Asphalt Paving Principles

NEW YORK STATE OF OPPORTUNITY. | Department of Transportation | Local Technical Assistance Program

Cornell Local Roads Program

New York State LTAP Center

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Preface

We prepared this workbook for use by highway superintendents who select paving alternatives, evaluate options, and analyze cost. Whether you use a paving contractor, share paving operations with another municipality, or do your own paving, these guidelines can help you get a quality job.

This workbook was created to be used primarily in the one–day training course, Asphalt Paving Principles, which we have offered continuously since the spring of 2004. The workbook is also available free of charge to local highway agencies throughout New York State.

Edward J. Kearney P.E., former Director of Engineering and Technical Services, Wirtgen America, and Chris Blades, former Vice President, A.L. Blades and Sons, Inc., wrote the workbook. Both consultants taught the course from 2004 until 2016. The information in the workbook draws somewhat from the Hot and Cold Mix Paving workbook and course, which the New York State LTAP Center - Cornell Local Roads Program (NYSLTAP-CLRP) offered in 1995. Rod Birdsall, P.E., wrote the workbook for that course.

Since the original conception of this workbook, there have been various changes and improvements in construction practices, inspection procedures, and materials specifications both statewide and nationwide. Therefore, NYSLTAP-CLRP instructed the current Asphalt Paving Principles consultant Gary Nelson, former Quality Control & Materials Manager of Buffalo Crushed Stone Inc., and also former Co-Chair of the New York Construction Materials Hot Mix Asphalt Technical Committee to update this workbook accordingly.

The New York State LTAP - Cornell Local Roads Program provides training and technical assistance to highway and public works officials in New York State. Support for the NYSLTAP-CLRP is provided by the Federal Highway Administration's Local Technical Assistance Program (LTAP), the New York State Department of Transportation, Cornell University, and workshop registration fees.

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1 INTRODUCTION

The purpose of this workbook is to provide enough basic and practical knowledge about asphalt pavements to be able to make good decisions when roads are in need of rehabilitation, repair or maintenance. This workbook will briefly touch on technical topics such as pavement structures, asphalt mixtures, and drainage. It is important to know where pavements and mixes get their strength, and how water, if not properly controlled, can destroy a road.

The workbook covers the following subjects:

- Fundamentals of a good road
- Materials used in roadway construction
- Types and causes of pavement failures
- Rehabilitation treatments for pavements
- Inspection of asphalt pavement construction

Each of these topics is important enough to warrant a separate, full–day training course. Therefore, the workbook can only cover the most critical points. The main goal of this workbook and accompanying course is to train participants to:

- Recognize various types of pavement failures
- Know the probable causes of pavement failures
- Recognize options to repair failures
- Assure that the repairs are properly constructed

The emphasis will be on hot mix asphalt (HMA) because it is the most widely used product. However, cold mixes will also be discussed. Because HMA is not the correct treatment for all pavement problems, rehabilitation treatments such as cold in–place recycling and full depth reclamation with stabilizing agents (asphalt emulsion, foamed asphalt, and portland cement) will also be covered.

Detailed explanations of these topics can be found in the references listed in Appendix A. These publications are readily available from industry groups such as the Asphalt Institute, National Asphalt Pavement Association, and the Asphalt Recycling and Reclaiming Association. The Cornell Local Roads Program has copies of these references available for loan. Also, the NYSDOT website www.dot.ny.gov provides current specifications and guidance on numerous subjects discussed in this manual.

The New York State Department of Transportation (NYSDOT) began transitioning back to U.S. customary units in 2008. Some engineering documents may be in metric units.

2 FUNDAMENTALS OF A GOOD ROAD

An experienced county highway superintendent once told the Cornell Local Roads Program Director, Lynne Irwin, ***"We need to build roads to hold the loads."*** This statement probably best describes one of the main goals for today's highway superintendent. If a road is properly designed and built, it will remain in good condition for many years with only minimal maintenance. This results in keeping the traveling public satisfied, the politician's happy, and allows time for the highway superintendent to attend to other critical matters.

The job of a road is to carry the loads under all weather conditions for a specified design life. This is achieved by:

- Stabilizing (i.e., strengthening) the existing subgrade and providing stable base and subbase layers above the subgrade
- Providing adequate water drainage, because water can weaken soils and asphalt pavements
- Constructing a pavement structure that is:
  - Thick enough to structurally carry all expected traffic loads for a period of time
  - Properly compacted to develop its full strength and prevent water penetration into the pavement and its base
  - Surfaced with a wearing course that resists wear, deformation, weather, and remains skid resistant

2.1 Pavement Structure and Design

Pavements are made up of several layers of different materials (Figure 1). The in–place soils, called the subgrade, serve as the foundation that supports the road. When a roadway is constructed on an embankment, the imported fill materials (embankment) become the subgrade. After removal of topsoil and other organic materials, the subgrade may be stabilized by compaction alone, or by compaction after mixing in asphalt emulsion, foamed asphalt, portland cement, lime, or other proprietary stabilizing materials. On top of the subgrade, a base layer is usually constructed from good quality gravel or crusher run aggregates. When heavy traffic is expected, the base layer is usually hot mix asphalt (HMA).

In some cases, because of very poor subgrade soils, construction of a subbase layer may be necessary to serve as a construction platform to prevent the intrusion of fines into the base, improve drainage, or reduce damage from frost action. If a processed subbase is required, a good starting point for reference can be found in NYSDOT's Standard Specifications under Section 304 Subbase. Detailed technical specifications for the materials are outlined in Section 733.04. The subgrade or embankment fill actually bears the traffic loads. The upper pavement layers support the wheel loads and distribute them across a wider area of the subgrade (Figure 2).

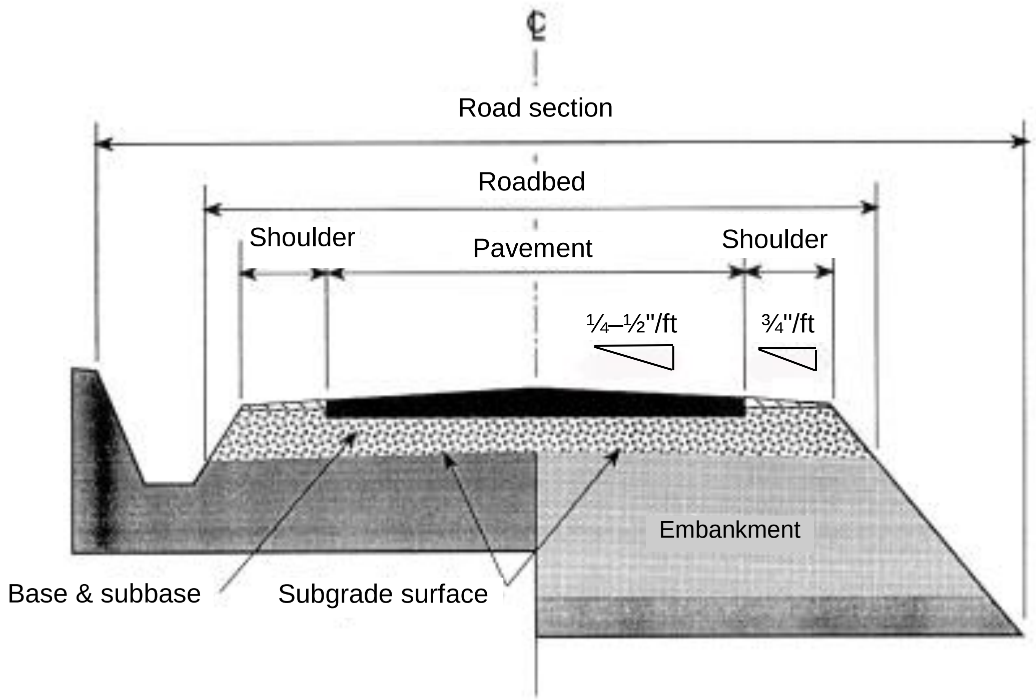


Figure 1 Typical pavement cross section

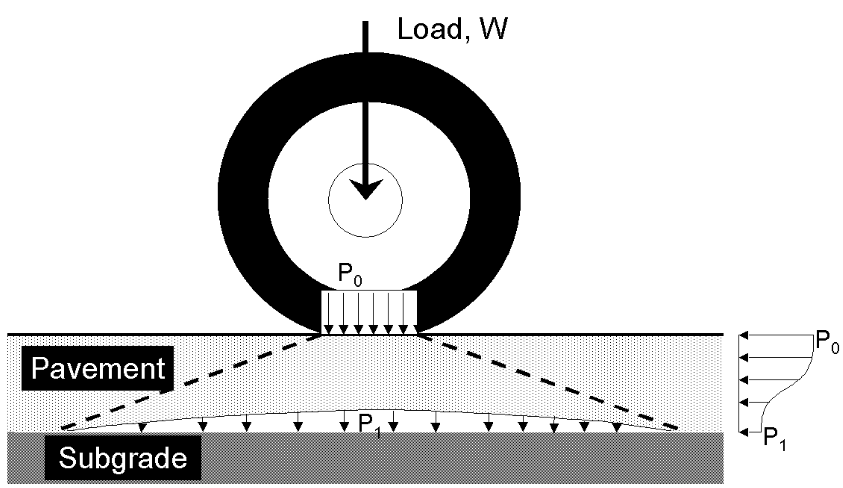


Figure 2 Spread of wheel load pressure through the pavement structure

Figure 2 shows a wheel load applying a downward pressure on a road surface. The load is spread out and reduced in intensity by the various pavement layers. The pressure, P_1, on the subgrade is much less than the tire pressure, P_0, on the pavement surface.

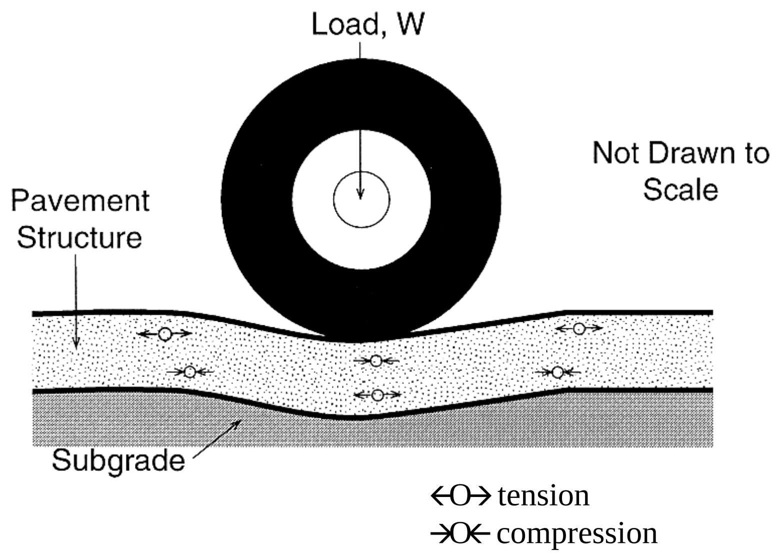


Figure 3 Pavement deflection under load

Figure 3 shows how the pavement and subgrade are deformed under a heavy load. The deformation (which is greatly exaggerated in the figure) causes compressive stresses in the top layers of the pavement and tensile stresses in the bottom. If the deflection is large enough and occurs enough times, the tension stress can cause a fatigue crack at the bottom of the layer. Additional loads cause this crack to migrate upward until it reaches the surface. Surface water can then penetrate through the crack into the base and weaken it. This causes larger deflections in the adjacent pavement and more cracks until pavement failure (alligator cracking) occurs. If the pavement is thick enough and/or the subgrade and base are strong enough, deflections and stresses are reduced, and load–related cracking may not occur for many years resulting in a long pavement life.

Because of these repeated loads, there are several factors to consider when designing pavements:

-Traffic – including vehicle type and weight, design life, and expected growth

-Subgrade soil properties

-Paving material properties and thickness of pavement

-Environmental factors- including temperature, moisture, and drainage

Engineers study traffic patterns and estimated growth rates to calculate these continuing stresses, and use the Equivalent Single Axle Load (ESAL) as the building block for traffic considerations when designing a new roadway. For example, one 34,000 lb. tandem truck can do as much damage as 5,000 cars. In New York, with knowledge of the soil properties and the ESAL counts, proper pavement thicknesses can then be determined using the *Comprehensive Pavement Design Manual* found on the NYSDOT website. The calculations for ESAL counts can be onerous, but the Regional NYSDOT offices can provide estimated ESAL counts for most roads in their Region.

2.2 Soils

All asphalt pavement design methods start with a fundamental consideration of the underlying soil strength. The properties and characteristics of the subgrade soil and design life ESAL count will determine the pavement thickness needed to carry the expected traffic loads. Some important engineering properties of soils are:

- Gradation
- Permeability
- Capillarity
- Plasticity
- Frost susceptibility

More details can be found in the Cornell Local Roads Program manual, *Basics of a Good Road*.

2.2.1 Gradation

Gradation is the size and distribution of the mineral grains in a soil. Typically soils are divided into two broad categories: coarse–grained and fine–grained. Coarse–grained soils are subdivided into boulder, gravel, or sand fractions, depending on their grain size. Fine–grained soils are either silt or clay. Types of soils are defined as follows:

- **Gravel** – rounded or angular particles of rock that will pass through a three–inch square sieve (76 mm) and be retained on a No. 10 U.S. sieve (2 mm)
- **Sand** – particles will pass the No. 10 sieve and be retained on the No. 200 sieve (.075 mm)
- **Silt** – material passing the No. 200 sieve and greater than 0.005 mm, and exhibits little or no strength when dried
- **Clay** – that portion of soil finer than 0.005 mm that is plastic (putty–like) within a wide range of water contents, and exhibits considerable dry strength
- **Fines** – the portion of soil passing the No. 200 sieve. Both silt and clay are included in this category.

Most naturally occurring subgrades involve mixtures of gravel, sand, silt, and clay. Materials that have very little silt and clay (typically less than 5 percent by weight) are termed “clean,” and they usually are strong even when wet. Materials with 12 percent or more fines are termed “dirty.” They tend to be frost–susceptible, and they have very little strength when they are wet.

2.2.2 Permeability

Permeability means the ease with which water flows through the pores of a soil. Since too much water in a soil reduces its strength, the ability to drain water is good. Particle texture, gradation, and degree of compaction have a strong influence on a soil's permeability. Coarse–grained soils are usually more permeable than fine–grained soils, but small amounts of fines (silt or clay) can change this. Table 1 shows typical permeability values for various soil types. Note that silt and clay have a very low permeability, meaning that they retain moisture for long periods of time.

Table 1
Typical soil permeability rates

Material	Permeability (feet/day)	Permeability (meters/day)
Gravel	30,000	9000
Sand	3,000	900
Fine sand and silt	3.0	0.9
Silty clay	0.003	0.0009

Note: Numbers have been rounded for clarity.

2.2.3 Capillarity

Capillarity is the upward movement of water by capillary action through a fine soil. Table 2 shows the extraordinary heights that water can rise in the fine silt and clay soils. These soils not only retain water because of their low permeability, but also draw in water by capillary action. This property influences the frost susceptibility of a soil.

Table 2
Height of capillary rise of water in various soils

Soil type	Height of rise (feet)	Height of rise (meters)
Gravel	Nil	Nil
Coarse sand	0.5	0.15
Fine sand	1 to 3	0.3 to 0.9
Silt	3 to 30	0.9 to 9
Clay	30 to 90	9 to 27

Note: Numbers have been rounded for clarity.

