT-PLATFORM FOR BUILDING CONSTRUCTION AND SITE PAVING

Site paving is the recommended first step in many types of building construction projects. It offers several advantages as a working mat or platform before building construction begins for shopping centers, schools, manufacturing concerns, warehouses, and similar facilities.

In this technique, an HMA base course is constructed on a prepared subgrade over the entire area that will become the parking areas, service roadways, and buildings. When building construction is completed, a final HMA surface course is placed on the asphalt base.

Paving a building site before construction is completed has several benefits. These include the following:

- It ensures constant accessibility and provides a firm platform upon which people and machines can operate efficiently; speeding construction.
- It provides a dry, mud-free area for construction offices, materials storage, and worker parking; eliminating dust-control expenditures.
- It eliminates the need for costly select material - the asphalt subfloor ensures a floor slab that is dry and waterproof.
- Steel-erection costs can be reduced because a smooth, unyielding surface results in greater mobility for cranes and hoists.
- The engineer can set nails in the asphalt pavement as vertical and horizontal control points, effectively avoiding the risk of loss or disturbance of this necessary survey work.
- Excavation for footings and foundations and trenching for grade beams can be accomplished without regard for the asphalt base.

HOT MIX ASPHALT MIXTURE DESIGN

The Superpave Mix Design Method has been incorporated into Colorado practice starting in 1997. Today, nearly all asphalt pavements in Colorado are designed using the Superpave mixture design method. It is the recommended design method for determining the appropriate job mix formula, or “recipe” for combining aggregates and binder into Hot Mixed Asphalt (HMA) pavement material for paving.

1 Cautionary Notice to the designer: If using staged construction (or if the placement of the top lift will be delayed), the pavement section placed should be established so adequate depth of asphalt is provided for construction traffic.
The major features of the Superpave Mix Design Method are:
- Utilization of the Superpave Gyratory Compactor to compact laboratory samples
- Composite gradations that tend not to be dense graded
- Performance graded (PG) asphalt binder specification requirements

**THE SUPERPAVE GYRATORY COMPACTOR** ~ The Superpave gyratory compactor was developed during the Strategic Highway Research Program (SHRP). The gyratory compactor better approximates the compactive effort of the vibratory rollers used by the contractor to compact the asphalt mix during construction. The mix designs that are produced with the gyratory compactor still produce an increase in density (pcf) as the asphalt binder content is increased up to the point where additional increases in binder start to displace the heavier aggregate particles and the density starts to drop. The number of design gyrations varies based on traffic loading and is similar to the number of blows required for the Marshall Method of Mix Design. Table – 2 shows the Superpave Mixture Properties.

<table>
<thead>
<tr>
<th>Test Property</th>
<th>Traffic Levels</th>
<th>Light Cars only</th>
<th>Moderate Light truck Traffic</th>
<th>Heavy Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Period ESALs</td>
<td>&lt;100,000</td>
<td>&lt; 3 million</td>
<td>&gt; 3 Million</td>
<td></td>
</tr>
<tr>
<td>Initial Gyrations</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Design Gyrations</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Hveem Stability</td>
<td>NA</td>
<td>28 min.</td>
<td>30 min.</td>
<td></td>
</tr>
<tr>
<td>Air Voids, %</td>
<td>3-5</td>
<td>3-5</td>
<td>3-5</td>
<td></td>
</tr>
<tr>
<td>Voids Filled w/Asphalt, %</td>
<td>70-80</td>
<td>65-78</td>
<td>65-75</td>
<td></td>
</tr>
<tr>
<td>Lottman, TSR, % retained, min.</td>
<td>80 min.</td>
<td>80 min.</td>
<td>80 min.</td>
<td></td>
</tr>
<tr>
<td>Lottman, Dry Tensile Strength, psi</td>
<td>30 min.</td>
<td>30 min.</td>
<td>30 min.</td>
<td></td>
</tr>
</tbody>
</table>

Table – 3 shows the Voids in Mineral Aggregate requirements.

<table>
<thead>
<tr>
<th>Nominal Maximum Particle Size</th>
<th>Minimum VMA, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design Air Voids %</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>½”</td>
<td>13</td>
</tr>
<tr>
<td>¾”</td>
<td>12</td>
</tr>
<tr>
<td>1”</td>
<td>11</td>
</tr>
</tbody>
</table>

The nominal maximum particle size is one sieve size larger than the first sieve to retain more than 10 percent.
AGGREGATE PROPERTY REQUIREMENTS ~ Aggregate property requirements such as particle hardness, durability, shape, angularity and texture are important and should be followed. Table – 4 shows the Master Range for Superpave Hot Mix Asphalt Pavement.

Table – 4
Master Range Table for Superpave Pave Hot Mix Asphalt Pavement

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent by weight Passing Square Mesh Sieves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grading SX (1/2&quot;)</td>
</tr>
<tr>
<td>37.5 mm (1 ½&quot;)</td>
<td>100</td>
</tr>
<tr>
<td>25.0 mm (1&quot;)</td>
<td>100</td>
</tr>
<tr>
<td>19.0 mm (3/4&quot;)</td>
<td>100</td>
</tr>
<tr>
<td>12.5 mm (½&quot;)</td>
<td>90 – 100</td>
</tr>
<tr>
<td>9.5 mm (3/8&quot;)</td>
<td>*</td>
</tr>
<tr>
<td>4.75 (#4)</td>
<td>*</td>
</tr>
<tr>
<td>2.36 (#8)</td>
<td>28 – 58</td>
</tr>
<tr>
<td>1.18 (#16)</td>
<td>*</td>
</tr>
<tr>
<td>600µm (#30)</td>
<td>*</td>
</tr>
<tr>
<td>300µm (#50)</td>
<td></td>
</tr>
<tr>
<td>150µm (#100)</td>
<td></td>
</tr>
<tr>
<td>75µm (#200)</td>
<td>2-10</td>
</tr>
</tbody>
</table>

* These additional screens will be established for the Contractor’s Quality Control testing using values from the as used gradation shown on the Design Mix.
1 For definition of mix aggregate size, see definitions below.

Superpave uses the following definitions for designing the aggregate mixture size for the various gradings shown in Table – 4:

1. Maximum Size – One sieve size larger than the nominal Maximum size.

2. Nominal maximum aggregate size - One sieve size larger than the first sieve to retain more than 10 percent.

For commercial parking lots the “SX” grading should be used for the top mat. Both the “SX” and the “S” grading can be used for lower lifts. The “SG” grading is recommended for the lower lifts for industrial parking lots with heavy traffic. To add additional strength, the “S” grading, rather than the “SX” grading can be used for the top lift of industrial parking lots. “SG” mixes should be restricted in use to “Special Use” parking lots.
The Superpave system requires high quality aggregates. Table – 5 summarizes the aggregate quality requirements.

### Table – 5
Aggregate Properties for Superpave HMA Mixes

<table>
<thead>
<tr>
<th>Aggregate Test Property</th>
<th>Coarse Retained on # 4</th>
<th>Fine Passing # 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine aggregate Angularity, CP 5113, Method A</td>
<td>45% Minimum</td>
<td></td>
</tr>
<tr>
<td>Two Fractured Faces</td>
<td>60% Minimum</td>
<td></td>
</tr>
<tr>
<td>L. A. Abrasion AASHTO T 96</td>
<td>40% Maximum</td>
<td></td>
</tr>
<tr>
<td>Flat and Elongated Pieces, (Ratio 5:1) AASHTO M383</td>
<td>10% Maximum</td>
<td></td>
</tr>
<tr>
<td>Sodium Sulfate Soundness, AASHTO T104</td>
<td>12% Maximum</td>
<td></td>
</tr>
<tr>
<td>Sand Equivalent, AASHTO T176</td>
<td>45% Minimum</td>
<td></td>
</tr>
<tr>
<td>Plasticity Index, AASHTO T89 &amp; T90</td>
<td>NP</td>
<td></td>
</tr>
</tbody>
</table>

**PG Graded Binders** ~ The Superpave performance Graded (PG) binders are listed in Table – 6.

### Table – 6
Recommended PG Graded Asphalt Binders

<table>
<thead>
<tr>
<th>Traffic Levels</th>
<th>Recommended Gyrations</th>
<th>Non Modified Asphalt Binder</th>
<th>Modified Asphalt Binder</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 300,000 ESALs (Light Traffic/Loading)</td>
<td>50</td>
<td>PG 58-28</td>
<td>PG 58-34</td>
</tr>
<tr>
<td>3 – 3 Million ESALs (Moderate Traffic/Loading)</td>
<td>75</td>
<td>PG 58-28 or PG 64-22</td>
<td>PG 64-28</td>
</tr>
<tr>
<td>&lt; 3 Million ESALs (Heavy/Traffic/Loading)</td>
<td>100</td>
<td>PG 64-22</td>
<td>PG 64-28 or 76-28</td>
</tr>
</tbody>
</table>

1 Environmental and loading conditions need to be considered when selecting the appropriate PG asphalt binder. The use of modified asphalt binders are more suited for severe climate (e.g. mountainous) and severe loading areas.