2.2.4 Plasticity

Plasticity is the ability of a soil to deform under a load without cracking, and to maintain the deformed shape after the load is released. At the right moisture content, plastic soils can be rolled into a thin thread that will not crumble.

2.2.5 Frost susceptibility

Frost heaves are a serious problem in the Northeast and wherever freezing temperatures occur for prolonged periods. They are the result of ice lenses forming in the soil under the pavement. Ice lenses grow in the downward direction (just as water in a pond freezes), and are fed by water drawn up from below by capillary action.

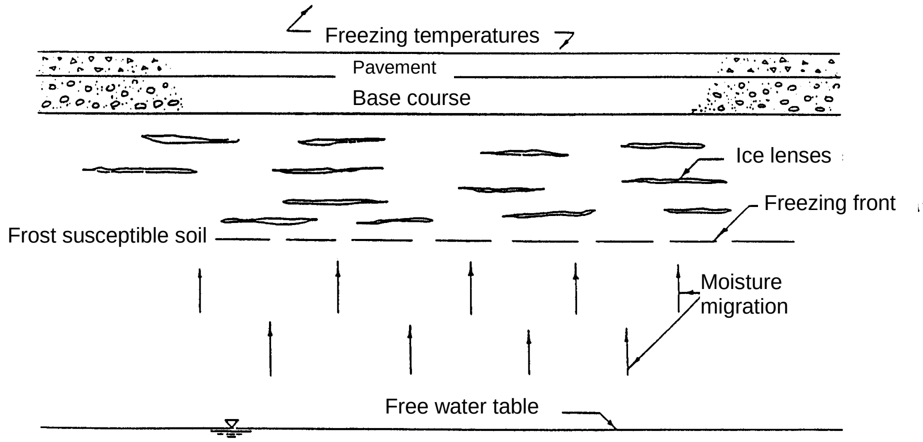


Figure 4 Capillary water rising to feed the growth of ice

For ice lenses to form and grow in a soil there must be freezing soil temperatures, a water table close to the frost line, and a soil favorable to the rapid movement of capillary water. Where freezing temperatures are prolonged, the frost line moves downward, ice lenses grow, and the ground and pavement heave.

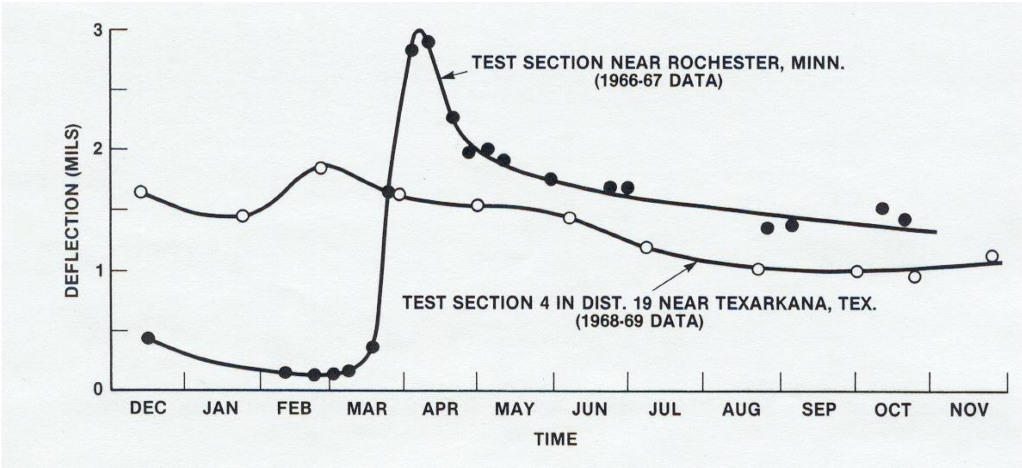
Since we cannot control the weather, we concentrate on eliminating the water source or using non–frost susceptible soils. However, eliminating the water source and lowering the water table are of limited effectiveness due to the high level water can be raised from capillary action in frost–susceptible soils (Table 2). Frost–susceptible soils are ones that have both high capillarity and permeability. Clays are not as frost susceptible as silts, but are very weak when wet. They have a high capillary action, but pull water so slowly that by the time enough water has been pulled to create ice lenses, it's spring. Silts are very susceptible to frost heaving. Gravel and/or sands are the best materials to use to eliminate the frost heave problem because they have little, if any, capillarity.

We typically cannot replace the subgrade (native materials), so we MUST use non–frost susceptible materials in our bases to help reduce frost heave problems.

Figure 5 Frost heave cracking (in wheel path) and construction joint crack (on centerline)

2.2.6 Spring thaw

The worst aspect of frost action is the weakening of the subgrade during the thawing period. The soil and moisture conditions that cause frost heaving are just as severe for thawing damage. The greatest loss of subgrade support is encountered when a wet fall is followed by a winter with many freeze–thaw cycles and a rapid spring thaw.



The chart on page 9 shows the seasonal pavement deflections of two roadways in quite different climatic conditions. Notice the wide shift and very quick deterioration during the thawing months of March and April for the roadway in Minnesota. For this reason, many municipalities post weight restrictions on some of their roadways during this time.

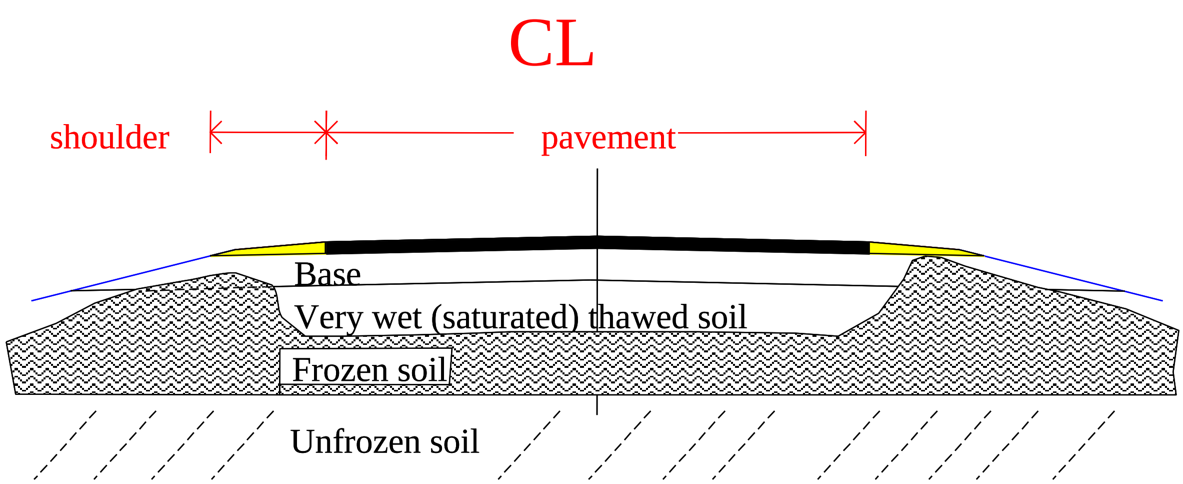


Figure 6 Thawing of pavement creating spring time bathtub

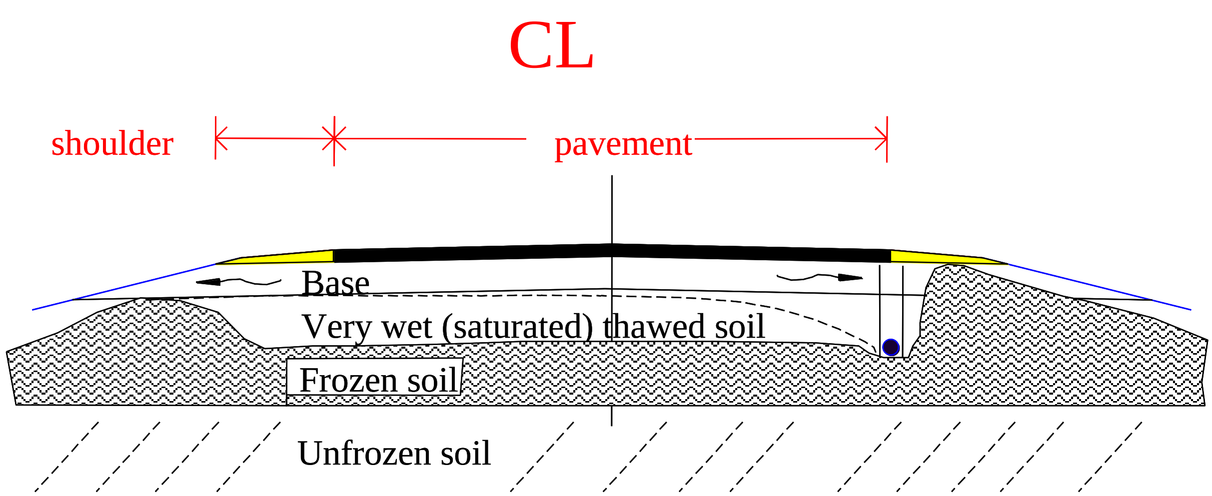


Figure 7 Draining thawing base (one side with underdrains, one with daylight)

The thawing of the roadbed in the spring occurs from the top down and usually starts under the center of the roadway. The shoulders stay frozen and trap water in the base and subgrade, because snow is left mounded there. The saturated material is very weak and will probably fail prematurely.

Removal of excess water can be done either by daylighting the base (the clean, daylighted material thaws faster than a dirty material) or installing subsurface drains to help remove the free water. More details can be found in the Cornell Local Roads Program manual, *Roadway and Roadside Drainage.*

2.2.7 Soil Discussion

More often than not, roads fail from the bottom up. Unfortunately, highway personnel can't see what is underneath the pavement. Depending on the characteristics of the underlying soil, there may be instances where some parts of a road fail often, and other parts remain intact much longer. Figure 8 shows a typical cross section of a valley that could occur anywhere in New York State. You can see that if a roadway would traverse the valley from the left to the right, it would cross over numerous different soil types. This could affect the long term life of the pavement to varying degrees along the length of the roadway:

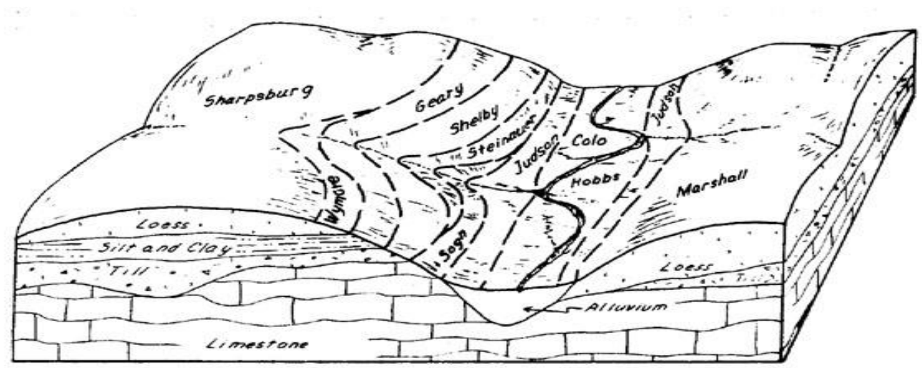


Figure 8 New York State Soils Cross-Section

Nearly every county has a *Soils Survey Manual* where the different types of soils are mapped. There are detailed charts listing numerous engineering properties, drainage characteristics, etc. of each type of soil in the county. This data, as well as information gathered from coring or an observation trench cut into the roadway, could be very helpful when planning rehabilitation projects. See Appendix A for the website address.

2.3 Drainage

One of the earliest lessons a road builder learns is that the three most important things in the design and construction of a road are **"drainage, drainage, and drainage."** Probably no other feature is as important in determining the ability of a pavement to withstand the effects of weather and traffic, and to provide trouble–free service for long periods of time.

2.3.1 Hydrologic cycle

Rain and snow falling on the ground will run overland or soak into the ground. Eventually all the runoff will reach lakes, streams, or the ocean where the water will evaporate and start the cycle all over again.

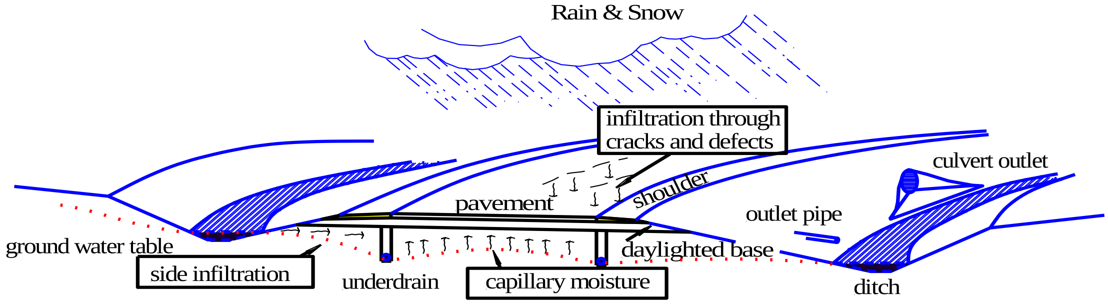


Figure 9 Conceptual road drainage system

2.3.2 Water movement around roads

Drainage problems are either surface or subsurface. Each must be dealt with separately. In developing a drainage system, remember its principal purposes are to:

- Collect and drain surface and subsurface water
- Prevent or retard erosion
- Intercept water from surrounding areas and carry it from the area
- Lower the groundwater table

When water gets into the pavement, significant weakening can occur, eventually causing premature failure. Some soils expand significantly with the addition of water, causing differential heaving of the pavement in addition to the weakening of the pavement structure. In colder climates, such as in New York State, frost heaves result from water freezing in and under the pavement. They are the primary cause of volume changes that lead to pavement breakup and potholes. Open–graded and/or poorly compacted asphalt mixes that allow water to penetrate through them may fall apart due to freeze–thaw action or stripping of the asphalt off the aggregates. All of these scenarios can result in premature pavement failure. Getting rid of the water above and below the pavement is critical.

Surface drainage includes disposal of all water on the pavement and nearby ground. Efficient drainage of the pavement and shoulder surfaces is necessary to prevent saturation of the pavement structure and subgrade, and to minimize hazardous driving conditions due to rainwater on the travel lanes. This can be done with full–width (travel lanes and shoulder) chip sealing, or paving with HMA or cold mix. The pavements should be built with a crown or cross–slope (Figure 1), so water quickly runs off the road. Inevitably, some water will enter the pavement structure, but it should be kept to a minimum by maintaining the pavement free of holes and cracks.

3 MATERIALS

3.1 Asphalt mixes

Hot and cold asphalt mixes are comprised of two major materials: aggregates and asphalt cement. Higher quality materials produce higher quality mixtures. Because most municipalities lack the resources to analyze these materials for each project, it is well advised that you insist on materials from a New York State Department of Transportation (NYSDOT) approved source. NYSDOT maintains approved sources for materials on its web site: www.dot.ny.gov.

3.1.1 Aggregates

To produce quality asphalt pavements, use quality aggregates. Aggregates should be clean, hard, sound, and durable, with a majority of crushed particles. Aggregates fall into several categories. The five major categories are sand, gravel, crushed stone, slag, and mineral filler:

- **Sand** – the product of the breakdown of rock or sandstone. The result is a fine granular material. Different types of sand are blow sand, lake sand, gravel pit sand, bank run sand, manufactured sand, and river sand.
- **Gravel** – larger than sand, usually larger than the #4 sieve, is generally a glacial deposit. Different types of gravel are pea gravel, river gravel, and bank gravel. Gravels are usually crushed and graded into various sizes.
- **Crushed Stone** – produced from crushing ledge rock such as Limestone and Dolomite or Traprock and granite to produce 100 percent crushed aggregate of various sizes.
- **Slag** – a non–metallic product containing silicates, derived from the production of steel.
- **Mineral filler** – a very fine material that usually passes the #200 sieve. Types of mineral filler are granular dust, or powdered rock, such as limestone screenings.

Hot mix asphalts (HMA) produced in a NYSDOT approved facility and from a NYSDOT approved job mix formula will be made with high quality aggregates.

When purchasing aggregate for use in cold mix asphalt mixes, the choice of a NYSDOT approved source will help ensure that the aggregate is of high quality. NYSDOT routinely tests aggregates for soundness (durability) and hardness. The materials that gain NYSDOT approval should provide long–lasting pavements. NYSDOT routinely updates their *Approved List Sources of Fine & Coarse Aggregates*. The list is specific to Region and material type (Stone, Gravel, Sand) and can be found on their website. The four types of aggregate Friction specifications are detailed in Section 401 of the Standard Specifications. The designations F1, F2, F3, are considered as “Hi- Friction” aggregate acceptable for use in surface courses based on the specific circumstances. The F9 designation is considered “Non-Friction” and is used primarily in base and binder courses. Where to use each type can be found in the *NYSDOT Comprehensive Pavement Design Manual – Chapter 6 Materials.* In general, F1 is used downstate in the surface course on high volume roadways; F2 is used upstate in the surface course on high volume roadways; F3 is used in the surface course on low volume roadways statewide; and F9 in base and binder courses. The Friction designation is assigned to a source upon original approval by NYSDOT.

3.1.2 Asphalt cement

Asphalt cement is the residue of the refinery distillation of crude oil. In the refining process, crude oil is heated rapidly until the lighter more volatile fractions vaporize, are drawn off, and separated into naphtha, gasoline, kerosene and other petroleum products. The heavy residue from this stage of refining is further processed to produce various grades of asphalt cement.

In addition to heating, there are three other ways to liquefy asphalt for construction operations. It can be dissolved in various petroleum solvents, emulsified with an emulsifying agent and water, or it can be foamed.

Asphalt is a thermoplastic material, meaning it gradually liquefies when heated. At ambient temperatures it is semi–solid, but at high temperatures (250 to 325°F) it becomes a liquid that can be pumped through pipes, sprayed through nozzles or mixed with aggregate. When it cools, it becomes a semi–solid cementing and waterproofing material that gives asphalt pavements their strength and flexibility.

One of the most important outcomes of the Federal Highway Administration's (FHWA) Strategic Highway Research Program (SHRP) was the development of a new grading system for asphalt cements used as the binding agents for HMA mixes. Prior to this new system, asphalt binders were graded by penetration (how far a standard needle penetrated into a sample of asphalt binder at a specific temperature), and viscosity (how quickly an asphalt binder flowed through a standard orifice at a specific temperature).

The new binder grading system includes specifications that relate measured physical properties to field performance. The new tests use aging conditions, temperatures, and loads that are similar to those encountered in the pavements.

Asphalt cement, now called Performance Graded (PG) binders, is selected on the basis of climate and traffic at the location where it will be used. An example of a PG binder designation would be PG 64–28. The first number, 64, is the high temperature in degrees Celsius that the pavement is expected to reach. The second number, –28, is the lowest service temperature expected.
PG 64–28 asphalt is "soft" enough to resist low temperature thermal cracking down to a temperature of –28°C (–18°F), but "stiff" enough to prevent a pavement from rutting due to traffic during a very hot week when pavement temperatures reach 64°C (147°F).

Originally, NYSDOT narrowed the potential PG binders according to the following Table:

Table 3
Original grades of PG binders used in New York State

Grade	Use
PG 58–34	New pavement, very cold environment
PG 64–22	Common general purpose grade, standard mixes
PG 64–28	Upstate New York
PG 70–22	Normal paving, downstate
PG 76–22	High traffic conditions, downstate

The PG grading system worked well for light to moderate traffic volume pavements. However, the system did not always perform as required for heavier loads and higher traffic volumes. To compensate for this, pavement designers "bumped" the required PG Binder up to a different grade. For example, to combat chronic rutting conditions, an upstate designer would choose PG 70-22, or even PG 76-22, instead of PG 64-28 or PG 64-22.

These "bumped" PG Binder specifications usually required the asphalt to be modified with polymers or other chemicals to enhance its properties and meet performance requirements. These modifiers can reduce temperature susceptibility and age hardening, resist low temperature cracking, and improve stiffness of the asphalt at high temperatures. These are the desired properties to mitigate rutting. Modified asphalts are more costly. However, the difference in cost is much less than when they were introduced now that they are in widespread use and oil refineries have modified their production facilities.

Because of these necessary adjustments, the asphalt researchers kept working and devised the Multiple Stress Creep & Recovery (MSCR) test. With this test, they are able to determine high temperature limits and predict rutting better than with the original PG Grading system. Table 4 lists the MSCR grades now in use in New York:

Table 4

Table 6-4 Performance Graded Binder Selection[3]

Location	Location by Counties	Standard PG Binder Grades (Material Designation)	Polymer Modified PG Binder Grades (Material Designation)
Upstate	All Other Counties Not Listed Under Downstate	64S-22 (702-64S22)	64V-22[1,2] (702-64V22)
Downstate	Orange, Putnam, Rockland, Westchester, Nassau, Suffolk Counties and City of New York	64H-22 (702-64H22)	64E-22 (702-64E22)

1. For high volume roadways in Dutchess County, PG 64V-22 or PG 64E-22 may be specified with the concurrence of the Regional Materials Engineer.
2. For the Adirondack Region, PG 58E-34 (702-58E34) may be specified.
3. "S" is Standard grade, "H" is High grade, "V" is Very High grade, "E" is Extreme grade

The following Table 5 is a cross reference chart comparing the original PG Grades with the current MSCR Grades. ER indicates polymer modification.

Table 5

PG Binder Substitution Guidance

PG Binder Originally Specified	Comparable Substitution MSCR PG Binder
PG 58-34 with ER	**PG 58E-34**
PG 64-22	**PG 64S-22**
PG 64-22 with ER	**PG 64V-22**
PG 70-22	**PG 64H-22**
PG 76-22 with ER	**PG 64E-22**

Nearly always, PG 64V-22 and 64E-22 are polymer modified. NYSDOT now *requires* polymer modified grades on all of their projects. For most local roads, the non-modified PG 64S-22 is the grade to use upstate and PG 64H-22 for downstate. If there are instances where modified grades may be needed such as very busy intersections or there are heavy truck volumes, contact CLRP for guidance.

3.2 Emulsified asphalts

Asphalt emulsions are produced by grinding or milling warm asphalt cement into minute globules and dispersing it in water treated with a small quantity of emulsifying agent (a soap–type liquid). Between 55 and 70 percent of an emulsion is asphalt with the balance being water. The type of emulsion produced and its properties are controlled by the amount and type of emulsifying agent used. Some of the emulsions used in producing cold mixes also may contain a small amount of solvent.

By choice of emulsifying agent, the emulsion may be anionic (negatively–charged asphalt particles) or cationic (positively–charged asphalt particles). Anionic emulsions generally work best with positively–charged aggregate surfaces (limestone and dolomite). Cationic emulsions work best with negatively–charged materials such as quartz or sandstone. Emulsions are made in several grades; here is the current list as found in NYSDOT Section 702 of the Standard Specifications

Anionic	Cationic
RS-1	CRS-1
RS-1h	CRS-1h
RS-2	CRS-2
HFRS-2	-
MS-2	CMS-2
HFMS-2	-
HFMS-2h	CMS-2h
HFMS-2s	-
SS-1	CSS-1
SS-1h	CSS-1h

- CQS-1h

The RS, MS or SS indicate the setting rate of the emulsion: RS = rapid set, MS = medium set and SS = slow set. The “h” means that a hard asphalt was used and “s” means a soft base was used. The ‘Q’ indicates that the emulsion is a quick-set emulsion. The difference between ‘1’ and ‘2’ is the amount of asphalt remaining after the curing process. The grades with # 1 will have less asphalt residue than those with # 2. The “HF” designates a high float emulsion. High float emulsions have certain chemicals added that allow thicker asphalt films on the aggregate particles with minimal drain down.

For use in construction operations, emulsions must remain fluid enough for proper application and stable enough to keep the asphalt particles suspended in the water phase until it is in contact with the aggregate or pavement surface. After it is applied, the asphalt droplets coalesce (come together) because of water evaporation and neutralization of the electrostatic charges. The time in which the asphalt droplets coalesce is called the breaking or setting time.

3.3 Cutback asphalts

Cutbacks are made by blending asphalt cement with petroleum solvents. When mixed with aggregates and exposed to the air, the distillate in the cutback evaporates into the atmosphere leaving the asphalt to hold the road together.
There are three types of cutbacks:

- Rapid–curing (RC) cutbacks contain a highly volatile diluent such as gasoline or naphtha
- Medium–curing (MC) cutbacks use kerosene
- Slow–curing (SC) cutbacks are made with fuel oil and are often called “road oils”

In the early days of the highway industry, cutbacks were used widely and successfully in many applications. Because the distillates are high–energy products that are lost by evaporation into the atmosphere, environmental concerns and regulations have resulted in emulsified asphalts supplanting cutbacks in most applications. Their main use today is in the manufacture of asphalt cold patching materials and as a prime coat spray application.

3.4 Foamed asphalt

When small amounts of water are added to hot (> 350°F/180°C) paving grade asphalt cement, foamed asphalt is produced. When injected into the hot asphalt, the water evaporates abruptly causing the explosive foaming of the asphalt. The asphalt expands 15 to 20 times its original volume, and its viscosity is significantly lowered. In this condition, the asphalt is ideally suited for mixing with cold and damp aggregates and/or recycled asphalt pavement (RAP).

Two parameters, “expansion ratio” and “half–life,” measure the quality of foamed asphalt. Expansion is the ratio of maximum volume of the foamed asphalt to the original volume of the non–foamed asphalt. Typically asphalt expands 10 to 20 times with 8 times being the minimum acceptable. The “half-life” is the time it takes for the foamed asphalt to be reduced to half its maximum achieved volume. The minimum acceptable half–life is 12 seconds. These minimums ensure that in the full depth reclamation and/or cold in–place recycling processes, where foamed asphalt is most commonly used, there will be a sufficient volume of asphalt and sufficient time for mixing and coating. The foaming characteristics of asphalt from all potential sources should be evaluated in the lab prior to project startup. The amount of water to be injected in the field foaming operation is the one that gives the maximum expansion ratio with a half–life that exceeds the 12–second minimum.

3.5 Cold mixes

Cold mix asphalt pavements are so named because the aggregate used in the mix is not heated or dried when the asphalt mixture is being produced. Cold mix asphalt mixtures have generally used either a cutback asphalt or an asphalt emulsion blended with the mineral aggregate to produce the cold mix asphalt mixture at or near ambient temperature. In recent years, because of environmental restrictions and economics, asphalt emulsions have become the predominant binder used in cold mix applications.

3.5.1 Emulsion asphalt mixes

Open or coarse–graded cold mixes generally use a medium setting (MS) grade emulsion. The typical grades used are MS–2, HFMS–2, HFMS–2h, CMS–2 and CMS–2h.

Dense–graded cold mixes may use the same medium set emulsions, but may also use a slow setting emulsion such as SS–1, SS–1h, CSS–1, and CSS–1h.

The "h" designation on these emulsion grades refers to the hardness of the base asphalt. An "h" designation will be manufactured with a base asphalt that has a lower penetration number and will make it stiffer and a little less flexible.

3.5.2 Open–graded mixes

An open–graded mix (OGM) consists primarily of coarse aggregate and asphalt, with a minimum amount of sand or fine aggregate. The mix has a high air void content after compaction, typically 15 to 25 percent by volume. Open–graded mixes are very permeable allowing for the passage of a large quantity of water through the mix. They act as a drainage course.

NYSDOT specifies open–graded cold mixes in Section 405 of their Standard Specifications. The gradations of the three types are based on using blends of two coarse aggregates, approximately 67 percent of the larger and 33 percent of the smaller coarse aggregate. Type 3 mix is much coarser than Type 1 and requires less asphalt for coating, however it must be placed in much thicker lifts.

Table 4, page 18, is a copy of the NYSDOT Table 405–1 for composition of mixtures.

Table 6
Composition of open–graded cold mixes

Sieve size	Mixes		
	Type 1 General limits percent passing [1]	**Type 2 General limits percent passing [1]**	**Type 3 General limits percent passing [1]**
50mm (2")	–	–	100
37.5mm (1½")	–	100	75–100
25mm (1")	100	90–100	50–80
12.5mm (½")	90–100	15–45	0–15
6.3mm (¼")	15–45	0–10	–
3.2mm (⅛")	0–10	–	–
75µm (#200)	0–1.0	0–1.0	0–1.0
Bituminous material [2,3]	4.7–7.0	4.0–6.0	3.5–5.5
Description	Open, coarse texture	Open, coarse texture	Open, coarse texture
Typical uses	Surface course	Intermediate	Base course

Source: New York State Department of Transportation Standard Specifications, Section 405–1

[1] Percentage based on total aggregate weight.
[2] Total emulsion percentage based on total mix weight.
[3] When crushed air–cooled blast furnace slag aggregate is selected, the above bituminous material content shall be increased approximately 25 percent.

Open–graded mixes require fractured aggregate to ensure good interlocking of the aggregate for stability of the placed mix. Non–crushed aggregates should not be used.

A properly produced open–graded mix will have the bituminous material uniformly distributed throughout and all aggregate particles uniformly coated. Coating is a function of the amount and type of asphalt used. If an excess of asphalt must be used to get acceptable coatings, or if drain down or runoff occurs, the emulsion supplier should be notified to rectify the problem. Generally, an emulsion modification must be made at the asphalt emulsion plant to correct these problems.

Open–graded cold mixes are generally used for base and binder courses. They are free draining, have high stone–on–stone contact for stability, are resistant to fatigue and reflective cracking, and are self–healing when placed over bases that move or flex during frost periods in the road. They are used extensively on town and county roads throughout New York State for base and binder courses, then topped with dense mix or sealed in some way, such as surface treating.

Roads over which open–graded mixes are placed must have good drainage and ditching to allow water to get out of the pavement and to the ditch. When used as a base course, a positive moisture seal should be provided under the open–graded mix to prevent water from entering and weakening the subgrade materials.

3.5.3 Dense–graded mixes

A dense–graded mix has a balance of aggregate particle sizes distributed from coarse to fine, resulting in a mixture that has relatively low void space when compacted. Typically after compaction the air void content is 3 to 10 percent by volume of the mix, depending on the mix type.

Dense–graded mixtures can vary in top size from large stone in base courses to sand size in surface courses. These mixes consist of blends of various coarse aggregate depending on depth and top size required and 30 to 50 percent sand size material to provide dense gradation. Dense–graded mixes are relatively impervious to water.