2 **Non-Modified asphalt binders (PG 58-28 and PG 64-22)** are recommended for standard use in parking lots in Colorado. Modified asphalt binders are 20% to 40% higher in cost than non-modified asphalts and should only be used in parking lots under unique loading or climate conditions. The cost of modified asphalt binder mixes is dependent on their availability and quantity required. The local asphalt industry should be consulted prior to specifying the use of modified asphalts.
The recommended mixing and compaction temperature for the Superpave HMA Mixes are shown in Table – 7

<table>
<thead>
<tr>
<th>Asphalt Binder Grade</th>
<th>Mixing Temperature</th>
<th>Minimum Mix Delivery Temperature*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 58-28</td>
<td>260-310° F</td>
<td>235° F</td>
</tr>
<tr>
<td>PG 58-34</td>
<td>260-310° F</td>
<td>235° F</td>
</tr>
<tr>
<td>PG 64-22</td>
<td>265-320°F</td>
<td>280° F</td>
</tr>
<tr>
<td>PG 64-28</td>
<td>265-320°F</td>
<td>280° F</td>
</tr>
<tr>
<td>PG 76-28</td>
<td>280-330°F</td>
<td>280° F</td>
</tr>
</tbody>
</table>

*Delivered mix temperature shall be measured behind the screed.

SELECTING THE RIGHT HOT MIX ASPHALT (HMA) FOR YOUR PROJECT

In the Front Range of Colorado, fine graded mixes are most common. This mixes tend to have a “tight” dense appearance and if combined with adequate asphalt binder, will result in a very good parking lot appearance.

When gradations are on the coarse side the mixes can be a challenge to place on parking lots and other areas where hand working and short run stop-and-go paving is required. Coarse graded mixes also cool faster then fine graded mixes and may be more challenging to achieve the required compaction.

Without exception, the Superpave “Fine” gradation mixes (SX) are the best looking mixes for parking lots. It is recommended ½” Mixes (nominal maximum particle size) be used for standard parking lots. These mixes would be preferable to either Superpave “Coarse” or “S” shaped gradation mixes.

Try to select a mix that has a smooth gradation curve with low percent passing the #200 sieve and a high VMA.

Select asphalt binder contents that will result in mix design voids in the 3 to 4 percent range rather than the 4 to 5 percent range.

CONSTRUCTION RECOMMENDATIONS

There are several keys to quality construction when placing hot mix asphalt in parking lots. Initial mix selection is important. Also important is the detail to construction practices which must be followed when placing the Superpave mixes.
Providing enough compaction effort at sufficient temperatures when paving parking lots can be a problem. Using small parking lot rollers in areas where the placement of the mix is slowed by the need for hand working and stop-and-go short runs with the paver often result in low densities and rough finishes. Also, there is often a problem with mix setting in trucks for long periods of time or even worse, mix that is placed, and then not compacted for long periods of time. The contractor needs to consider these potential problems and make adjustments to his method of paving to minimize the potential for having to compact the mix when it has cooled below the recommended temperatures.

- Make sure that the surface to be paved is properly prepared; both grade and density should be checked. Pay special attention to areas around valve boxes, man holes and other obstructions where it is not easy to get construction equipment.

- Spend time laying out the sequence of paving to minimize the number of passes and set backs required by the paver.

- Have a “tail gate” meeting with the paving crew to exchange ideas, discuss special problems and consider alternatives.

- During compaction, follow the temperature recommendations for the PG graded asphalt binders.

- Individual lift thickness should be at least 3 times the nominal maximum size aggregate in the gradation, four times is better.

- During (initial) break down rolling, keep the roller as close to the paver as possible and use extra rollers as required. Roller distance from the paver and sequence will be affected by the weather conditions and should be adjusted based on the weather conditions.

- Try to minimize hand placement of the mix and limit hand raking as much as possible.

- When possible use hot longitudinal joints.

- Schedule delivery of the asphalt mix to the project so that it remains in the delivery trucks for the shortest duration possible. However, remember that the mix will stay much hotter if it remains in the trucks so don’t place the mix faster than it can be compacted.

- Consider postponing paving if inclement wet or cold weather is pending. The HMA should be placed on properly constructed surfaces that are free from water, snow, or ice. Follow published guidelines for cold weather paving when ever possible.
### Table 1
Placement Temperature Guidelines

<table>
<thead>
<tr>
<th>Compacted Layer Thickness in inches (MM)</th>
<th>Minimum Air and Surface Temperature, °F (°C)</th>
<th>Top Layer of Layers Below Top Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Note ¹</td>
</tr>
<tr>
<td>1 (25) or less</td>
<td>60 (15)</td>
<td>50 (10)</td>
</tr>
<tr>
<td>&gt;1-3 (25 -75)</td>
<td>50 (10)</td>
<td>40 (5)</td>
</tr>
<tr>
<td>&gt;3 (75)</td>
<td>-</td>
<td>30 (0)</td>
</tr>
</tbody>
</table>

Notes: Air Temperature is taken in the shade. Surface is defined as the existing base on which the new pavement is to be placed.

¹ Temperatures to be used when mix contains unmodified asphalt binder (PG 58-28, PG 58-22, PG 64-22). Temperatures to be used with PG 76-28, Pg 70-34, PG 64-28 and PG 58-40.

- During paving use nuclear gauges to monitor the compaction process. Remember that nuclear gauges often read deeper than the lift thickness being placed. Without a core correction, which will probably not be obtainable for small parking lots, the gauge readings can be misleading.

- Upon completion of laydown and compaction the finished grade of the asphalt pavement should be even with or slightly higher than the edges of adjoining gutter pans and curb faces. Also make sure that curb and gutter and cross pan flow lines are properly constructed so that water runs in the gutter portion and not along the interface between the asphalt pavement and concrete.

- Warranty – It is standard industry practice to provide a limited 1 year workmanship and materials warranty for asphalt parking lot construction. The warranty is generally limited to premature distress caused by poor workmanship and/or poor quality materials.

### HOT MIX ASPHALT (HMA) CURB (OPTIONAL)

Asphalt curbs have become increasingly popular as accessories to paving because they are:

- Economical and easy to construct
- Can be built much faster than other types
- Aren’t affected by ice-and snow-melting chemicals
- Able to be laid on an existing pavement using a slip form paver.

Many parking facilities have some form of curbing around the perimeter for both functional and aesthetic reasons. The curbs control drainage, delineate the pavement edge, prevent vehicular encroachment on adjacent areas, and enhances the esthetics of the parking lot. A typical HMA curb cross section is shown in Figure 1.
The asphalt binder content and gradation should be modified as necessary to produce a suitable mixture for HMA curb construction. Curb mixes that are proportioned using aggregate mixture sizes of three eighths (3/8") or one half inch (1/2") have proven to be most satisfactory and are recommended for curb construction in Colorado.

Before curb construction begins, the placement area should be cleaned thoroughly. A tack coat should be applied to the pavement surface at a maximum rate of 0.10 gallons per square yard.

The HMA curb should be laid true to the specified line, profile, and cross section with an approved self-propelled curb-laying machine. The mixture should be fed to the hopper of the machine directly from the truck with a chute, conveyor, or by shoveling into the hopper.

HMA curbs should be backed with earth fill or by constructing a double line of curb and filling the median with compacted asphalt mix.

**Porous Asphalt Parking Lot Pavements**

**Background** - Porous asphalt parking areas can provide cost effective, attractive parking lots with a life span of 20 years or more. At the same time, this unique pavement design can give stormwater management systems that promote infiltration, improve water quality, and eliminate the need for a detention basin. Water from rainstorms quickly runs off these pervious surfaces. Porous asphalt pavement is comprised of a permeable asphalt surface placed over a granular working platform on top of a reservoir of large stone.

**Design Applications** - It is recommended that porous asphalt pavement should only be used on sites with gentle slopes, permeable soils (typically 0.50 in/hr) and relatively deep water table and bedrock levels. Soils should be well to moderately drained. Lack of well draining soil may prevent the use of porous asphalt pavement without significant additional
site work and drainage features. In arid areas, large quantities of blowing dust will tend to clog the pores of the porous asphalt surface, thereby restricting or even eliminating percolation through the top layer of the system.