NYSDOT does not have a standard specification for dense–graded cold mixes at this time, only written interim trial specifications. Dense–graded mixes are used frequently on local government roads. Table 5 shows typical gradations for dense–graded cold mixes.

Table 7
Composition of dense–graded cold mixes

Mixture requirements [1] / Screen sizes	Type 4 General limits percent passing and tolerance [1]		Type 5 General limits percent passing and tolerance [1]		Type 6 General limits percent passing and tolerance [1]	
50mm (2")						
37.5mm (1½")	100	—				
25mm (1")	95-100	—	100	—		
12.5mm (½")	70-90	±6	90-100	—	100	
6.3mm (¼")	48-74	±7	20-70	±7	90–100	
3.2mm (⅛")	32-62	±7	15-70	±7	30-70	±7
0.85mm (#20)	10-40	±7	10-40	±7	10-40	±7
0.425mm (#40)	5-22	±7	5-22	±4	5-22	±4
0.180mm (#80)	1-7	±3	1-9	±4	1-11	±4
75μm (#200)	0-3	±2	0-3	—	0-3	—
Bituminous materials [2,3]	4.5–7.0		6.2–7.5		6.5–7.8	
Typical uses	Dense–graded Intermediate course		Dense–graded Truing & leveling		Dense–graded Fine top course	

Source: Adapted from Asphalt Emulsion Handbook, Suit–Kote Corp., page 34

[1] Percentage based on total aggregate weight.
[2] Total emulsion percentage based on total mix weight. Residue percentage is determined by multiplying emulsion percentage by asphalt content percentage of the emulsion.
[3] When crushed air–cooled blast furnace slag is selected, the above bituminous material content shall be increased approximately 25 percent.

Dense–graded mixes are best if mixed using high quality, fractured coarse and fine aggregate to ensure good stability of the produced mix.

A properly produced dense–graded cold mix will have the bituminous material uniformly distributed throughout without any globbing of the asphalt or fines. The coarse aggregate is generally not totally coated. If it is totally coated it is usually an indication of an excessive amount of asphalt in the mixture. Don't be alarmed. Normal mixes are usually 85–95 percent coated. Dense–graded mixes are used for base, binder, and surface courses. The coarser mixes (1"– 1½" top size) are used for base and binder, and the finer mixes (¼" – ½" top size) are used for shim and top courses. When used as surface courses, dense–graded cold mixes can be left unsealed. However, often they are sealed in some manner, such as fog sealing, surface treating, slurry seal, micropaving, or hot mix overlay to enhance their durability.

3.5.4 Asphalt emulsion selection

The selection of the asphalt emulsion for cold mixes is based on compatibility of the emulsion with the aggregate, the ability of the emulsion to coat the aggregate at the design rate, and the conditions for use. The key determinants are the type of aggregate, the gradation of the mixture, the amount of material passing the #200 sieve, and the use of the mix.

Prior to starting any project the emulsion supplier should be consulted and the job aggregates evaluated for compatibility and coating. Most manufacturers adjust their formulations for specific aggregate types or sources and mix gradations in order to control coating and setting properties of the emulsion. A supplier usually produces several specific emulsions that will all meet the medium setting specification for cold mixes depending upon the intended use and aggregate type. The selection of anionic or cationic is often the preference of the supplier based on available chemistry and experience.

Experience is a great selector of asphalt emulsions. If projects have been done successfully for many years using a particular aggregate source and gradation with a particular emulsion, build on those successes. Look to enhance performance by working with the supplier to improve workmanship, placement, setting and curing, and performance.

3.5.5 Asphalt emulsion quantity

The quantity of asphalt emulsion required in a mix is a function of the aggregate gradation, the aggregate properties, and the intended use of the mixture. The aggregate gradation including the minus #200 sieve material and the resultant surface area of the aggregate is of primary importance. Coarse mixes have less surface area requiring less asphalt. Fine mixes have more surface area and require more asphalt. Surface area can be calculated from the gradation. For each one–half size of a sieve, the surface area approximately doubles. A ¼–inch aggregate has a surface area of about two square feet per pound versus 160 square feet per pound for material passing the #200 sieve, a dramatic difference.

There are several rules of thumb to determine the amount of asphalt in cold mixes based on intended use. For base courses, the material retained on the #4 sieve (coarse aggregate) requires one percent residue by weight, and the material passing the #4 (fine aggregate) requires six percent residue. For surface courses, these are three and seven percent, respectively. To determine the emulsion percentage, multiply residue percent by 1.5 for an approximation. Modified mix design procedures look for optimum values of stability after curing of the mix in the lab. Base courses have slightly less asphalt than surface courses to obtain the higher stability. The amount of asphalt required can be specified as the percentage of emulsion residue, percent emulsion, or as gallons per ton of asphalt emulsion per ton of mix, including the water. The mix designs are usually specified on the residue percentage by weight of the mix, and the gallons–per–ton of emulsion is calculated knowing the percentage of water in the emulsion. Most emulsions contain 65 to 70 percent asphalt. For example, if the mix requires 4 percent residue and the emulsion has 65 percent asphalt, it would require about 6 percent emulsion or 14.5 gallons per ton (54 liters per ton).

A cardinal rule in the cold mix business is that you are better off to be slightly below the optimum asphalt content than above the optimum. Mixes with asphalt contents less than optimum have higher stability but poorer durability. Mixes with excessive asphalt have lower stability, cure slower, make the mix sticky, and tend to bleed, flush, and rut, resulting in long term problems difficult to correct. For this reason, the laboratory technicians perform a timed drain-down test procedure at different emulsion ratios. This test indicates where the emulsion content should be and when it is prone to bleeding.

3.6 Hot mixes

Hot mix asphalt (HMA) is a combination of different sized aggregates and asphalt cement, which binds the mixture together. HMA is generally composed of 93 to 97 percent by weight of aggregate and 3 to 7 percent asphalt cement.

HMA is manufactured at a mixing plant where the aggregates are properly proportioned, heated to a temperature of between 250 to 325ºF (120 to 160°C), and mixed with the proper amount of hot asphalt cement. The completed mixture is then hauled by trucks to a mechanical spreader, placed in a smooth layer, and compacted by rollers to a specified density. Since the workability of the mix depends on heat, compaction must be achieved before the mix cools to a temperature of 150 to 185ºF (65 to 85°C). HMA mixtures are generally produced in either a batch plant or a drum mix plant.

In a batch plant (Figure 11), the aggregates are heated and sorted (by screening) into different sizes. They are then recombined (batched) in a pugmill in precise proportions (by weight) according to a mix design. A measured quantity of asphalt cement is added and mixed with the aggregate.

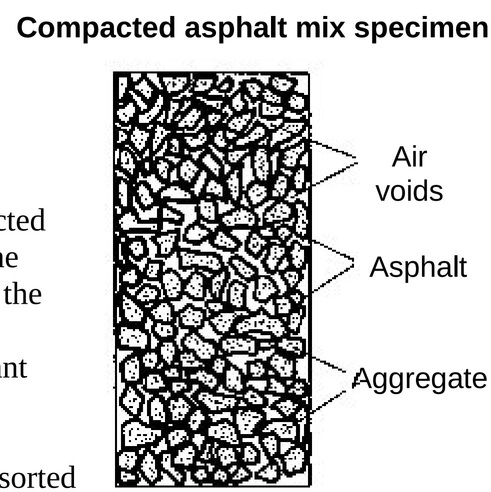


Figure 10
Hot mix asphalt components

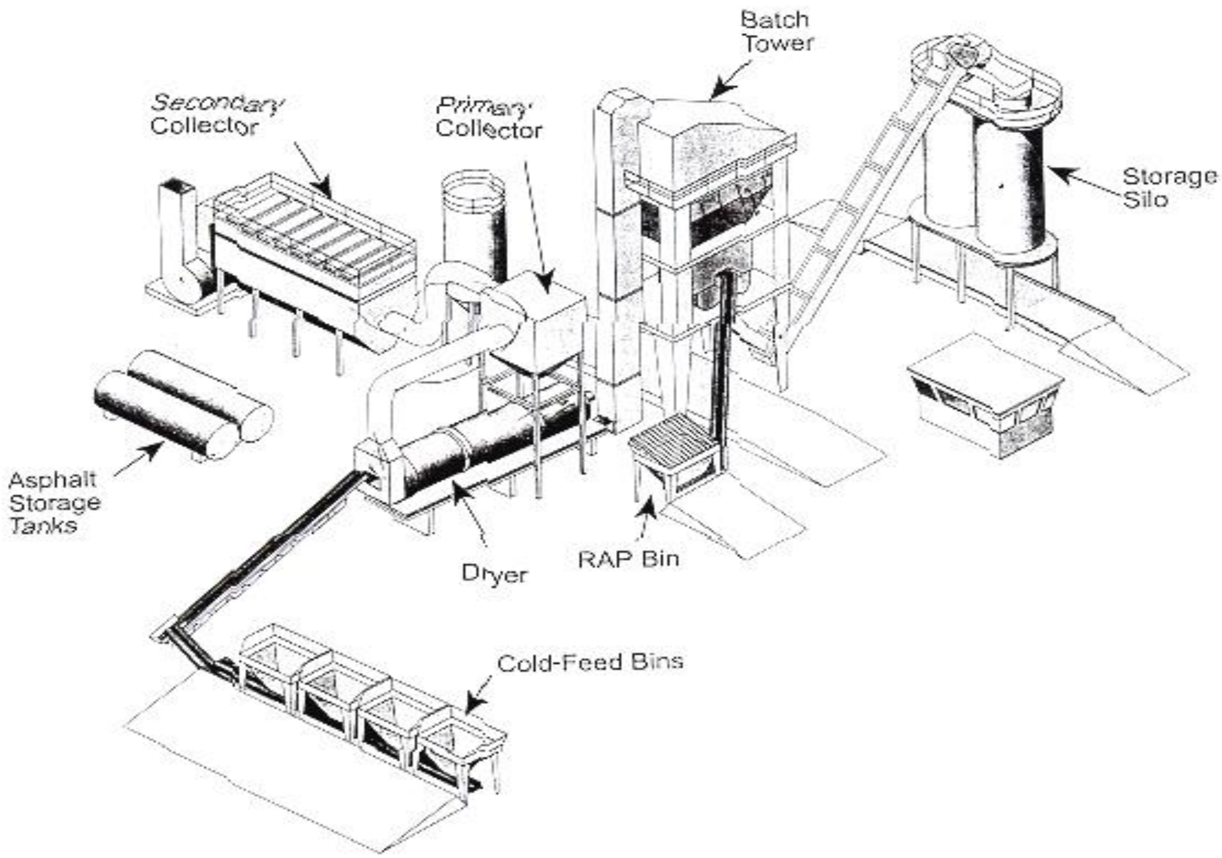


Figure 11   Typical batch plant

In a drum plant (Figure 12), a cold feed system of individual bins and precise feeders proportion the aggregates. The combined aggregates, along with asphalt cement are continuously fed into a drum dryer where the aggregates are dried and mixed with the asphalt. The resultant mixture is conveyed to a holding silo where it is then loaded into hauling vehicles.

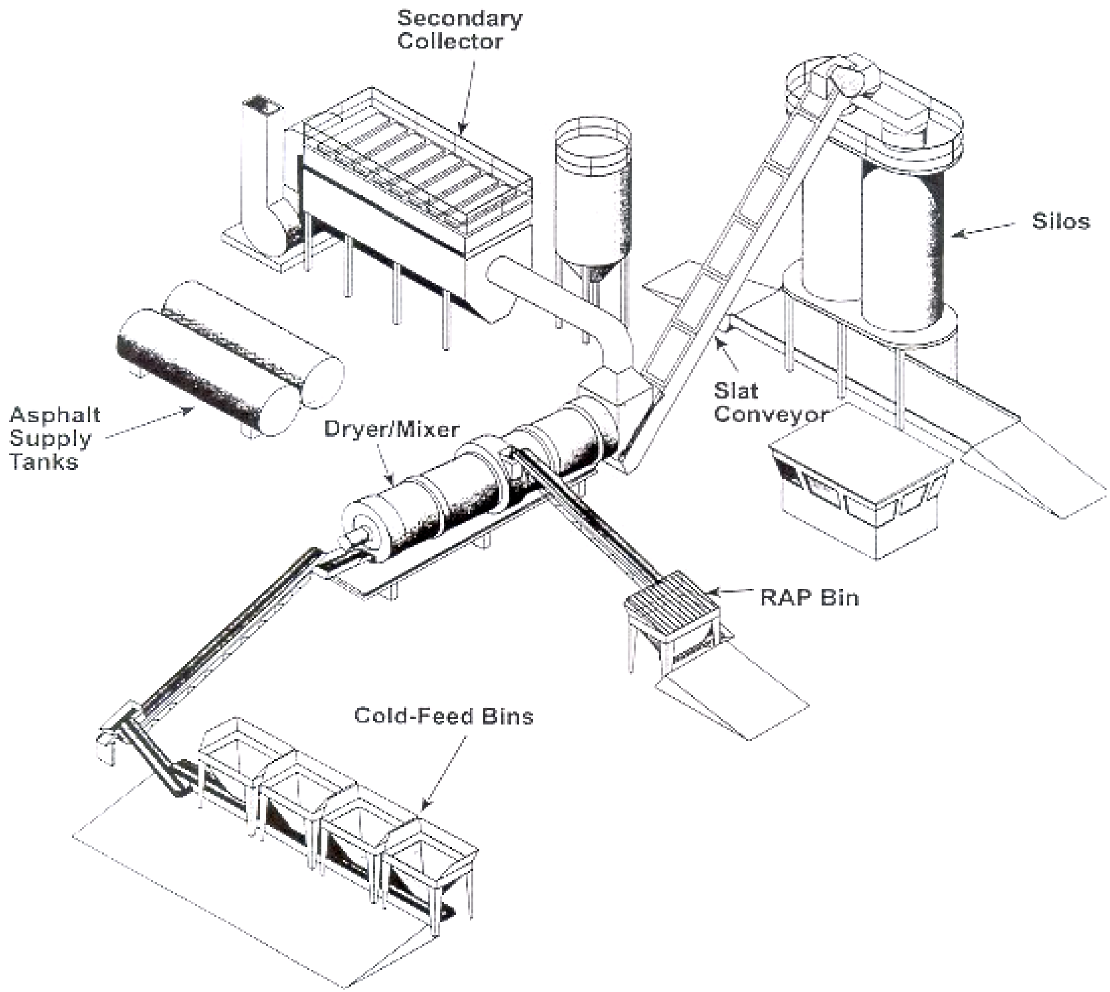


Figure 12   Typical Drum Plant

All HMA plants that are approved by NYSDOT are required to be automated. This automation assures that the mix is properly proportioned, is at the proper temperature, and is recorded on a printed ticket. This automation greatly improves the consistency of the manufactured HMA.