A typical porous asphalt pavement consists of a porous asphalt top course, a top filter course, a reservoir course an optional bottom filter course, filter fabric, and existing soil or subgrade material. The porous asphalt course consists of open graded asphalt concrete approximately 2 to 4 inches thick. The pavement should be a mix containing little sand or duct, with a void space of approximately 16% or more. A top filter course, 2 inches thick using 0.5 inch crushed stone aggregate is typically recommended. The reservoir course is a base course of crushed stone of a depth determined by the storage volume, structural capacity, or frost depth, which requires the greater thickness. The minimum thickness for this course is often 8 to 9 inches. This reservoir must not only provide stormwater storage and passage, but it must also carry vehicle traffic loadings. Storage requirements may often be a factor in determining reservoir depth only when the porous pavement system is required to accept stormwater from an area larger than the paved surface. With soils with marginal permeability, the reservoir course thickness would be increased to provide additional storage. With soils composed primarily of clay or silt, the infiltration capacity may be so slow that a porous pavement system may not be appropriate for the site. Below the optional filter course or reservoir course, a filter fabric must be placed to prevent fines from migrating into the reservoir. Below the fabric, the subgrade soil should be undisturbed with minimal use of equipment to prevent soil compaction which may affect permeability.

Construction – It is often best to install the porous pavement towards the end of the construction period. Then, in the later stages of the project, workers can excavate the bed to final grade and install the porous pavement system. Carelessness in compacting the subgrade soils, poor erosion control, and poor quality materials are all causes of failure. Detailed specifications on site preparation, soil protection, and system installation are required. A pre-construction meeting should be held to discuss the need to prevent heavy equipment from compacting soils, the need to prevent sediment-laden waters from washing on to the pavement, the need for clean stone, etc.
**Porous Pavement Summary** – Because of the unique features of porous pavement it is strongly suggested that these design and other factors be evaluated by a registered Professional Engineer. Detailed design, construction, and maintenance guidelines, as found in the National Asphalt Pavement Association, Information Series 131, “Porous Asphalt Pavement”, should be closely followed.

**SUMMARY**

Hot Mix Asphalt paved parking lots can be constructed so that they serve as a center piece for the building they serve. Best practices can be followed to ensure that the parking lots using Superpave asphalt mixes can be done so that they are cost effective, structurally competent, and esthetically pleasing. Pre-planning, proper design, and construction are essential to ensure a long lasting asphalt parking lot.
SUBSECTION 7

“POROUS ASPHALT PAVEMENTS FOR STORMWATER MANAGEMENT – DESIGN, CONSTRUCTION, AND MAINTENANCE GUIDE”

NATIONAL ASPHALT PAVEMENT ASSOCIATION (NAPA)
INFORMATION SERIES 131
Porous Asphalt Pavements for Stormwater Management

Design, Construction and Maintenance Guide
This publication is provided by the Members of the National Asphalt Pavement Association (NAPA), who are the nation's leading hot-mix asphalt (HMA) producer/contractor firms and those furnishing equipment and services for the construction of quality HMA pavements.

NAPA Members are dedicated to providing the highest quality HMA paving materials and pavements, and to increasing the knowledge of quality HMA pavement design, construction, maintenance and rehabilitation. NAPA also strongly supports the development and dissemination of research, engineering and educational information that meets America's needs in transportation, recreational, and environmental pavements.

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Porous Asphalt Pavements for Stormwater Management
Design, Construction and Maintenance Guide

By Kent Hansen, P.E.

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In a seniors' community in Iowa, a water truck demonstrates how porous pavement at the right drains quickly, while water stands on the conventional pavement at the left.
Porous Asphalt Pavements for Stormwater Management
Design, Construction and Maintenance Guide

Introduction

Porous asphalt pavements are designed for dual duty: they provide pavements for parking and roads and also serve as stormwater storage and infiltration systems. They are in demand because they offer site planners and public works officials the opportunity to manage stormwater in an environmentally friendly way. With the proper design and installation, porous asphalt structures can offer cost-effective, attractive parking lots with a long life span, while also providing stormwater management systems that promote infiltration, improve water quality, recharge groundwater, and keep peak and total volume of flow at or below pre-development values.

From the bottom up, the standard porous pavement structure consists of:

- An uncompacted subgrade to maximize the infiltration rate of the soil.
- A geotextile fabric that allows water to pass through, but prevents migration of fine material from the subgrade into the stone recharge bed.

- A stone recharge bed consisting of clean single-size crushed large stone with about 40 percent voids. This serves as a structural layer and also temporarily stores stormwater as it infiltrates into the soil below.
- A stabilizing course or “choker course” consisting of a clean single-size crushed stone smaller than the stone in the recharge bed to stabilize the surface for paving equipment.
- An open-graded asphalt surface with interconnected voids that allow stormwater to flow through the pavement into the stone recharge bed.

Porous pavements do not follow the traditional design of typical pavements. First, traditional pavement structures require the subgrade to be compacted to increase the soil strength. For porous pavements the subgrade should not be compacted since this would decrease the infiltration rate, requiring a thicker stone recharge bed or reducing the permeability enough to make a porous pavement ineffective. Second, typical pavements are constructed with a dense surface that is impermeable to water. For porous pavements, the water flows through the surface into the stone bed where it is temporarily stored and allowed to infiltrate through the soil.

FIGURE 1
Typical porous pavement cross section

Unpaved Stone Edge
Non-Woven Geotextile
Uncompacted Subgrade

Porous Asphalt Pavement
Choker Coarse
Stone Recharge Bed
Uniformly graded clean crushed stone
40% Voids
Overview and History

In the late 1960s, the concept of porous pavement was proposed to “promote percolation, reduce storm sewer loads, reduce flood, raise water tables, and replenish aquifers.” (Thelen, 1978) Throughout the 1970s, the concept was discussed and refined to a point where the Environmental Protection Agency (EPA) contracted to “determine the capabilities of several types of porous pavements for urban runoff control, in terms of cost and efficiency.” (Thelen, 1978) Some of the initial installations of porous asphalt pavement were in Delaware, Pennsylvania, and Texas. The Woodlands site in Texas, which was constructed under an EPA grant, was the only site where substantial scientific monitoring instrumentation was installed. (U.S. Environmental Protection Agency, 1980) In 1977, Edmund Thelen and L. Fielding Howe co-authored a design guide for porous pavement for the Franklin Institute in Philadelphia. This document has been widely referenced in subsequent years and provides a solid foundation for porous pavement designers.

Many additional porous pavement sites have been constructed since the late 1970s. While there have been both successes and failures, the overwhelming majority have succeeded. The most often cited reason for porous pavement failure was failure to control silts entering the porous pavement site, essentially clogging the pavement. Some of the benefits conferred by the successful installations include runoff control, aquifer recharge, reduction of drainage structures needed to comply with stormwater regulations, and increased skid resistance. Cahill Associates has been involved in the design and construction of more than 200 porous asphalt pavements since the 1980s and have reported no failures of pavements for which proper design and construction practices were followed.

This document provides guidelines and recommendations for design, construction, and maintenance of porous asphalt pavements. Factors considered for determining applicability include rainfall, soil infiltration capability, usage/loading, frequency of use, cost, and stormwater regulations.

Under the right conditions, a properly designed porous asphalt pavement will provide a best management practice (BMP) for stormwater runoff problems as well as groundwater recharge.

Economics and Feasibility

Porous pavement does not usually cost more than conventional pavement. On a yard-by-yard basis, the asphalt cost is approximately the same as the cost of conventional asphalt. The underlying stone base is usually more expensive than a conventional compacted sub-base, but this cost difference is generally offset by the significant reduction in stormwater pipes and inlets. Additionally, because porous pavement is designed to “fit into” the topography of a site, there is generally less earthwork and there are no deep excavations. When the cost savings provided by eliminating the detention basin are considered, porous pavement is generally an economically sound choice. Cahill Associates has compared the costs of porous pavements to other stormwater management options. Generally the porous pavement has been the less expensive option.

Open-graded asphalt mix can be produced in any asphalt plant. Any qualified asphalt contractor can install a porous asphalt pavement system. Certification is not required.
Water Quality

Porous pavements are one of the most effective treatment methods for reducing pollution in stormwater runoff from pavements. Cahill reports that, although sampling on porous pavement systems has been limited, the available data indicate a high removal rate for total suspended solids (TSS), metals, and oil and grease. (Cahill, Adams, & Marm, 2005) Table 1 shows pollution removal efficiencies reported by Cahill.

Table 2 shows the pollution removal efficiency for a porous asphalt parking lot constructed at the University of New Hampshire (UNH) in 2004. (UNH Stormwater Center, 2007) The University reports that “The water quality treatment performance of the porous asphalt lot generally has been excellent. It consistently exceeds EPA's recommended level of removal of total suspended solids, and meets regional ambient water quality criteria for petroleum hydrocarbons and zinc. Researchers observed limited phosphorus treatment and none for nitrogen, which is consistent with other non-vegetated infiltration systems.”

They also observed that the system did not remove chloride, but since it drastically reduced the salt needed for winter maintenance, it may prove effective at reducing chloride pollution. They reported that winter main-

**TABLE 1**

Water Quality Benefits of Porous Pavement with Infiltration (% Removal Efficiency)

<table>
<thead>
<tr>
<th>Water Quality Parameter</th>
<th>Infiltration BMP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trench 1</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS)</td>
<td>90</td>
</tr>
<tr>
<td>Total Phosphorus (TP)</td>
<td>60</td>
</tr>
<tr>
<td>Total Nitrogen (TN)</td>
<td>60</td>
</tr>
<tr>
<td>Total Organic Compounds (TOC)</td>
<td>90</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>—</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>—</td>
</tr>
<tr>
<td>Metals</td>
<td>90</td>
</tr>
<tr>
<td>Bacteria</td>
<td>90</td>
</tr>
<tr>
<td>Biological Oxygen Demand (BOD)</td>
<td>75</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>—</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>—</td>
</tr>
<tr>
<td>Total Kjeldahhn Nitrogen (TKN)</td>
<td>—</td>
</tr>
<tr>
<td>Nitrate</td>
<td>—</td>
</tr>
<tr>
<td>Ammonia</td>
<td>—</td>
</tr>
</tbody>
</table>

**TABLE 2**

Pollution removal efficiencies

<table>
<thead>
<tr>
<th>Treatment System</th>
<th>Total Suspended Solids (% Removal)</th>
<th>Total Phosphorus (% Removal)</th>
<th>Total Zinc (% Removal)</th>
<th>Total Petroleum Hydrocarbons in the Diesel Range (% Removal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porous Pavement</td>
<td>99</td>
<td>38</td>
<td>96</td>
<td>99</td>
</tr>
</tbody>
</table>
Tenance requires "between zero and 25 percent of the salt routinely applied to impervious asphalt to achieve equivalent, or better, deicing and traction."

The design of the porous asphalt pavement at UNH is different from the standard design due to poor quality soils and high groundwater. The pavement structure is shown in Figure 2.

A Texas study examined the quality of runoff from a conventional asphalt pavement and a porous friction course (PFC). Porous friction course is the name commonly used in Texas for the pavements called open-graded friction course elsewhere in the U.S. In the project the porous asphalt mix was placed directly on a dense-graded asphalt pavement so that there was no dissolved forms of lead, zinc, and phosphorus showed little change between the two surface types. The researchers concluded, "From these results it is evident that the runoff generated from the PFC surface is of better quality than that from the traditional asphalt surface." (Barrett & Shaw, 2007) This study indicates that even the porous asphalt surface removes some of the pollutants normally associated with runoff from pavement.

Dempsey and Swischer studied the hydrologic and chemical performance of a porous pavement/infiltration system at the Centre County/Penn State Visitor Center. (Dempsey & Swischer, 2003) They reported, "The system consists of porous pavement, a 462-m³ (604 cubic yards) storage/infiltration bed with coarse aggregate (40% porosity), geo-textile filter fabric, and an average 2 m (6.5 feet) of un-compacted soil." "Eleven storm events generated at least 10 cm (4 inches) standing water in the 1.6 m (5 foot) reservoir, allowing sampling. There has been no surface runoff from the site, and infiltration rates have remained relatively constant at 17 cm/hr (6.7 in/hr)." "The aggressiveness of the water towards calcium carbonate was considerably reduced upon contact with limestone materials in the pavement and in the reservoir, decreasing the potential for sinkhole development. The concentrations of Zn, Cu, and Pb (zinc, copper, and lead) were low, and the total annual loading of metals onto the soil beneath the reservoir was much less than the annual loading of metals that is allowed during the application of soil-amendments to agricultural soils. Organic loadings were relatively low and there was evidence of an active community of organisms within the reservoir."

Sampling for water quality was from a sampling well that extended to the top of the geotextile filter fabric so this does not account for any treatment of water infiltrating through the subgrade soils. They also report, "Infiltrating water at the Visitor Center had low chemical oxygen demand (COD) values. This indicates low concentrations of organic materials such as petroleum hydrocarbons. The literature indicates that organic materials will be sorbed and bio-degraded within the top few cm of the sub-grade soil. Macro and microorganisms were consistently observed in the storage/infiltration bed at the Visitor Center. Therefore, there is little potential for contamination of groundwater by organic materials due to normal use of the porous pavement parking lots at the Visitor Center."

FIGURE 2
UNH porous pavement cross section

![Porous Pavement Cross Section Diagram]
Design

The design of a porous pavement can be broken down into location, hydrology and structural design.

The general guidelines for the porous asphalt pavement design are:

1. Consider the location for porous pavements early in the design process.
2. Soil infiltration rates of 0.1 to 10 inches/hour work best.
3. Minimum depth to bedrock or seasonal high water should be greater than two feet.
4. The bottom of the infiltration bed should be flat to maximize the infiltration area.
5. Limit the maximum slope of porous pavement surface to 5 percent. For parking areas on steeper slopes, terrace the parking areas with berms between parking areas.
6. Look for opportunities to route runoff from nearby impervious areas to the infiltration bed to minimize stormwater structures. Pretreatment may be required.
7. Spread out the infiltration. The maximum ratio of impervious to pervious area should be 5:1. For carbonate soils where there is a risk of sinkholes, the maximum ratio should be 3:1. Do not place porous pavements over known sinkhole areas.
8. The design should provide for an alternate path for stormwater to enter the stone recharge bed in the event that the pavement surface becomes plugged or experiences extreme storm events.
9. An overflow system should be included to prevent water in the stone bed from rising into the pavement surface during extreme storm events.
10. The stone recharge bed should be able to drain within 12 and 72 hours.

When a site is being newly developed, the location of the porous pavement should be considered early in the design process. In conventional construction plans, pavements are often placed at the lowest portion of a site, where high groundwater and poor soil infiltration rates may exist. Infiltration systems perform best on upland soils. (Cahill, Adams, & Marm, 2005) Soil Series and Hydrologic Soil Group Maps from the Natural Resources Conservation Service at http://websoilsurvey.nrcs.usda.gov are helpful in this initial design phase. Custom soil reports can also be generated from the same source. Figure 3 shows an example of such a map.

**FIGURE 3**
Example of hydrologic soil group map
Such maps serve as a good starting point early in the design. “Hydrologic soil groups (A) and (B) are ideal for porous paving sites. However, potential areas in soil groups (C) and (D) require more attention.” (U.S. Environmental Protection Agency, 1980) Definitions of soil groups are available from the Natural Resources Conservation Service. Hydraulic conductivities for the different soil groups are shown in Table 3 and Table 4.

Another consideration early in the design process is to look for opportunities to use the stone recharge bed to infiltrate stormwater from nearby impervious areas on the site. The stone recharge bed is typically between 12 and 36 inches in depth. With 40 percent voids in stone this would mean the recharge bed is capable of storing between 4.8 and 14.4 inches of precipitation. This will typically exceed most design storm volumes. Therefore, there may be opportunities to store and infiltrate stormwater from impervious areas at the site to avoid piping water long distances. Pretreatment of the runoff from these impervious areas may be required to reduce sediment or other pollutants, depending on the source of runoff. For example, an impervious pavement that is sanded as part of snow and ice control should not be allowed to flow to the porous pavement area without sediment control.

The bottom of the infiltration bed should be flat to maximize the infiltration area and reduce the amount of stone required, as illustrated in Figure 4.

Slope should also be considered in selecting the location of porous pavements. Porous pavements work best on flat or gently sloping areas. The slope of the surface of the porous pavement should not exceed 5 percent. For parking or sloping areas, consider terracing the parking areas with berms separating the parking bay as shown in Figure 5. These parking areas can be connected with conventional dense-graded asphalt pavement. “Orientation of the parking bays along the existing contours will significantly reduce the need for cut and fill.” (Pennsylvania Department of Environmental Protection, 2006)

### Table 3
Saturated hydraulic conductivity of hydrologic soil groups when a water impermeable layer exists at a depth between 20 and 40 inches

<table>
<thead>
<tr>
<th>Hydrologic soil group A</th>
<th>Hydrologic soil group B</th>
<th>Hydrologic soil group C</th>
<th>Hydrologic soil group D</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;5.67 in/h</td>
<td>≤5.67 to &gt;1.42 in/h</td>
<td>≤1.42 to &gt;0.14 in/h</td>
<td>≤0.14 in/h</td>
</tr>
</tbody>
</table>

### Table 4
Saturated hydraulic conductivity of hydrologic soil groups when any water impermeable layer exists at a depth greater than 40 inches

<table>
<thead>
<tr>
<th>Hydrologic soil group A</th>
<th>Hydrologic soil group B</th>
<th>Hydrologic soil group C</th>
<th>Hydrologic soil group D</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1.42 in/h</td>
<td>≤1.42 to &gt;0.57 in/h</td>
<td>≤0.57 to &gt;0.06 in/h</td>
<td>≤0.06 in/h</td>
</tr>
</tbody>
</table>

The thickness of the stone recharge bed will be determined by the amount of water that needs to be stored, the infiltration rate of the soil, and traffic loading. In most cases, the water quantity and soil infiltration rate will control the thickness of the stone recharge bed and traffic loads will control the thickness of the porous asphalt surface.