HMA in New York State can be divided into two broad categories, both of which are made up of aggregates and asphalt binder:

- Standard mixes
- Superpave mixes

3.6.1 Standard mixes

Standard Mixes are HMA mixes that were designed using the Marshall Method have been in use for many years and provide pavements with excellent service lives in most instances. These mixes used to be found in the NYSDOT Standard Specifications, Section 403. However, NYSDOT officially eliminated these mixes in 2012, and have fully implemented Superpave mixes which are designed using the Superpave Method. These are found in Section 402 of the Standard Specifications. Table 8 shown here includes the Standard Mix Chart. The complete 403 specifications can still be found on the NYSDOT website; look for the 2002, 2006, or 2008 versions of the Standard Specifications or contact CLRP directly.

Standard mixes were designed using the Marshall Method which produced mixes relatively rich in asphalt content. This worked very well until the combination of higher traffic, high pressure radial tires, and greater truck volume began adversely affecting pavements. Engineers then modified the Marshall Method laboratory mix design procedures in order to alleviate the stresses they were experiencing on the roadways. This was successful in many cases, but not entirely. Because of this, in 1987 the Federal Government instituted the Strategic Highway Research Project (SHRP). The result of the effort was the Superpave System in use today.

Table 8
NYSDOT standard hot mix asphalt mixtures

Mixture	**Base**				**Binder**		**Shim**		**Top** [3,4]			
Require-ments [1]	**Type 1**		**Type 2**		**Type 3**		**Type 5**		**Type 6, 6F2, 6F3**		**Type 7, 7F2, 7F3**	
Screen sizes	General limits % passing	Job mix tol. %	General limits % passing	Job mix tol. %	General limits % passing	Job mix tol. %	General limits % passing	Job mix tol. %	General limits % passing	Job mix tol. %	General limits % passing	Job mix tol. %
50.0 mm (2")	100	—	100	—	—	—	—	—	—	—	—	—
37.5 mm (1½")	90–100	—	75–100	± 7	100	—	—	—	—	—	—	—
25.0 mm (1")	78–95	± 5	55–80	± 8	95–100	—	—	—	100	—	—	—
12.5 mm (½")	57–84	± 6	23–42	± 7	70–90	± 6	—	—	95–100	—	100	—
6.3 mm (¼")	40–72	± 7	5–20	± 6	48–74	± 7	100	—	65–85	± 7	90–100	—
3.2 mm (⅛")	26–57	± 7	2–15	± 4	32–62	± 7	80–100	± 6	36–65	± 7	45–70	± 6
850 µm (#20)	12–36	± 7	—	—	15–39	± 7	32–72	± 7	15–39	± 7	15–40	± 7
425 µm (#40)	8–25	± 7	—	—	8–27	± 7	18–52	± 7	8–27	± 7	8–27	± 7
180 µm (#80)	4–16	± 4	—	—	4–16	± 4	7–26	± 4	4–16	± 4	4–16	± 4
75 µm (#200)	2–8	± 2	—	—	2–8	± 2	2–12	± 2	2–6	± 2	2–6	± 2
Binder content, % [2]	4.0–6.0	± 0.4	2.5–4.5	± 0.4	4.5–6.5	± 0.4	7.0–9.5	± 0.4	5.4–7.0	NA	5.7–8.0	NA
Mixing & [5] placing temp. range,°C	120–165 (250-325°F)		110–150 (225-300°F)		120–165 (250-325°F)		120–165 (250-325°F)		120–165 (250-325°F)		120–165 (250-325°F)	
Description and typical uses	Dense base: For general use		Open base: For permeable base layer		Dense binder: Intermediate layer for general use		Shim: Fine HMA mixture for shimming ruts and leveling		Top course: Dense course for single course resurfacing of rural, suburban, and urban roadways			

Source: New York State Department of Transportation Standard Specifications, Section 403–1

[1] All aggregate percentages are based on the total weight of the aggregate.
[2] The asphalt content is based on the total weight of the mix. When using slag aggregates in the mix, increase the PGB content accordingly, a minimum of 25 percent for an all slag mix.
[3] 6F2, 6F3, 7F2, 7F3 mix types require friction coarse aggregates, and are required for mainline driving surface courses.
[4] For Type 6 and Type 7 (F9) aggregate requirements, Marshall design will not be required. These mix types are suitable where the State's requirements for F9 aggregate apply.
[5] Introduce the PG Binder into the pugmill between 110ºC and 175ºC, or as recommended by the PG Binder supplier.

3.6.2 Superpave mixes

Superpave, not specifically a HMA mixture, refers to a complete paving system. The name Superpave comes from "SUperior PERforming PAVEments. The Superpave mix design system was developed through research performed during the Strategic Highway Research Program (SHRP). The paving system consists of a new asphalt binder grading specification, a new mix design method, and new HMA paving performance specifications.

There is no magic ingredient in Superpave mixes. They are still a mixture of aggregate and asphalt cement. The SHRP research revealed that the three main distresses of today's pavements are pavement deformation (rutting), fatigue cracking, and low temperature cracking. The Superpave mix design system addresses these dominant issues. Mixes are designed to accommodate the traffic loading expected as well as the historical climatic conditions of the location for the pavement.

The components for the HMA mixture are carefully selected, each having to meet specific requirements. The PG binder grade is established by looking at both the historical high and low temperatures of the pavement at the site. Aggregate must meet specific consensus properties including coarse and fine aggregate angularity, flat and elongated particles, and clay content. New York State is fortunate to have very good aggregate deposits and formations compared to many other states. Nearly all NYSDOT approved aggregate sources are acceptable for use in Superpave mixes.

Figure 13 Gyratory compactor

Soon after their introduction, it became apparent that the original Superpave mixes were actually too coarse and dry. They were nearly the opposite of the original Standard mixes that were too rich and prone to rutting. Incremental changes and adjustments were made to the Superpave specifications to address the situation. Without going into great detail, changes were made to the gyration count in the laboratory, the air void content was lowered, and the gradation curve was relaxed to allow somewhat finer mixes.

At the same time, but more gradually, NYSDOT began to recognize the benefits of the polymer modified asphalts and use it on all projects now. Now, PG 64V-22 is used Upstate and PG 64E-22 Downstate. The end result of these continued improvements is that on higher volume roads, Superpave mixes are much more rut resistant and durable, which was the original goal of the SHRP research. For lower volume local roads, the Marshall Method designed Standard mixes using non-modified PG 64S-22 are very similar in texture to their Superpave counterparts. Either choice is more than satisfactory for most local roads since adjustments to both design methods have brought them closer together. Again, in higher volume or severe applications, Superpave mixes with modified asphalt can easily be chosen.

Standard mixes are arbitrarily named Type 1, Type 3, Type 7 etc. The name really gives no indication of what the mix looks like. Superpave mixes are named for the nominal aggregate size in the specific mix. For example, a 12.5mm mix would contain a ½” (12.5mm) nominal size aggregate. This is a New York size # 1. Here is a comparison chart for Superpave and Standard mixtures. The corresponding mixes are now similar in texture:

Superpave	Standard
37.5mm	Type 1
25.0mm	[Obsolete Type 4]
19.0mm	Type 3
12.5mm	Type 6F
9.5mm	Type 7F
6.3mm	Type 7F (finer)

The heart of the new mix design method is the use of the Superpave gyratory compactor for the compaction of the design specimens. This compactor is a product of the SHRP research and is designed to approximate the compactive effort of the pavement rollers. The Superpave mixes are designed to match the expected traffic loads and the high and low expected pavement temperatures of the pavements.

The paving specifications for Superpave have an increased emphasis on field compaction. Achieving the proper compaction of any mix is critical to its performance. The primary problem that led to the development of the Superpave paving system was pavement deformation in the form of rutting. Even the adjusted Superpave mixes still have somewhat greater stone-on-stone contact than previous mixes, and are more rut resistant, but are also more difficult to compact. Proper compaction effort is required to achieve acceptable mix density. To ensure that the proper density is being achieved, contractors are often required to monitor the densities with density gauges.

Also, although much better than the original designs, Superpave mixes can still be more prone to segregation. Paving crews and producers need to be aware of this and take steps to minimize it.

3.6.3 Determining which mix to use

Three important Superpave parameters must be determined to ensure that the correct mix is specified. First is the PG binder that will be used. Second is the traffic (traffic is measured in Equivalent 80–KN Single Axle Loads [ESAL]) level which will be used to determine the design level. Third is the lift thickness and corresponding appropriate aggregate size.

3.6.3.1 PG binder selection

NYSDOT has narrowed down the MSCR graded PG Binders to just a few for use in New York. For a list of the current grades in use, see Table 4 on page 15. For most normal use, PG 64S-22 is the choice. If you have an unusual circumstance, contact your local NYSDOT Regional Materials Engineer for a recommendation or visit the Cornell Local Roads Program website: www.clrp.cornell.edu for more information. Click on *Technical Assistance→Tech Tips→Superpave Hot Mix Asphalt.*

3.6.3.2 Traffic level (ESAL)

In Chapter 2, we discussed how engineers use the ESAL method to determine a roadways structural design and material thicknesses. They use the same ESAL count when specifying Superpave mix design gyration levels. Three different categories are determined by the ESAL (traffic) levels. Each category has a different gyratory compactive effort reflected in the number of gyrations used to create the laboratory test specimens for the mix design. For local roads, the >30 option is not chosen, as it applies primarily to high speed four lane highways. Here are the three options:

ESALS (millions)	# GYRATIONS
<0.3	50
0.3-30	75
>30	100

3.6.3.3 ESAL Definition

Traffic is generally classified by cars and trucks. It takes approximately 20,000 cars to equal one 80,000 lb truck. There is a large difference between the stresses of a passenger car and a loaded truck. Traffic loads are equated to "Equivalent 80–kN (18,000 lb) single–axle loads" or "ESALs." ESAL is the equivalent number of 80–kN (18,000 lb) single axle loads that will have the same effect on pavement performance (in terms of fatigue damage) as the actual applied load.

3.6.3.4 Estimating ESALs

NYSDOT has two methods for determining an ESAL Level: simple and rigorous.

In reality neither is really simple and both require a number of assumptions that can have a dramatic effect on the resultant ESAL count. These methods are described in the New York State Department of Transportation's, *Comprehensive Pavement Design Manual.* Because of the impact that an erroneous assumption can make and the fact that most village, town, and county roads will fall into a lower ESAL level, it may be adequate to use the following "simplified" procedure.

Simplified procedure to determine design ESALs

One way to estimate the ESAL level of your road is to compare it to the NYSDOT highways in your area and pick out a couple of routes with similar traffic to your road. Make sure you try to match up the level of truck traffic. Call your NYSDOT regional planning and program management group and ask them for the ESAL level of the NYSDOT highways that are similar. They should have a listing of the ESAL levels for each of the New York State highways. Using this comparison will help you estimate your ESAL level. Assume a growth rate of one to two percent per year over the lifetime of the pavement.

3.6.4 Lift thickness and aggregate size

Minimum lift thickness and aggregate size should always be considered together. The FHWA recommends that the minimum lift thickness should be four times the nominal top size aggregate in the mix. It is important to understand that the "nominal" top size aggregate does not refer to the maximum size of the aggregate in the mix, but to the sieve that retains 10 percent of the aggregate. Therefore a 19.0 mm (¾") nominal size mix could contain 10 percent of the aggregate larger than the 19.0 mm (¾") sieve.

In the New York State *Comprehensive Pavement Design Manual*, NYSDOT has put limits on permissible lift thickness in order to achieve proper compaction. This is summarized in Table 9:

Table 9
Limits on permissible lift thicknesses

Maximum nominal aggregate size (mm)	Minimum lift thickness (mm)	Maximum lift thickness (mm)
37.5 (1½")	75 (3")	125 (5")
25.0 (1")	65 (2½")	100 (4")
19.0 (¾")	50 (2")	75 (3")
12.5 (½")	40 (1½")	50 (2")
9.5 (⅜")	40 (1½")	50 (2")
6.3 (¼")	19 (¾")	25 (1")

For leveling courses the minimum thickness requirement may be waived. However, it is important that the final course of HMA meets the minimum lift thickness requirement.

3.6.5 Superpave Mix Examples

Here are a few example of how to specify a Superpave mix. There can be other options chosen, but these are typical:

1. For a residential street where a 1” to 1 ½”wearing course is desired, a Standard Type 7F mix has been used historically. This street has a lot of big shade trees, and raveling occurs where the roadway stays wet. A typical residential street would be low volume, so an ESAL count of <0.3 (50 gyrations) is chosen. The .3-30 ESAL mix would work also, but the <0.3 (50 gyrations) mix would be a little bit richer in asphalt and will help mitigate the raveling. The Superpave 9.5mm mix is basically equivalent to Type 7F, and the asphalt grade would be the unmodified PG 64S-22. So, **“9.5mm, <0.3 (50 gyrations), PG 64S-22”**would be specified. The local NYSDOT Regional Materials Engineer and any NYSDOT approved HMA plant would recognize this mix.

2. For an upstate higher volume urban roadway intersection where rutting has been experienced in the past, most likely a different approach would be taken. In the past, perhaps 2” of a Standard Type 6F might have been chosen because of the larger particle size. With higher traffic volumes on this road, the ESAL count would most likely be <30 (0.3-30 / 75 gyrations).The 12.5mm Superpave mix is equivalent to Type 6F, and it is decided to use the polymer Modified grade of PG 64V-22 for extra rut resistance. In this case then, the specified mix would be “**12.5mm, <30 (0.3-30 / 75 gyrations), PG 64V-22”**. This is a common Superpave choice in this circumstance.

3. For a dense binder lift similar to Type 3 Binder, a 19mm Superpave is the choice. Under normal conditions for local roads either **“19.0mm, <0.3 (50 gyrations), PG 64S-22”** or **19.0mm, 0.3-30, PG 64S-22”** would be used, depending on the actual traffic (ESAL) conditions.

3.6.6 Superpave Item Number Descriptions

The Superpave Item Number Description Chart is designed for use on NYSDOT highways. It is found in the New York State *Comprehensive Pavement Design Manual.* Table10 is the chart:

Table 10

402	**.XX**	**Y**	**Z**	**Q**	**R**

The individual letters are as follows:

402 - This is the NYSDOT Standard Specification Section

XX - This indicates the nominal maximum size:
37 = 37.5mm Base Course
25 = 25mm Binder or Base Course
19 = 19mm Binder Course
12 = 12.5mm Top Course
09 = 9.5mm Top Course
05 = Shim
01 = Permeable Base/ T & L
06 = 6.3mm Top Course

Y - This refers to the compaction requirements. These requirements will be discussed in-depth in Chapter 6. Nearly all local roads will be 8- the Method Type:
5= Daily Coring with Payment Adjustments - 50 series
6= Density Gauge Monitoring with Core Verification - 60 series
7= Density gauge Monitoring Only - 70 series
8 = Method Type; Roller Passes Specified - 80 series

Z - This refers to the aggregate Friction requirements:
1= F1 = Downstate High Volume
2= F2 = Upstate High Volume
3= F3 = Low Volume
4= F9 = Shoulders, Misc, and Subsurface (Base & Binder)

Q - These are the NYSDOT Quality Adjustment Units, and typically aren't used in Local Roads contracts. So usually 0 would be chosen:
0 = Specified HMA Item (Core Item)
1 = Plant Production Quality Adjustment
2 = Payment density Quality Adjustment
3 = Longitudinal Joint Density Quality Adjustment
4 = Pavement Smoothness Quality Adjustment

R - This is the specification revision number, currently 3.