**FIGURE 4**
Keep bed bottom flat for maximum infiltration

---

Bottom Must Be Flat

Minimize Excess Stone

Maximize Infiltration Area

Wasted Stone

Less Infiltration Area at Low Depths
FIGURE 5
Terraced porous parking

Hydrologic Design
Detailed hydrologic design is beyond the scope of this publication. The hydrologic design of porous pavement should be performed by a licensed engineer proficient in hydrology and stormwater design. What is presented here is a summary of the concepts which are considered by the engineer.

The two most common methods for modeling stormwater runoff are the Curve Number (CN) method and the Rational method. The Rational method is generally not recommended for evaluating systems such as porous pavements and therefore will not be discussed.

The Curve Number method is used in a number of public domain computer models as well as proprietary programs. At this time no curve numbers have been determined for porous pavements. However, the porous pavement can be modeled assuming that the porous pavement has the same runoff coefficient as a conventional dense-graded pavement (e.g. Curve Number of 98) routing the runoff through the stone recharge bed. (HydroCAD Software Solutions LLC) Outflow from the stone recharge bed will be through infiltration and overflow devices.

The assumption of a high CN causes some concerns among persons modeling stormwater. It is important to note that using this high CN does not mean that the stormwater will be running off the site. Rainfall landing on porous pavement is directly transferred to the underlying stone bed with virtually no loss.

A sign at Walden Pond Visitor Center in Massachusetts informs visitors about the porous pavement that has been in place there for over 30 years.
A good starting point for the design of a porous pavement is to assume that all the rainfall for the storm events will enter the stone recharge bed from the pavement and any other adjacent impervious surfaces with the minimum allowable time of concentration (T). A simple spreadsheet can be used for this purpose. Figure 6 shows a graph that was developed using such a spreadsheet to determine the bed depth that would be required for two-year and 100-year storm events for rain that falls on the porous pavement as well as for stormwater that is routed from adjacent impervious areas to the stone recharge bed. The two-year storm was 3.5 inches in 24 hours, and the 100-year storm was 7.5 inches in 24 hours.

In this example, a very low soil permeability of 0.1 inches/hour was assumed and still a bed depth of only five inches would be required to store and infiltrate the two-year 24-hour storm for rain falling only on the pavement surface. If stormwater from other impervious surfaces on the site is routed to the stone bed, the depth would increase to about 12 inches. To completely store and infiltrate the 100-year 24-hour storm for rain falling only on the pavement and routing stormwater from other impervious areas, the required bed depths would be about 13 and 31 inches, respectively. It should also be noted that for a two-year 24-hour design storm, the bed would be able to drain between the recommended drain times of 12 to 72 hours for both conditions.

**Structural Design**

The vast majority of projects constructed to date were designed to carry light automobile traffic only. For these applications, the structural requirements are not significant. The material thicknesses are determined based on water storage capacity of the base aggregates and on minimum thickness requirements for the porous asphalt. For applications where the porous pavements will be required to carry truck loads, consideration for the structural requirements of the pavement section becomes more critical.

The structural design of porous pavement is based on data from a limited number of studies; however, suffice it to say that many porous pavements have served their traffic-supporting functions for over 20 years.

The most thorough structural evaluation of a porous pavement was on a porous roadway constructed by the Arizona DOT. This pavement was constructed in 1986 and consisted of 6 inches of an open-graded asphalt (3/8 inch maximum aggregate size) over 6 inches of asphalt-
TABLE 5  
Layer equivalency for open-graded asphalt

<table>
<thead>
<tr>
<th>Temp., °F</th>
<th>Based on Core Testing</th>
<th>Based on Lab-Prepared Specimens</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>1.41</td>
<td>1.33</td>
<td>1.37</td>
</tr>
<tr>
<td>77</td>
<td>1.98</td>
<td>1.57</td>
<td>1.78</td>
</tr>
<tr>
<td>Average</td>
<td>1.70</td>
<td>1.45</td>
<td>1.57</td>
</tr>
</tbody>
</table>

Aporous pavement is on the right in this San Diego parking lot.

treated permeable base (ATPB) over 8 inches of open-graded subbase (stone recharge bed). At this writing (in fall 2008), the pavement is still functioning well. It is located in Chandler, Arizona on the northbound lanes of Arizona Avenue between Elliott and Warner Roads.

The pavement designers selected structural coefficients of 0.40 for the open-graded surface, 0.20 for the ATPB, and 0.11 for the open-graded subbase. This compares to structural coefficients of 0.44 for dense-graded asphalt and 0.14 for dense-graded aggregate base. Gemayel and Mamlouk reported that 1.7 inches of open-graded asphalt surface is equivalent to 1.0 inches of dense-graded asphalt based on a layer elastic analysis. (Gemayel & Mamlouk, 1988). This is compared to the 1.1 equivalency used in the original design.

A final report on the Arizona project in 1991 reported the resilient modulus of the pavement layers based on falling weight deflectometer (FWD) tests. (Hossain & Scofield, 1991) Laboratory resilient modulus of cores for the porous pavement from the 1988 study were about 180 and 560 ksi for the open-graded and conventional pavement, respectively. This means that the resilient modulus of the open-graded asphalt is about 32 percent of the conventional pavement. On average the same comparison from the back-calculated moduli is about 45 percent.

Although the modulus values for the porous pavement were lower than the conventional pavement, the fact that the pavement has performed well for more than 20 years indicates that the original layer coefficients of 0.40, 0.20 and 0.11 for the porous asphalt, ATPB, and open-graded stone base, respectively, were adequate.

Other data are available on the strength of the different materials, open-graded aggregates, and ATPB. One study by the Oregon Department of Transportation (Zhou, Moore, Huddleston, & Gower, 1992) evaluated untreated and treated free-draining base materials using results from other research reports and testing of materials used by the Oregon DOT. The untreated free-draining aggregate base properties would be appropriate for the strength of the stone recharge bed. In this report a layer coefficient between 0.08 and 0.14 for the untreated aggregate base was recommended. This is similar to the layer coefficients typically assigned to dense-graded aggregate bases. ATPB layer coefficients between 0.14 and 0.19 were determined for Oregon materials. They also reported that ten states assign a layer coefficient for ATPB equivalent to aggregate base and six states assign layer coefficients between 0.20 and 0.30. The Oregon DOT Pavement Design Guide assigns layer coefficients of 0.42 for open-graded mixes and 0.24 for ATPB.

A study by the Vermont Agency of Transportation recommended a layer coefficient of 0.331 for ATPB based
on FWD testing. (Pologruto 2004) The Vermont Agency of Transportation Pavement Design Guide recommends a layer coefficient of 0.33 for ATPB.

Even though there is some uncertainty on structural design values for porous pavements, there is substantial anecdotal experience supporting the use of porous asphalt for applications with trucks. The previously mentioned Arizona project is a good case in point. In Oregon, agencies have designed and built open-graded cold mixes for farm to market applications for over 30 years. These pavements are generally 3 to 5 inches of open-graded cold mixes over dense aggregate, typically with a chip seal surface. They have performed better inch for inch than a dense mix would in the same application. Another example is the recent experience with the Pringle Creek subdivision (see Construction Guidelines, page 19,) in Salem, Oregon, in which the ATPB handled heavy construction truck traffic with no distress. The porous aggregate bases perform very well, both because they tend to be thick and because they are just as sound when wet as when dry, unlike conventional dense aggregate bases. It is probable that the layer coefficient of the open-graded base rock is substantially better than dense aggregate when seasonal effects are considered.

Table 6 provides recommended layer coefficients for structural evaluation of porous asphalt pavements. Table 7 provides recommended minimum thicknesses for the porous asphalt surface for different truck loadings.