For the examples outlined in Section 3.6.5, the Item Numbers would be:

1. **402.098303** 9.5mm design; 80 series compaction specifications (no coring or density gauge required); F3 Friction for lower volume roads; no special Quality Adjustments; current Superpave revision # 3.

2. **402.128203** 12.5mm design; 80 series compaction specifications (no coring or density gauge required); F2 Friction for higher volume roads upstate; no special Quality Adjustments; current Superpave revision # 3.

3. **402.198903** 19.0mm design; 80 series compaction specifications (no coring or density gauge required); F9 Friction for base & binder courses; no special Quality Adjustments; current Superpave revision # 3.

3.7 Thin lift mixes

There are a number of mixes that fall into the thin lift category that are normally used for pavement preservation. They generally should be placed on structurally sound pavements that exhibit only minor surface distress. Pavements that have started to ravel, show minor cracking, or become slippery would be examples of good candidates. Since these mixes are placed thin (usually less than 19 mm [¾"] in depth), they are ideal treatments to use when maintaining curb reveal or where avoiding utility adjustments are desirable. It is beyond the scope of this manual to go into detail on these treatments, however a description of some of the major types of thin lift treatments follows.

3.7.1 Paver placed surface treatment (Nova Chip)

Nova Chip is a proprietary paving process developed in Europe that was introduced in the United States in 1992. The NYSDOT has given a generic name, Nova Chip, to the process of Paver Placed Surface Treatment. Paver placed surface treatment consists of a warm polymer modified asphalt emulsion coat followed immediately with a thin HMA wearing course. A self–priming paver applies the warm emulsion coat directly in front of the paving screed. Three gradations are available for the HMA wearing course: Types A, B or C. The nominal maximum aggregate sizes are 6.3 mm (¼"), 9.5 mm (⅜") and 12.5 mm (½") for Types A, B, and C, respectively. In New York, aggregate sizes # 1A, # 1ST, and # 1 are used. The HMA overlay is placed 1 to 1.5 aggregate particles thick.

Paver placed surface treatment will seal the pavement, reducing oxidation and weathering of the surface. The reduction in oxidation will allow the pavement to remain resilient to fatigue and to low temperature cracking. Surface distresses such as raveling and moderate rutting may also be corrected. The final thickness of paver placed surface treatment is 12 mm (½") for Type A, and 20 mm (⅞") for Types B and C.

- **Type A** is the finest gradation and is considered the lightest duty mix. Its fine surface texture is excellent for urban and suburban applications with light truck traffic. Type A is not recommended for highways that are borderline candidates for preventive maintenance. One of the coarser gradations should be used in those applications.

- **Type B** is the middle gradation and is durable enough to handle moderate to heavy truck traffic on highways with moderate speeds. Type B can also be used in lighter duty applications if a slightly thicker lift is desired, or if more surface distress is present.

- **Type C** is the coarsest gradation and heaviest duty mix. Type C can be used for any application, regardless of traffic levels. This mix is recommended for high speed and high traffic applications, and for applications with moderate rutting. This type may be noisier under traffic.

3.7.2 Quickset slurry

Quickset slurry is a mixture of asphalt emulsion, aggregate, mineral filler and water. The slurry is continuously mixed and applied to the pavement in a single lift with specialized equipment. There are two aggregate gradations available: Type 2 and Type 3. The maximum size of aggregate used is 9.5 mm (⅜") or 4.75 mm (#4 sieve) depending on the mixture type. No compaction is required for quickset slurry, but the emulsion must be allowed to cure before opening to traffic, usually for two to three hours.

Quickset slurry will seal the pavement, reducing oxidation and weathering of the surface. The reduction in oxidation will allow the pavement to remain resilient to fatigue and low temperature cracking. Minor surface distresses such as raveling or low skid resistance may also be corrected. The final thickness of a quickset slurry is approximately 9 mm (⅜") to 15 mm (⅝").

3.7.3 Microsurfacing

Microsurfacing is a mixture of polymer modified asphalt emulsion, aggregate mineral filler, and water that has a slurry consistency during mixing and application. The microsurfacing is continuously mixed and applied with specialized equipment. There are two aggregate gradations available: Type 2 and Type 3.

Figure 14 Microsurfacing

Microsurfacing overlays are applied in two passes. The first pass, often called the scratch course, is applied to even out surface irregularities such as wheelpath rutting, and to prepare the pavement for the surface course. The surface course is applied to provide a smooth wearing course. No compaction is required, however the emulsion must be allowed to cure before traffic is allowed. Microsurfacing will accept traffic one hour after application under most conditions.

Microsurfacing will seal the pavement, reducing oxidation and weathering of the surface. The reduction in oxidation will allow the pavement to remain resilient to fatigue and low temperature cracking. Minor surface distresses such as raveling may also be prevented or corrected. The final thickness of microsurfacing is approximately 12 (½") to 20 mm (⅞").

NYSDOT Materials Procedure 09-01 *Microsurfacing and Slurry Guidelines* provides information on all aspects of these processes and includes chapters on pre-construction meetings, calibration of equipment, and mix design. This can be found on their website under Materials Bureau Forms/Manuals.

3.7.4 6.3 mm HMA mix

The 6.3 mm mix is a thin HMA designed using the Superpave mix design procedure. It consists of a high quality aggregate mixture and a PG 64V-22 polymer modified binder upstate and a PG 64E-22 polymer modified binder downstate. In texture, it would resemble a somewhat finer Type 7F. The tack coat used is undiluted rapid-setting emulsion asphalt. The material, placed with conventional paving equipment, is generally ¾” to 1”in depth. It is generally intended to provide a new pavement surface, eliminate minor rutting, and minimize the loss of curb reveal.

3.7.5 Single course surface treatment (Chip Seal)

Single course surface treatment is a thin overlay consisting of a heavy asphalt emulsion application followed by a single layer of clean, uniformly sized coarse aggregate. The emulsion is applied to the cleaned road surface, and immediately covered with the stone. The stone is placed, producing a dense one aggregate thick layer with no bald spots or bleeding areas. The stones are then oriented and seated with pneumatic tire rollers. The emulsion must be allowed to cure before the road can accept uncontrolled traffic.

Figure 15 Surface treatment

Surface treatment will seal the pavement, reducing oxidation and weathering of the surface. The reduction in oxidation will allow the pavement to remain resilient to fatigue and low temperature cracking. Minor surface distresses such as raveling may also be corrected or prevented. The final thickness of a surface treatment is approximately 15 mm (⅝").

Chip Seal specifications are detailed in Section 410 *Chip Seal* of NYSDOT’s Standard Specifications. Weather limitations, equipment calibration procedures, application procedures, etc. are discussed.

3.8 Warm Mix

Recently, a new asphalt option has emerged and it is known as Warm Mix Asphalt (WMA). What exactly is WMA? Perhaps the best definition can be found on the FHWA website (www.fhwa.dot.gov). Search for *EDC-1:Warm Mix Asphalt.* The web page begins with “Warm

Mix Asphalt (WMA) is the product of using a variety of technologies that allow producers of Hot Mix Asphalt (HMA) pavement material to lower temperatures at which the materials are mixed and placed on the road. It is a proven technology that can:

- Reduce paving costs
- Extend the paving season
- Improve compaction
- Allow asphalt mix to be hauled longer distances
- Improve working conditions by reducing exposure to fuel emissions, fumes, and odors"

Right away you can see that this is not really a new separate asphalt category that stands alone as HMA and Cold Mix do. Rather, it is a modification of HMA using a variety of technology types. Furthermore, the benefits for contractors, owner/agencies, and laborers on the job are well worth considering. WMA technologies can be used on any type of HMA mix including Standard, Superpave, and even 6.3mm Thin Lift.

We will look at a brief history of WMA development; list the benefits; outline the different types of technology along with NYSDOT's experiences; and then look at how WMA can be beneficial to local municipalities.

3.8.1 History of WMA

WMA was developed in Europe in response to the international 1997 Kyoto treaty to reduce greenhouse gases. If HMA production temperatures can be lowered by *any* amount, emissions will be reduced. While there is not a strict definition of what a Warm Mix temperature should be, in general differences of 30 to 70 degrees lower have been achieved depending on the type of technology. Figure 16 shows an actual comparison:

Figure 16

The National Asphalt Pavement Association introduced WMA at their Annual Meeting in San Diego in 2003, and then again at the World of Asphalt conference in 2004. Acceptance by industry and state agencies grew rapidly. In 2005, there were 3 technologies available in the U.S., by 2014 over 30. During this period, there were numerous test projects undertaken to gain information on the long term performance and to understand the benefits. The end result is that WMA is a proven alternative and the benefits are real.

3.8.2 WMA Benefits

Numerous studies worldwide have shown that the original goal of reducing volatile emissions during the production of WMA has been met. This is desirable for the overall environment as well as the paving crew. Figure 17 illustrates the difference between HMA and WMA while loading from a silo:

Figure 17

Reduced fuel costs are certainly helpful also. However, perhaps the best benefits to come out of the WMA initiative relate to the workability of the mix and to the mix properties. Similar to what was discussed earlier in this chapter regarding emulsions, WMA reduces the viscosity of the liquid asphalt. However, since the technologies are applied to hot mix and not emulsified asphalt or ambient temperature aggregates, several desirable enhancements occur relative to traditional HMA:

- Better workability in general
- Less oxidative hardening of the asphalt
- Less compactive effort to achieve density
- Extended paving season

At the end of this section, we will see how these enhancements are able to benefit local municipalities.

3.8.3 Technologies and NYSDOT experiences

There are 3 general categories of WMA technologies:

- Special Waxes (organic additives)
- Surfactants (chemical additives)
- Foaming technologies

Again, in 2005 there were 3 available in the U.S., and 30 by 2014. This has since been whittled down somewhat, primarily by market forces and ease of adaptability. NYSDOT developed an approval process to determine the acceptability of the various technologies. This process has been adopted as the standard procedure in the northeastern United States. Currently, NYSDOT has 12 WMA technologies approved on their website. The most commonly used today in New York are the foaming processes and the Evotherm chemical additive. All 12 are suitable for use.

By 2012, NYSDOT released Engineering Instruction *EI 12-008.*This *EI* considers WMA as equal to HMA quality-wise, and allows contractors to use it as an option on NYSDOT projects. Today, the compaction benefits are so well acknowledged that NYSDOT will allow the use of WMA technologies regardless of the supplier's production temperature. Of course most HMA suppliers strive for something in the 30-70 degree reduction, therefore making true Warm Mix.

3.8.4 Local Agency benefits

Obviously, the lowered emissions around paving operations are beneficial for everyone, and the mix property enhancements benefit all parties also. It is worth it to take a closer look at these enhancements specifically relating to local highway departments.

- **Better workability –** One of the most noticeable differences between HMA and WMA is what can be called the "pliability" of WMA. It is not the same as "tenderness", which will be discussed in Chapter 6. On many projects in urban or suburban municipalities, there can be numerous obstacles such as manholes, drainage inlets, etc. This often requires a lot of handwork and casting a thin layer of mix to get the proper elevation. Usually, a noticeable shadow remains in these areas and the resulting compaction isn't as good as the rest of the mat. Because of its improved workability at lower temperatures, these handwork areas knit in almost immediately with only a few roller passes. This eliminates the shadow areas, which often are the first parts of a project to show raveling distresses.

- **Less oxidative hardening of the asphalt –** A certain amount of asphalt hardening occurs during production of HMA. Then, this oxidation process slowly continues over the years until the mix actually becomes brittle. The lower temperatures required for WMA production reduce the initial oxidation accordingly. Therefore, WMA has more life in it right from the beginning, so it takes longer to reach the brittle phase. In distress areas where the type of cracking is unrelated to major underlying structural issues, the use of WMA can delay the onset of occurrence. Among other causes reflective, thermal, and block cracking are related to the long-term hardening of the liquid asphalt in the mix, so anything to mitigate this is helpful.

- **Less compactive effort –** Because of the pliability of WMA and the fact that the mix is starting at lower temperatures to begin with, less compactive effort is required to achieve density specifications. Long-term, this will save time and money, and could also increase productivity.

Extended paving season – Because of the benefits listed above, many state agencies are allowing for an extended paving season on their projects. Of course common sense must be observed and warranties may still apply for out of season paving, but the fact is that good projects can be constructed in cooler weather with WMA. Many local municipalities follow a seasonal work detail schedule year after year. In New York this could include paving, ditching, snowplowing, leaf removal, patching, and others. Weather is usually a major determinant, which is certainly unpredictable. WMA can give local municipalities some flexibility in their paving scheduling. Perhaps an emergency arises, funding becomes available, or the weather is somewhat cooler but snow isn't predicted for a couple of weeks. Knowing you can still get a good project with the properties and flexibility WMA can provide is just another good tool in your toolbox.

4 ASPHALT PAVEMENT FAILURE TYPES AND CAUSES

This chapter discusses the various types of asphalt pavement failure, and the most common causes of each. A failure/distress can be the result of traffic loadings, environmental factors, poor drainage and/or soils, deficient materials, poor construction practices, or external causes such as a utility cut. Most pavement failures are caused by a combination of these factors. For example, poor soils may not be a problem unless there is also heavy traffic and moisture.

Asphalt pavement failures are typically divided into four classes:

- Cracking
- Distortion
- Disintegration
- Surface defects

Within each class there are several subcategories, each with different causes.

Refer to Cornell Local Roads Program publication 06-5 *Pavement Maintenance* for detailed discussions on repair methods and techniques for the pavement failures discussed in this chapter.

4.1 Cracking

There are several types of cracks. The selection for a maintenance and/or rehabilitation treatment is dependent upon the cause and extent of the distress. It is necessary to be able to recognize the crack type and consequently its causes. Generally, all cracks greater than 6.3 mm (¼") in width should be sealed to prevent the infiltration of water and incompressible materials (rocks, sand, etc.) into the crack and the underlying pavement structure. Water entering a pavement's base soils through a crack can cause significant weakening of the base and, if left untreated, will lead to the formation of additional cracks and eventually failure of the pavement.

Following are descriptions of different types of cracks: reflective, alligator, thermal, block, linear, edge and slippage.

4.1.1 Reflective cracks

Reflective cracks form in an asphalt overlay directly over cracks in the underlying pavement. The pattern reflects the original crack pattern and can be longitudinal, transverse, diagonal or block. Horizontal expansion or contraction movement due to temperature or moisture changes in the original pavement causes reflective cracking. They also can be the result of vertical movements due to traffic loads. They are especially prominent in asphalt overlays on portland cement concrete (PCC) pavements. Reflective cracks can appear very quickly. The rule of thumb is one to two years per inch of overlay. Figure 18 shows a series of reflective cracks in an overlay on top of a PCC pavement.

Figure 18 Reflective cracks in an overlay

4.1.2 Alligator cracks

Alligator cracking (fatigue cracks) is a series of interconnected cracks that look like the skin of an alligator or chicken wire. They are caused by repeated large deflections of asphalt pavement under heavy traffic. The bending and unbending of the pavement under these heavy loads cause the pavement to crack due to fatigue. This is similar to bending a paper clip back and forth until it breaks. This type of crack pattern indicates one or more of the following:

- The asphalt pavement was too thin
- The pavement base or subgrade materials were of poor quality or saturated with water
- The traffic loads were too much for the pavement design
- The asphalt in the mix has become oxidized and brittle
- There is high moisture content and poor drainage beneath the pavement

Generally, alligator cracked areas, due to a poor base, are not large. When associated with repeated heavy loads, however, they can cover entire pavement sections (Figure 19). With thin asphalt pavements (less than 4 inches thick), alligator cracked areas can quickly progress to potholes (Figure 20).

Figure 19 Alligator cracked shoulder

Figure 20 Alligator cracks with pothole

4.1.3 Thermal cracks

Thermal or low temperature cracks are transverse cracks perpendicular to the road centerline, and are generally equally spaced along the road (Figure 18). They result from low temperature contraction of the pavement, usually initiated at the surface, and grow downward into the pavement. As the pavement contracts with falling temperatures, the asphalt binder cannot relieve the stresses and it cracks. Temperature cycling accelerates this problem.

Figure 21 Thermal/low temperature cracking

While aggregate is the major contributor to pavement strength, the resistance to thermal cracking is almost wholly determined by the properties of the asphalt. Thermal cracking is predominantly a cold region problem, but it also occurs in southern climates where harder asphalt (that will crack at higher temperatures) is typically used to combat hot weather pavement problems such as rutting. With the continued asphalt research based on climatic and temperature considerations; and the progression from Performance Grading to MSCR grading, this pavement failure mode is expected to be minimized.

4.1.4 Block cracks

In this type of cracking, the pavement divides into rectangular pieces. The pieces range in size from approximately one–foot square to ten–feet square. It is more common on low–volume roads and on large paved areas such as parking lots. Because these pavements typically are not as well compacted as major roads, higher air voids are a suspected cause. Typically these cracks are caused by the same factors as thermal cracking. Block cracking is not load related. Sometimes longitudinal and transverse cracks merge to appear as block cracks. These can be load related.

Figure 22 Block cracking

4.1.5 Linear cracks

Linear longitudinal cracks are caused by many factors. The longitudinal paving joint crack is the most common one and can be found on all classes of roads (Figure 20). It is caused by the inability to fully compact the unconfined edge of a paving pass. The resulting low–density mix has insufficient strength to prevent cracking and will allow the asphalt to prematurely oxidize, harden, and eventually ravel. Another longitudinal crack frequently occurs between the wheelpaths and is attributed to a certain popular brand of paver. Segregation occurs where the two paver slat conveyors drop the HMA in front of the paver augers. The segregation usually does not show up in the mat surface behind the screed, but the crack appears in a few years.

Longitudinal cracks in the wheelpath are usually load related and can lead to alligator cracking.

Figure 23
Longitudinal wheel path cracking

Another source of longitudinal cracks is frost heaves in the base or subgrade. Localized heaving pushes the pavement up from below, and spring thaw provides a weakened area. These cracks often appear in the wheelpaths, or immediately adjacent to them.

4.1.6 Edge cracks

Edge cracks are longitudinal cracks away from the pavement edge with or without transverse cracks branching out to the shoulder. Lack of lateral or shoulder support is the most common cause. Settlement of the base soils, poor drainage and frost heaves are other causes. Edge cracks combined with a buildup of winter sand deposits at the pavement edge can make the problem much worse. The sand buildup prevents water from running off the shoulder so that it must drain through the cracks and further weakens the underlying soils (Figure 21).

Figure 24 Edge cracks

4.1.7 Slippage cracks

Slippage cracks are crescent shaped cracks resulting from traffic–induced horizontal forces (Figure 22). They are caused by a lack of a bond between the surface layer and the course below. This lack of bond may be due to dusts, dirt, oil, or the absence of a tack coat prior to placing the surface course. Low asphalt or ‘dry’ mix designs are a secondary cause and will accelerate the failure.

Figure 25 Slippage cracks

4.2 Distortion

Pavement distortion is the result of asphalt mix instability, movement, or weakness in the granular base or subgrade. Cracking may accompany some types of distortion. It can take many forms, but rutting and shoving are the most common.

4.2.1 Rutting

Ruts are channelized depressions in the wheel tracks of a pavement surface. In severe cases, uplift on the outside of the rut may occur. Severe rutting on several sections of the Interstate highway system in the late 1970s and early 80s was one of the main reasons for the Federal government initiating the $300 million Strategic Highway Research Program. Prior to that time, most rutting was on the local roads systems and was caused by consolidation, moisture, or movement in the subgrade or aggregate base under traffic loads.

The Interstate ruts, however, were only in the top layers of the pavement. They were caused by trucks carrying heavy loads on tires with greatly increased inflation pressures on pavements not designed to withstand that kind of stress. Those mixes had too high an asphalt content, too high a fines content, round and smooth textured aggregates, and too soft an asphalt. As discussed in Chapter 3, with the adjustments to the Standard mixes over time, the SHRP improvements in mix design procedures, aggregate specifications, and PG/MSCR asphalt binders; rutting problems have been significantly reduced.

On cold mix pavements, lack of aeration or curing of the emulsion can result in a tender mix that will rut. This is especially a problem when cold mix paving is done too late in the year.

4.2.2 Shoving or corrugations

Corrugations, or washboarding, are a form of plastic deformation that results in ripples across the pavement surface. They typically occur when there is severe horizontal stress where traffic starts and stops, on downgrades where vehicles brake, at intersections, and on sharp horizontal curves. Corrugations are usually caused by too much asphalt or too soft asphalt in the mix.

Figure 26 Corrugations

4.3 Disintegration

Disintegration is the breakup of a pavement that begins with the loss of the fine aggregate particles from the pavement surface and progresses to the formation of potholes. Three types of pavement disintegration are raveling/weathering, delamination, and potholes.

4.3.1 Raveling/weathering

Raveling/weathering is the progressive loss of aggregate from the pavement surface. It begins with the loss of fine aggregate. As it progresses, larger aggregate particles come loose because of the lack of support from surrounding fines (Figure 27). Raveling is accelerated in the wheelpaths by traffic. Weathering occurs over the entire pavement surface including the non–traffic areas. Both water and traffic are usually needed to cause extensive raveling.

Figure 27 Surface raveling of an asphalt pavement

Raveling is caused by high air voids in HMA due to poor compaction or late season paving. Secondary causes are poor quality aggregates and overheating of the mix at the HMA plant during production. Also, poor mix design resulting in low asphalt mixtures are a large contributor to raveling pavements.

4.3.2 Delamination

Delamination is the localized loss of the entire thickness of an overlay (Figure 25). It is caused by the lack of a bond between the overlay and the original pavement. Water again is the culprit when it gets between the two layers of pavement. Delamination is usually confined to the wheelpath area and takes several years after the overlay to become a serious problem. Once they occur, they are difficult to properly patch.

Cleaning the old surface and applying a light asphalt emulsion tack coat will go a long way toward alleviating this problem. A tack coat is expecially helpful when the overlay thickness is two inches or less.

Figure 28 Delamination of an overlay

4.3.3 Potholes

Potholes are "bowl–shaped holes of various sizes in a pavement resulting from localized disintegration under traffic" (Figure 29). They can start with a small crack that lets water in and weakens the road's base, or a small area of raveling that goes full depth, or a whole bunch of potholes can occur overnight in an alligator cracked area of a thin pavement. Poor soils, poor drainage, too thin an asphalt surface, poor compaction, and poor pavement maintenance can all lead to potholes, which leads to phone calls to the highway superintendent.

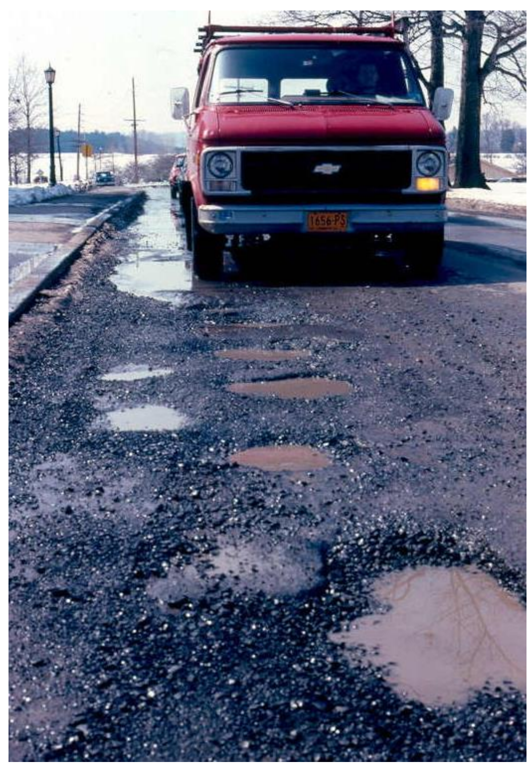


Figure 29 Potholes

4.4 Surface defects

4.4.1 Bleeding or flushed asphalt

Bleeding or flushing is the upward movement of asphalt to the pavement surface. This results in a pavement with a smooth, black, shiny appearance (Figure 30) that is sticky in hot, sunny weather.

The most common causes of bleeding are the loss of stone cover in a chip seal and the over–compaction of a tender HMA mix by heavy traffic. Overly rich asphalt mixes and application of a very heavy tack coat or excessive crack seal materials are other possible causes.

A bleeding surface is very smooth and almost as slippery as ice when wet. Since most bleeding occurs in the wheelpaths, it is a **serious safety hazard** that must be dealt with immediately.

Figure 30 Bleeding asphalt

4.4.2 Polished aggregate

Pavement skid resistance is dependent on contact between a vehicle's tires and the aggregates in the pavement surface. Clean, dry pavements have high friction values. However, even a small amount of rainwater can dramatically change a vehicle's stopping distance and its ability to negotiate a curve. To develop adequate friction, a tire must squeeze the water out from between its tread and the stone in the pavement surface. When soft aggregate, such as some limestones, is included in an asphalt surface mix, it gets polished smooth by traffic, loses its ability to squeeze out the water, and the pavement can become slippery. As discussed in Chapter 3, NYSDOT specifications require incorporation of F1, F2, or F3 hi-friction aggregates such as granite, traprock, most gravels, and selective limestones & dolomites in all surface course mixes. Consult with the NYSDOT Regional Materials Engineer's as they are aware of the High Friction sources in their respective regions.

5 REHABILITATION OF ASPHALT PAVEMENTS

There are many treatments for asphalt pavements that are showing signs of distress. Treatments can be divided into four general categories:

- **Preventive maintenance (PM)**
  Preventive maintenance treatments may correct a minor defect, but are primarily intended to prevent further deterioration and extend the life of a pavement. Microsurfacing, surface treatments, and crack sealing are examples of PM treatments. They may improve rideability but do not add structural strength to the road.

- **Corrective maintenance**
  Corrective maintenance treatments correct existing defects and deficiencies until more permanent and extensive treatments are necessary. Single course 25 – 37.5 mm (1 to 1½") overlays, hot in–place recycling 25 mm (< 1"), and "mill and fill" overlays are examples.

- **Pavement rehabilitation**
  Pavement rehabilitation treatments are intended to address serious pavement failures and restore the roadway to a condition that will ensure a service life of 10 to 20 years with normal maintenance.

- **Pavement reconstruction**
  Pavement reconstruction treatment is essentially "take it up, throw it away, and start rebuilding from the bottom up." The existing pavement condition is such that it can no longer serve a useful purpose, and a life cycle cost analysis shows that other treatments are not cost effective.

Of the four general treatments, only pavement rehabilitation is covered in this workbook. Pavement rehabilitation treatments include two–course overlay, hot in–place recycling with an overlay, cold in–place recycling with an overlay, and full–depth reclamation.

5.1 Pavement rehabilitation

5.1.1 Two–course overlay

Moderately severe wheelpath cracking, settlements, heaves, corrugations, slippage cracks, and raveling are all problems that can be corrected with a two–course overlay of HMA or cold mix. The two-course overlay is typically a 50mm (2") binder mix followed by a 37.5mm (1 ½") or 25mm (1") surface course depending on which mix is chosen. Surface course options would include 12.5mm/Type 6F or 9.5mm/Type 7F. When rutting, depressions or corrugations are obvious, application of a shim course or milling the surface should be the initial step in the rehabilitation. If a shim is placed, it should be compacted with a rubber tire roller to assure proper compaction of the variable thickness of the paving. A tack coat should be applied to the original pavement or milled surface prior to the paving of the binder course.

75 mm (3") of new mix adds structural strength to the pavement, in addition to restoring the ride, skid resistance, and cross–slope. A 15–year life expectancy is given to this treatment in the NYSDOT *Pavement Rehabilitation* manual. However, where the base is weak and drainage is poor, even this thickness of new pavement may not be sufficient to support heavy truck traffic. Early failure may result. Obviously, a 75 mm (3") thick overlay causes problems with curb reveal, utilities, and overhead bridge clearances. Milling the existing pavement prior to the overlaying can alleviate many of these problems.

5.1.2 Hot in–place recycling with single–course overlay

The equipment used in hot in–place recycling (HIR) has three configurations and processes:

- Surface recycling
- Remixing
- Repaving

Since surface recycling only involves heating and recycling the top inch of pavement, it is considered a maintenance operation and is not discussed in this workbook. HIR with a single–course overlay (remixing and repaving) can correct the same pavement defects as the two–course overlay. However, the truing and leveling of ruts, corrugations, etc., is done during the hot recycling process, saving the cost of a shim course or milling. Pavements with extensive structural failures are **not** good HIR candidates.

In the HIR process, the existing pavement is heated to 120 to 150°C (250 to 300°F) by two of more indirect radiant or infrared heaters. In the **remixing HIR process**, between 37.5 and 50 mm (1½ to 2") of the pavement is heated, softened, and hot milled into a pugmill or mixing drum. A rejuvenating agent or virgin HMA is added and mixed with the hot recycled pavement millings. The recycling agent softens the age–hardened asphalt. The HMA admixture can be selected to change the recycled mix’s aggregate gradation, skid properties, binder content or rheology, mix stability or air void content. The maximum admix application is 30 percent by weight of recycled mix. This milling and admix produces a 75 mm (3") thick recycled mat that is compacted by conventional HMA rollers, usually a rubber tire roller for breakdown and a double drum steel vibrating roller for finishing.

In the **repaving HIR process**, the existing pavement is heated and recycled in the same way as in the remixer process. However, rather than incorporating an admix, a thin HMA mix is placed on top of the screeded, but uncompacted, recycled mat and both layers are compacted as one lift.

NYSDOT expects a 15–year life from this treatment but warns that the very high heat and smoke emissions may preclude its use in residential areas.

5.1.3 Cold in–place recycling with single–course overlay

In the cold in–place recycling (CIR) process, 75 to 100 mm (3 to 4") of the existing asphalt pavement is cold milled, mixed with a small amount of asphalt emulsion (about 2 percent), and paved and compacted, without any heat added. Although CIR can rehabilitate most types of pavement distress, badly cracked pavements that are structurally sound and have well drained bases are the best candidates. The main benefit of CIR is that pavement cracks are eliminated and do not reappear for several years, thus increasing pavement life.

Recent research has shown that CIR of asphalt overlays on top of PCC pavement had less than one–third the reflective cracks of a conventional overlay on PCC after 8 to 14 years. After the recycling is complete, the mat should be allowed to cure (dry out) for 7 to 10 days, then be surfaced with a minimum of 37.5 mm (1½") HMA or cold mix. In the NYSDOT *Pavement Rehabilitation* manual, the expected life of CIR followed by a 37.5 mm (1½") HMA overlay is 15 years, the same life as a total reconstruction project.