Frost

In the past it has been recommended that the bottom of the recharge bed should exceed the depth of frost penetration in the region where the porous pavement is to be installed. More recently this has come into question since a number of porous pavements have been installed in freezing climates with total depths much shallower than this. These include pathways at Swarthmore College (Pennsylvania) at a depth of 12 inches and a Walden Pond Visitor Center (Massachusetts) parking lot: with a bed depth of 12 inches. None of these pavements have shown damage due to frost heave. The only research on frost depth has occurred at the University of New Hampshire, where the frost depth is 48 inches. While the porous pavement at the site extends to below the frost depth, their data from 2006 shows frost penetration in the recharge bed of less than one foot. The University conservatively recommends the depth of the bed be 65 percent of the frost depth in their design specifications.

Soil Investigation

Before any infiltration system is designed, soil investigation must be done. This consists of two steps. First, simple test pits six to eight feet in depth are excavated with a backhoe and the soil conditions are observed. The depth of the test pits will vary depending on the anticipated depth of the bottom of the reservoir bed. The bottom of the excavation should extend a minimum of two feet below the planned recharge bed. While auger borings may be used, there are benefits to physically observing and describing the soil horizons. Test pits also facilitate the next step in checking the infiltration rate of the soils. According to the Pennsylvania Department of Environmental Protection (2006), observations that should be included are:

- Soil horizons (upper and lower boundary)
- Soil texture and color for each horizon

<table>
<thead>
<tr>
<th>TABLE 6</th>
<th>Recommended layer coefficients for porous pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Layer Coefficient</td>
</tr>
<tr>
<td>Porous Asphalt</td>
<td>0.40 – 0.42</td>
</tr>
<tr>
<td>Asphalt Treated Permeable Base (ATPB)</td>
<td>0.30 – 0.35</td>
</tr>
<tr>
<td>Porous Aggregate Base (Stone Recharge Bed)</td>
<td>0.10 – 0.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 7</th>
<th>Minimum compacted porous asphalt thicknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Loading</td>
<td>Minimum Compacted Thickness, inches</td>
</tr>
<tr>
<td>Paving – Little or no trucks</td>
<td>2.5</td>
</tr>
<tr>
<td>Residential Street – Some truck</td>
<td>4.0</td>
</tr>
<tr>
<td>Heavy Truck</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Color patterns (mottling) and observed depth
- Depth to water table
- Depth to bedrock
- Observed presence of roots (size, depth)
- Estimated type and percent coarse fragments
- Hardpan or limiting layer
- Strike and dip of horizons (especially lateral direction of flow at limiting layers)

Always follow safe operating procedures when entering test pits. OSHA regulations should always be observed.

The number of test pits varies depending on site conditions, variability, and the proposed development plan. General guidelines from the Pennsylvania Department of Environmental Protection are as follows:

- For single-family residential subdivisions with on-lot BMPs, one test pit per lot is recommended, preferably within 25 feet of the proposed BMP area. Verification testing should take place when BMPs are sited at greater distances.
- For multi-family and high-density residential developments, one test pit per BMP area or acre is recommended.
- For larger infiltration areas (basins, commercial, institutional, industrial, and other proposed land uses), multiple test pits should be evenly distributed at the rate of four to six tests per acre of BMP area.

The recommendations above are guidelines. Additional tests should be conducted if local conditions indicate significant variability in soil types, geology, water table levels, bedrock, topography, etc. Similarly, uniform site conditions may indicate that fewer test pits are required.

Next, infiltration measurements are performed at the anticipated bed bottom location. There are a variety of field tests that are used to determine the infiltration rate of soils. The most commonly used tests are the double-ring infiltrometer and percolation tests (such as for onsite wastewater systems). The double-ring infiltrometer test estimates the vertical movement of water through the bottom of the test area. The outer ring helps to reduce the lateral movement of water in the soil from the inner ring. The percolation test allows water movement through both the bottom and sides of the test area. The infiltration rate for the percolation test needs to be adjusted to account for infiltration that occurs through the sides of the hole. Local stormwater regulations should be consulted to determine acceptable procedures for determining infiltration rates. These tests must be performed at multiple locations to determine the average infiltration rate for the site. Examples of infiltrometer tests are:

- Testing as described in the Maryland Stormwater Manual Appendix D.1 using 5-inch diameter casing.

Most references suggest that the underlying soils should have a minimum infiltration rate of 0.50 in/hr for full exfiltration systems. Some reports suggest that soils with permeability less than 0.25 inch per hour are probably not suitable for porous pavement applications without substantial additional facilities. However, porous pavements have been successfully used with soil infiltration rates as low as 0.1 inches/hour. The key is to design the reservoir course to hold water for the design storm while making sure that the water will drain within a 24- to 72-hour period for proper water treatment. Other engineered options in combination with the permeable pavement may be considered for slow infiltration rates.

Underlying geology must also be considered in areas such as those underlain by limestone or dolomite formations. In that situation, more detailed site investigation may include borings and ground-penetrating radar. Contrary to popular belief, properly designed infiltration

**FIGURE 7**
The first step in designing any infiltration feature is field investigation of the soils.
systems do not create sinkholes. A number of systems designed by Cahill Associates, including older systems, are located in carbonate areas. In several situations they have successfully installed porous pavement infiltration systems adjacent to areas where detention basins created sinkholes.

**Overflow Structures**

Porous pavements are not normally designed to store and infiltrate all stormwater from all storms. Therefore, it will be necessary to include some method of outlet control to prevent the water from rising into and over the porous asphalt surface. A common type of outlet control would be an inlet box with an internal weir and low-flow orifice. Examples of overflow devices are shown in Figure 9 and Figure 10.

**Other Design Considerations**

It is very important that porous pavements be protected from sediment during and after the construction process. Therefore, for larger projects where porous pavements are being considered, it may be advantageous to construct some pavement areas as impervious. It is very important that porous pavements be protected from sediment during and after the construction process. Because construction sites are inherently dirty there are advantages to constructing porous pavement late in the construction schedule. However, many building/fire codes require hard surfaces to be in place before structures are built. Therefore there may be advantages to constructing access roads and driveways of dense-graded asphalt and using other areas that may be constructed later for porous pavements. It is also possible to construct a porous pavement, either partially or entirely, early in the development process and cover it with a geotextile to protect it from clogging. The geotextile can then be removed at an appropriate time. This technique is discussed below under Construction Practices, page 19.

**FIGURE 8**

Roof leaders can be connected directly to the subsurface infiltration bed.

![Diagram of roof leaders connected to subsurface infiltration bed]

- A Precipitation is carried from roof by roof leaders to storage bed.
- B Stormwater runoff from impervious areas and lawn areas is carried to storage bed.
- C Precipitation that falls on porous parking enters storage bed directly.
- D Stone bed stores water. Continuously perforated pipes distribute the stormwater from impervious surfaces evenly throughout the bed.
- E Stormwater infiltrates from storage bed into soil, recharging groundwater.
Paths
In addition to parking lots and roads, porous pavements have also been used successfully for paths and trails. One complication in using porous pavements for paths is that they normally follow the natural contours of the land, so the bed bottoms might not necessarily be flat. They do reduce the amount of impervious surface. They also mimic the natural infiltration of the surrounding terrain and will therefore reduce runoff and improve water quality. Because the pavement/infiltration system follows the surrounding contours, it is necessary to provide drains at low points as shown in Figure 11. In some cases it may be possible to terrace the bed bottom with short berms below the pavement surface to increase the storage capacity and improve infiltration as shown in Figure 12.

FIGURE 11
Porous asphalt path

FIGURE 12
Porous asphalt path with berms for increased storage and infiltration
Materials

Geotextile (Filter Fabric)

Non-woven geotextiles are typically used to prevent fines in the subgrade from migrating into the stone recharge bed. The following is an example of a typical specification for this material:

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<td>Grab Tensile Strength</td>
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<td>UV Resistance after 500 hrs</td>
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Heat-set or heat-calendered fabrics are not permitted. Acceptable types include Minifl 140N, Amoco 4547, Geotex 451, or approved equivalent.

Stone Recharge Bed and Choker Course

Aggregate for the stone recharge bed needs to be clean, crushed stone. In many cases AASHTO No. 3 stone is specified; however, other aggregate gradations such as AASHTO No. 1, No. 2, and smaller have also been used successfully. The key to the aggregate is that it be clean, uniformly graded, and crushed with minimum voids of 40 percent as determined by ASTM C29. An additional grading requirement of 0 to 2 percent passing the No. 100 sieve is recommended to make sure the aggregate does not have excessive fines that could clog the bed.

In most cases when using an AASHTO No. 3 stone for the recharge bed, an AASHTO No. 57 stone has worked well as a choker course. If a larger or smaller stone is used for the recharge bed, the size of the choker stone will need to be adjusted. The thickness of the choker course is also important. It should be placed no more than one inch thick and be sufficient to fill the voids of the recharge bed stone in order to provide a smooth paving surface. A number of contractors have reported that they have found no advantage to using a choker course and have successfully constructed pavements without this course. Therefore, the choker course may be considered optional.

Porous Asphalt

Since the first porous asphalt pavements were constructed in the 1970s, we have learned much about the porous asphalt mixes, commonly referred to in the U.S. as open-graded friction courses (OGFC) when used on highways. The early mixes were typically specified using the Marshall mix design with the only requirements being aggregate quality, gradation, and minimum asphalt content. Originally, these mixes also used unmodified asphalt cement binders.

Today these mixes are designed using the Superpave or Marshall methods with requirements for higher air voids to assure permeability and low draindown for performance. In most cases, the mixes are made with polymer-modified asphalt and in some cases fibers. The polymer-modified asphalt helps to reduce draindown and improve the high-temperature performance of the mix (resistance to scuffing). Fibers are another way to reduce draindown. While modified asphalts should be used for most applications, these are not always necessary, or practical. Some asphalt plants do not have dedicated storage tanks for polymer-modified asphalts, making it impractical to provide modified asphalt in small quantities. One example of a recent successful project using a non-polymer-modified asphalt is the Port of Portland's terminal 6 project where a 35-acre porous pavement was constructed using an unmodified PG 70-22 binder. This project is performing well. It should be noted that while the standard grade of binder for the Portland area is a PG 64-22, the environmental criteria would only require a PG 58-22, so the binder used is two grades stiffer than what would be required for temperature.

There are a number of guides and specifications available for porous asphalt mixes. These include NAPA publication IS-115, Design, Construction, and Maintenance of Open-Graded Asphalt Friction Course, ASTM D7064, Standard Practice for Open-Graded Friction Course (OGFC) Mix Design, state department of transportation specifications, and state asphalt pavement associations. In most cases it is advantageous to use state DOT specifications since they have been developed for local
climates and materials, and contractors are familiar with them. While almost all states have specifications that are routinely used for ATPB materials, far fewer states routinely use open-graded friction courses. Therefore, when using a state DOT specification you should check to see if this is a standard practice in the state and if the following key properties are included as part of the specification:

- **Air voids:** 16 percent minimum — This assures permeability of the mix. It is important when testing air voids of open-graded mixes to measure the volume by dimension (ASTM D3203, Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures) or by ASTM D6857-03, Standard Test Method for Maximum Specific Gravity and Density of Bituminous Paving Mixtures Using Automatic Vacuum Sealing Method. **Do not determine the density of open-graded mixes using saturated surface dry (SSD) procedures.**

- **Asphalt content:** A good guideline is to require 5.75 percent minimum by weight of total mix. Adequate binder content is important for the durability of the mix. This minimum guideline above is for a 3/8-inch (9.5 mm) Nominal Maximum Aggregate Size (NMAS) such as is shown in the first two columns of Table 7. For larger NMAS mixes, a lower minimum asphalt content is acceptable. For ATPB, the asphalt content is typically between 3.0 and 3.5 percent.

- **Draindown:** 0.3 percent maximum — This test is important to make sure that the asphalt binder does not drain down during storage, transportation and placement. This test is performed in accordance with ASTM D6390-05, Standard Test Method for Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures. This test is run at 15°C (27°F) above the expected production temperature. Other draindown tests may exist in some states; for example, Oregon has developed a draindown procedure based on visual evaluation and has used this test successfully for many years to design OGFCs.

- **Moisture susceptibility** — Because porous asphalt surfaces do not hold water, they have very low risk of moisture-related damage. A very low-risk approach to designing porous asphalt mixes is to follow the same practice used for dense mixes using the same aggregate and asphalt. If the dense mix from a given source requires an anti-stripping agent, then one should be used with the porous mix as well. If no history exists from a site, then a "surrogate" stripping test for moisture susceptibility may be run on dense mix using the same aggregate and asphalt.

- **ASTM D7064** includes a moisture susceptibility test that is a modification of the Modified Letton test used on dense-graded mixtures. The following is a summary of this test procedure:
  - Compact using 50 gyrations
  - Vacuum saturate for 10 minutes (do not measure saturation level)
  - Use 5 freeze thaw cycles
- Keep specimens submerged in water during freezing
- Minimum tensile strength ratio (TSR) = 80 percent

This test is sometimes problematic with open-graded mixes since the final step in the procedure places the specimens in a 140°F (60°C) water bath. In some cases the mix may fall apart under these conditions and it is not an indication of the mix's quality. In general, as stated previously, if the aggregate being used normally requires an anti-stripping agent in dense-graded mixes, the anti-strip should also be used in the open-graded mix. A "surrogate" test for open-graded mixes in which the same aggregates and asphalt are used to produce a dense-graded mix and this dense-graded mix is tested for moisture susceptibility using standard procedures may be used.

In most cases, a 3/8 inch (9.5 mm) NMAS is used for the surface of porous asphalt pavements. These surfaces have proven to be durable in many instances and provide an appearance that is pleasing. However, there are larger NMAS mixes that may be used in applications other than what most porous pavements have been used for. Table 10 provides examples of other open-graded mixes and their potential applications. For design thicknesses requiring multiple lifts, consideration should be given to using larger stone mixes with higher air void contents in the base lifts and finer stone mixes in the surface lifts. This approach will aid in maintaining the pavement's porosity over the long term, as particulate matter passing through the surface layer is unlikely to clog the underlying layers. The ATPB material contains a substantially higher air void content and much lower asphalt content than the listed surface course materials and as such makes a very economical base that is unlikely to clog.

<table>
<thead>
<tr>
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<tr>
<td>Example open-graded asphalt mix gradations</td>
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<td>(Note: Check your state DOT and state asphalt pavement association for gradations commonly used for the project location.)</td>
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<th>Sleeve</th>
<th>NAPA IS-115</th>
<th>Oregon DOT Specifications</th>
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<tr>
<td></td>
<td>3/8&quot;*</td>
<td>1/2&quot;</td>
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<tr>
<td><strong>Percent Passing</strong></td>
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<td>1&quot; (25 mm)</td>
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</tr>
<tr>
<td>3/4&quot; (19 mm)</td>
<td>100</td>
<td>—</td>
</tr>
<tr>
<td>1/2&quot; (12.5 mm)</td>
<td>85 - 100</td>
<td>99 - 100</td>
</tr>
<tr>
<td>3/8&quot; (9.5 mm)</td>
<td>55 - 75</td>
<td>90 - 100</td>
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<tr>
<td>#4 (4.75 mm)</td>
<td>10 - 25</td>
<td>22 - 40</td>
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<td>#8 (2.36 mm)</td>
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<td>#200 (0.075 mm)</td>
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<td>1 - 5</td>
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* Asphal Pavement Association of Oregon

<table>
<thead>
<tr>
<th>TABLE 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential applications for different open-graded mixes</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Mix Size</th>
<th>Application</th>
<th>Layer Thickness</th>
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</thead>
<tbody>
<tr>
<td>3/8&quot; (9.5 mm) open graded</td>
<td>Parking/Recreational Facilities</td>
<td>1.5 - 3.5 inches</td>
</tr>
<tr>
<td>1/2&quot; (12.5 mm) open graded</td>
<td>Wearing Surface, Roads, Streets, Heavy Commercial</td>
<td>2.0 - 4.0 inches</td>
</tr>
<tr>
<td>3/4&quot; (19 mm) open graded</td>
<td>Wearing Surface, Roads, Heavy Commercial</td>
<td>2.0 - 5.0 inches</td>
</tr>
<tr>
<td>3/4&quot; (19 mm) ATPB</td>
<td>Base Course</td>
<td>3.0 - 6.0 inches</td>
</tr>
</tbody>
</table>
Construction Guidelines

Protecting the pavement from uncontrolled runoff from adjacent areas is critical. Temporary stormwater controls need to remain in place until the site is stabilized so that soil-laden stormwater does not wash onto the pavement, clogging the surface and filling the voids in the stone recharge bed. The porous pavement should be constructed late in the project schedule so that most of the dirty work such as grading and landscaping are completed first.

With regulations often requiring a hard paving surface before structures are constructed, conventional dense-graded pavements can be constructed for driveways and some of the other pavement surfaces. In rare cases this may not be possible. One example of this is Pringle Creek, a subdivision in Salem, Oregon constructed using porous pavement streets. In this case, the porous pavement needed to be constructed before the site work including utilities, sidewalks and landscaping was

FIGURE 13
At the Pringle Creek community, porous pavement was protected by geotextile fabric during construction (left). The geotextile was removed prior to final paving (right). The finished pavement is attractive and functional (bottom).
constructed. Here, the porous asphalt was constructed in two layers — 3 inches of ATPB with 1.5 inches porous asphalt surface. The ATPB was placed in the late summer before the site work was complete. The ATPB was covered with a geotextile fabric to protect it. Once the site work was substantially complete the following spring, the geotextile was removed, the pavement surface was cleaned, and the porous asphalt surface was placed. Figure 13 shows the three distinct stages of this project; even under very difficult site conditions the contractor was able to maintain the cleanliness and porosity of the ATPB.

In some cases, the area where the porous pavement is to be constructed may be used for temporary sediment control during construction. In this scenario, the bed should be excavated at least one foot above the final elevation of the bed. In the later stages of the project, the sediment is removed, the bed is excavated to final grade, and the porous pavement system installed. This also avoids the need for a separate sediment basin during construction and limits the exposure of the porous pavement to clogging by construction debris.

Invariably, when an infiltration best management practice (BMP) fails it is due to difficulties and mistakes in the design and construction process. This is true for porous pavement and all other infiltration BMPs. Carelessness in compacting the subgrade soils, poor erosion control, and poor-quality materials are all causes of failure. For that reason, detailed specifications on site protection, soil protection and system installation are required. A preconstruction meeting should be held to discuss the need to prevent heavy equipment from compacting soils, the need to prevent sediment-aden waters from washing on to the pavement, the need for clean stone, etc. Designers should review the installation process with the project foreman and routinely stop by the site to provide construction advice. Successful installation of any infiltration BMP is a hands-on process that requires an active role for the designer. Often, the failure does not lie with the contractor or with poor soils, but instead is due to a lack of specific guidance for construction procedures.

The following are some general guidelines for construction of porous pavements:

- The site area for the porous pavement should be protected from excessive heavy equipment running on the subgrade, compacting soil, and reducing permeability.
- Excavate the subgrade soil using equipment with tracks or over-sized tires. Narrow rubber tires should
be avoided since they compact the soil and reduce its infiltration capabilities.

- As soon as the bed has been excavated to the final grade, the filter fabric should be placed. Overlap the filter fabric a minimum of 16 inches. The filter fabric should extend at least four feet outside the bed to prevent sediment-laden runoff from entering the bed. This excess fabric will be folded over the stone bed to temporarily protect it from sediment until the porous asphalt surface is placed.

- Install drainage pipes if required.

- Place aggregate for the stone recharge bed, taking care not to damage the filter fabric. Aggregate should be dumped at the edge of the bed and placed in layers of 8 to 12 inches using track equipment. Compact each lift with a single pass of a light roller or vibratory plate compactor.

- The use of a choker course over the top of the stone recharge bed has been standard practice since the early beginnings of porous pavements. The purpose of this course is to stabilize the surface for the paving equipment. The purpose is not to cover the large stone in the recharge bed but to fill some of the surface voids and lock up the aggregate. Therefore some of the large stones will be visible after the choker course has been placed and compacted.

A number of contractors have reported that they are no longer using this layer since they see no benefit during the paving operation. The consensus is that the choker course should be optional. When using a choker course it is important that the aggregate be sized to interlock with the aggregate in the recharge bed.

- The porous asphalt layer is placed in 2- to 4-inch-thick lifts using track pavers, following state or national guidelines for the construction of open-graded asphalt mixes. Failure to follow these guidelines can lead to premature hardening of the asphalt and early failure of the pavement by raveling or loss of infiltration capacity. NAPA publication IS 115, Design, Construction, and Maintenance of Open-Graded Asphalt Friction Courses, provides guidance on constructing open-graded mixtures that can be used for porous pavements.

- The asphalt should be compacted with two to four passes of a ten-ton static roller. Normally, only a few passes are necessary. In many cases it will be necessary to let the mix cool before beginning compaction. Additional passes with a lighter roller may be required to remove roller marks at the surface; it is best to do this after the mix has cooled substantially.

- After final rolling, traffic should be restricted for the first 24 hours, as the pavement may be more tender during this time.

- It is critical to protect the porous pavement during and after construction from sediment-laden water and construction debris that may clog it.

**Post Construction**

- Where applicable, remove temporary stormwater drainage diversions after vegetation is established.

- Although snow and ice tend to melt more quickly on porous pavement, it may still be necessary to apply de-icing compounds such as salt or liquid de-ice. **Do not use sand or ash on the surface since clogging may occur.** As previously mentioned, the University of New Hampshire has shown that significantly less deicer may be applied than with conventional pavements.

- Signs are often posted at porous pavement sites to alert grounds keeping and maintenance personnel to keep silt and debris from entering the site, and to warn them not to seal the pavement or use sand or other abrasives for snow or ice conditions. In addition, these signs can include some educational information regarding the advantages of porous pavement.

When a fire hose pumps water onto a porous pavement, the water drains quickly.
Maintenance

As stated above, it is essential that porous pavements not be seal-coated by maintenance personnel. In addition, sand or ash must not be used for control of snow and ice.

All porous pavements should be inspected several times in the first few months after construction, and at least annually thereafter. Inspections should be conducted after large storms to check for surface ponding that might indicate possible clogging. Little research has been done on restoring permeability to porous pavements. In Europe and Japan, large pressure washing/vacuum equipment has been used to restore permeability on porous pavements (referred to as open-graded friction courses in the US) for roadways. The University of New Hampshire has done limited research on cleaning their porous asphalt sites with a combination of pressure washing (not high-pressure) and vacuuming. Their report on this research has not been issued at this writing. To prevent clogging of porous pavements it is recommended that they be vacuum swept twice per year. As previously discussed, it is also very important that sanding not be used for winter maintenance.

Damage to the porous pavement can be repaired using conventional, non-porous patching mixes, as long as the cumulative area repaired does not exceed 10 percent of the paved area.

The photos show a parking lot at University of New Hampshire one hour after plowing, with a close-up of the porous asphalt portion of the lot at bottom. Porous and non-porous areas were evaluated for the degree (percentage) of snow and ice cover and the friction factor (measured by ASTM E303-93). A 75 percent reduction in salt application was possible: that is, with only 25 percent of the salt, the snow and ice cover on the porous asphalt was the same as on conventional dense-mix asphalt. For the friction factor, a 100 percent reduction was determined (porous asphalt, even with no salt, has higher frictional resistance than dense-mix asphalt with 100 percent of the normal salt application). Therefore, a sizable reduction in salt application rate is possible for porous asphalt without compromising braking distance or increasing the chance of slipping and falling.
Conclusion

Porous asphalt pavements have been used for more than thirty years around the United States to minimize the environmental impact of pavements. In addition to providing hard surfaces for parking and driving, they serve as stormwater storage and infiltration systems. Site planners and public works officials have found that they offer the opportunity to manage stormwater storage in an environmentally friendly way, as they promote infiltration, improve water quality, recharge groundwater, and keep the flow of runoff in line with non-developed areas. They have been used successfully in a variety of climates for parking lots and city streets. Recent advances in understanding of porous pavements have made it possible to modify the design of these systems so that they may be used more widely and at lower cost.

The porous asphalt in the foreground offers a dry surface when a conventional dense-graded asphalt remains wet.
References


Photos and Illustrations
All photos and illustrations are the property of National Asphalt Pavement Association, unless otherwise stated.

Pages 4, 19, 21: Photos by Jim Huddleston
Page 6: Figure 2: Based on University of New Hampshire illustration
Page 13: Photo by Cahill Associates
Page 14: Figure 8: Based on Cahill Associates illustration
Page 22: University of New Hampshire photos

Tables
All tables are the property of National Asphalt Pavement Association, unless otherwise stated.
Table 1: Cahill, Adams & Marm, 2005
Table 2: University of New Hampshire
Table 5: Gemayel & Mamlouk, 1988
Table 8: Pennsylvania Department of Environmental Protection, 2006
Table 10: Asphalt Pavement Association of Oregon
**SI* (MODERN METRIC) CONVERSION FACTORS**

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</tbody>
</table>

### TEMPERATURE (exact)

<table>
<thead>
<tr>
<th>Temperature (exact)</th>
<th>Fahrenheit</th>
<th>Celsius</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>5(F-32)/9</td>
<td>°C</td>
</tr>
</tbody>
</table>

### TEMPERATURE (exact)

<table>
<thead>
<tr>
<th>Temperature (exact)</th>
<th>Celsius</th>
<th>Fahrenheit</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>1.8C + 32</td>
<td>°F</td>
</tr>
</tbody>
</table>

*SI is the symbol for the International System of Measurement.*

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**NAPA: THE SOURCE**

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