There are three types of cold recycling trains currently being used in New York State:

- **Type I (three unit) train**
  The Type I train has a full–lane wide miller, a screen/crusher unit, and a pugmill unit followed by a paver with a windrow elevator. The pavement is milled, the millings (RAP) are screened and any piece larger than 37.5 mm (1½") is crushed. The RAP is weighed, and the designed emulsion content is added and mixed in a pugmill. The recycled mix is deposited in a windrow, picked up, and paved with a conventional paver. Compaction is with a 30–ton rubber tire roller followed by a vibratory steel roller. This is the highest class of CIR since sizing is guaranteed. Asphalt proportioning is done by weight, and about 30 seconds of mixing occur in the pugmill. However, the train is nearly 70 meters (75 yards) long and is difficult to use on many local roads.

Figure 31 Type I train

- **Type Ia (two unit) train**
  This train is similar to the Type I train except the RAP is not screened and crushed. RAP sizing is achieved with a high RPM down–cutting head. A full–lane milling machine cuts 75 to 100 mm (3 to 4") deep, then conveys the RAP to the hopper of a mix paver. The RAP passes over a weighbridge and into a twin shaft pugmill on the paver. Emulsion is added, based on the RAP weight, and mixed. The mix is then deposited in front of the augers and paver screed. Compaction is the same as for the Type I train. This train produces recycled pavement with as high quality as the type I train, but it is only about 30 meters (100 feet) long, and better suited for work on local roads.

Figure 32 Type Ia train

- **Type II (single unit) train**
  In this train the milling, sizing and emulsion mixing are all done in the cutting chamber of the milling machine. Emulsion addition is based on volumetrics (depth and width of cut times the forward speed of the train). From the milling machine the mix is deposited on the ground and picked up by a windrow elevator on the paver. The recycled mix is then paved and compacted the same way as the other train types.

Recently a half–lane single unit train was introduced in Canada where the paving screed is attached to the rear of the milling machine. Asphalt is added, based on volumetrics, and mixed in the cutting chamber. RAP sizing is achieved by an adjustable “breaker bar” that closes the gap between itself and the cutting teeth. The recycling train is less than 12 meters (40 feet) long.

Figure 33 Single unit half–lane recycling train

In addition to eliminating the crack pattern in the existing pavement, CIR can be beneficial in other ways:

- The pavement can be widened by first removing the granular shoulder material (up to 30 percent of the pavement width and 100 mm [4"] deep), milling the existing pavement 100 mm (4") deep, then paving the recycled mix full width but only 75 mm (3") thick. The soil under the shoulder must be stable for this to work.
- The recycled mix structural strength can be improved by the incorporation of up to 20 percent stone. Typically one–size 20 mm (¾") stone is added to NYSDOT projects so that the recycled mix has a gradation similar to a binder mix.
- The age–hardened asphalt in the existing road can be softened by use of a rejuvenating agent or softer asphalt for the emulsion base.
- Some minor corrections to the pavement cross–slope are possible.

5.1.4 Full depth reclamation

"Full depth reclamation (FDR) is the rehabilitation technique in which the entire thickness of the asphalt pavement and a predetermined portion of the underlying base, subbase, or subgrade, is uniformly pulverized and blended to provide an upgraded, homogeneous material." (Definition from the Asphalt Recycling and Reclaiming Association. *Basic Asphalt Recycling Manual.)* Sometimes this blend is sufficiently strong to serve as the base for a new pavement.

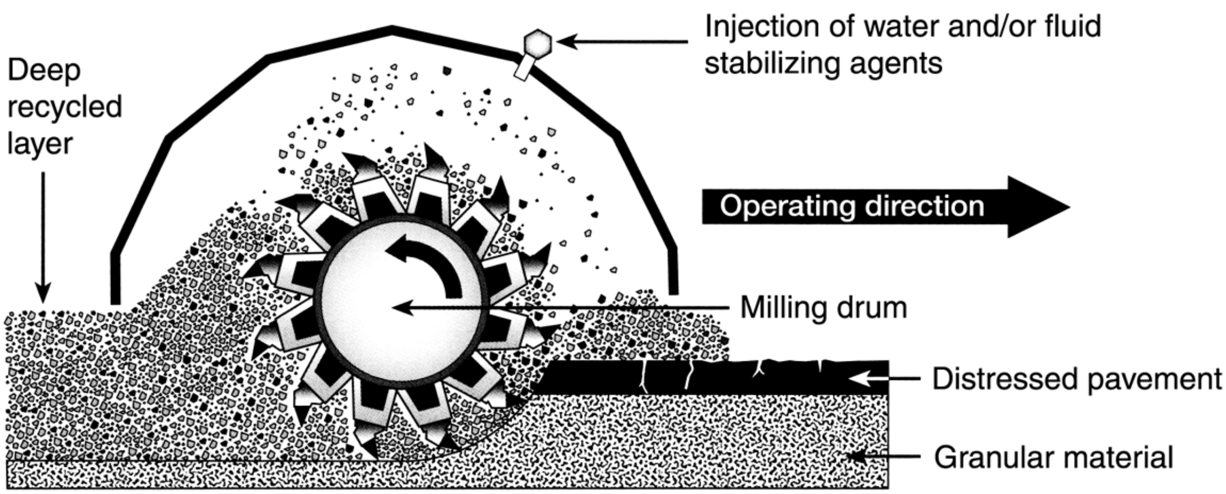
In most cases, one of the following three types of stabilization is used:

- **Mechanical –** Addition of virgin aggregate, RAP, or crushed portland cement concrete
- **Chemical –** Addition of portland cement, fly ash, kiln dust, lime, calcium chloride, or various proprietary chemical products
- **Bituminous** – Use of asphalt emulsions or foamed asphalt

Figure 34 is a cross section of the FDR process showing how the pavement and granular material are combined. The injection nozzle is available for adding stabilizers.

Combinations of two or more of these stabilizers can result in greatly increased strengths in addition to improved resistance to long–term moisture damage.

Figure 34



FDR is the fastest growing rehabilitation treatment in the United States. It primarily addresses structural failures of a pavement. These failures may show up as large areas of alligator cracking, deep rutting, shoulder drop off, and/or poor ride quality. A detailed assessment of the existing pavement (type and severity of distress, pavement thickness, and properties of the underlying soils), a structural design based on anticipated traffic, laboratory testing, and a mix design for the stabilization method is recommended. NYSDOT's Geotechnical Engineering Manual GEM-27 "Design and Construction Guidelines for Full Depth Reclamation of Asphalt Pavement" covers all aspects of the FDR process; from initial pavement analysis to quality assurance procedures during construction.

Nationally, the most common chemical stabilization methods utilize calcium chloride, portland cement, lime, fly ash, or blends of these materials. These materials increase the strength of the reclaimed roadway by cementing the particles together. Additionally, lime reacts with clay particles to reduce its plasticity. Portland cement is used to stabilize reclaimed materials with a Plasticity Index (PI) of less than 10 and lime used where the PI is greater than 10. Between 2 and

6 percent lime or cement are used for stabilization. Adding amounts above that will increase the rigidity of the base, reduce its fatigue properties, and increase shrinkage cracking. With many of the newer more powerful machines, it's possible to pulverize and mix in the stabilizer in one pass. Figure 35 shows a working FDR machine with the additive line attached.

Figure 35

Use of bituminous stabilizing agents is increasing due to recent advances in reclamation equipment and in emulsion technology. Bituminous stabilized bases are more flexible with better fatigue properties compared to the cementing agents. They have no shrinkage cracking and can be opened to traffic sooner.

Recently, foamed asphalt has generated renewed interest and is being used extensively throughout the United States. Foaming occurs when a small amount (<2 percent) of water is introduced into a very hot 150°C (300°F) asphalt cement. The water causes the asphalt to expand very rapidly into millions of bubbles. Ideally, the asphalt's volume increases 10 to 20 times (8 times is the minimum) and it takes 10 to 12 seconds (half life) for it to return to half that expanded volume. In the foamed state, the asphalt's viscosity is greatly reduced, and its surface area is greatly increased, enabling it to be readily dispersed throughout the reclaimed materials. As the bitumen bubbles break, the tiny globules of asphalt bond to the fine (minus #200) particles creating a mastic that binds the coarse particles together.

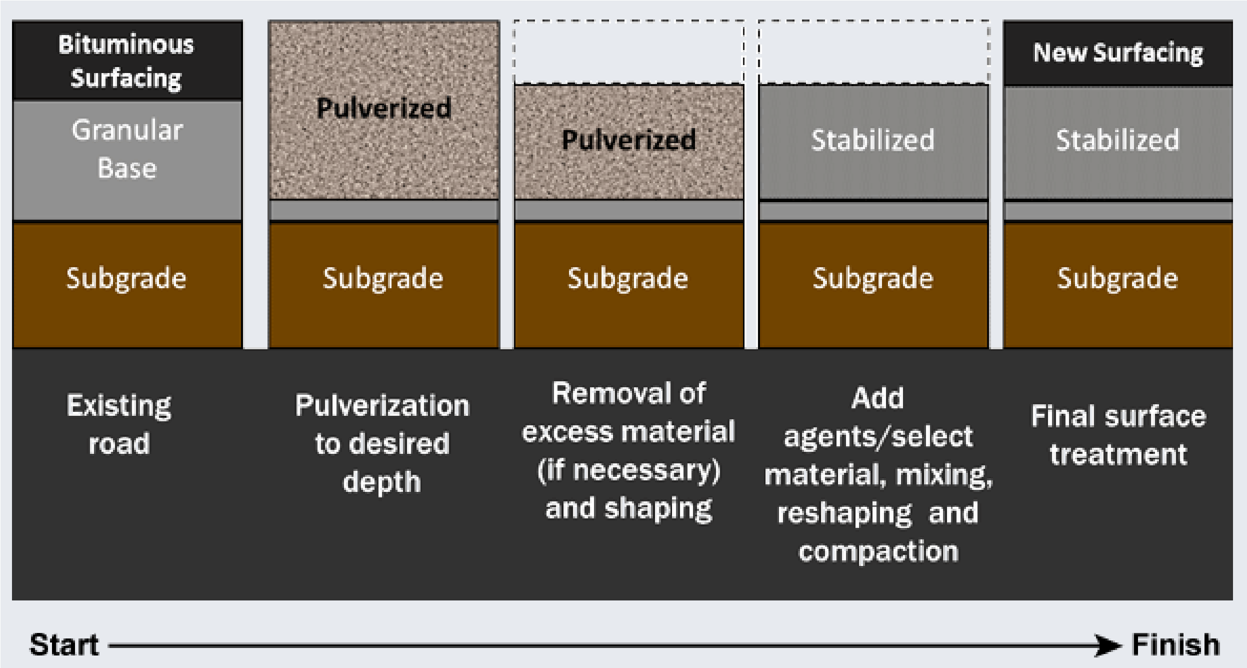
The main advantages of foamed asphalt are:

- Reclamation can be done in a wider range of weather conditions.
- Reclaimed materials remain workable for enough time to facilitate grading and compaction. This is especially true if the mat is kept moist.

- The road can be opened to traffic immediately after compaction.

Regardless whether the Mechanical, Chemical, or Bituminous stabilization method is used; and regardless if stabilization additive is added with the pulverization or later; the process is basically the same for each method. Figure 36 shows the basic steps. Note that about 20% of the original granular base was left in place.

Figure 36 Full Depth Reclamation process chart



6 ASPHALT PAVEMENT CONSTRUCTION INSPECTION GUIDELINES

6.1 Construction bids

Any municipality can take their own bid for paving materials or paving work. The downside of doing this is that good, clear specifications are difficult and time–consuming to produce. Unclear, ambiguous specifications can lead to a litany of problems. Fortunately, there are other avenues for bidding your paving work.

6.1.1 County bids

Most counties take material bids and in–place paving bids. Usually any municipality within the county can utilize the county bid. Contact your county highway department for details.

6.1.2 NYSOGS bids

The New York State Office of General Services (NYSOGS) takes bids each year for many of the highway products and services you might need. Some of these are:

*Group 31502 - Comprehensive Bituminous Concrete Hot Mix Asphalt and Cold Mix
*Group 31555 - Liquid Bituminous Materials (Chip Seal, Cold Recycling, Crack Sealer, Microsurfacing, Paver Placed Surface Treatment – Conventional & Rubber Modified)

Many of these bids are broken down into different processes that will sometimes allow a municipality to perform parts of the work. For example, on many of the bids the owner could opt to do the traffic control portion of the bid. In addition to this, some of the bids allow for a "quick quote" to be taken that can tailor the bid to your specific project utilizing the existing general specification of the existing bid. The NYSOGS maintains a list of current bids on their Web site at www.ogs.state.ny.us.

6.2 Pre–paving meeting

Whether a cold mix or hot mix paving project, it is a good idea to have a pre–paving meeting that will gather all parties involved and make sure that everyone has a good understanding of the equipment, materials and procedures involved. This pre–paving meeting can be as formal or informal as you desire, however, remember that the purpose of the meeting is for all the parties involved in the project to be aware of <u>each</u> party's responsibilities. This will help the project to proceed smoothly and resolve any potential conflicts and misunderstandings before they happen.

Many times a paving project will involve a material supplier, a paving contractor, and some municipal equipment and labor. Developing a good paving plan that all parties understand is essential for the project to be successful.

6.3 Cold mix asphalt construction guidelines

6.3.1 Mixing and spreading

Mixing and spreading cold mixes have been accomplished in varied ways through the years, but the two most predominant methods used today are a portable pugmill set up at a stockpile combined with a standard asphalt paver, or a travel plant sometimes called a mixpaver.

6.3.1.1 Pugmill method

The pugmill used is portable and equipped with an aggregate feed system that will provide a continuous controlled aggregate feed. Many pugmills can accurately blend two or sometimes three aggregates by means of split bins or multiple feeders. The pugmill is equipped with a conveyor that deposits the aggregate blend into the mixer or pugmill. The asphalt is injected at the aggregate entry point into the pugmill, and the two are mixed for the length of the pugmill. Most new pugmills are equipped with a belt scale that will provide accurate weights and proportioning of the aggregate and asphalt. The aggregate feed system and asphalt pump must be interlocked in some manner to ensure a constant proportioning of the materials.

Figure 37 Typical pugmill setup

The pugmill should be inspected prior to the project, and the aggregate feed and asphalt pump calibrated. The cold mix flows out of the end of the pugmill and can be hauled to a paver or to a stockpile. Cold mix can be deposited from the pugmill directly on the ground and on stockpiles with a bulldozer or a loader. It is very important that care be taken, especially with open–graded cold mix to minimize segregation of the mix.

6.3.1.2 Mixpaver method

The travel plant mixer or mixpaver is a single unit that mixes both the aggregate and asphalt and places it on the roadway. The mixpaver has an aggregate hopper, feedbelt, asphalt tank, asphalt pump and meter, pugmill mixer, and screed system. The graded aggregate is hauled to the mixpaver from the source or stockpile on the job and dumped into the hopper. The feed belt deposits the aggregate into the mixer where the asphalt is injected. The material travels the length of the mixer and is deposited in front of the screed and placed on the roadway. As with the pugmill, the aggregate feed system and asphalt pump must be interlocked to ensure a constant proportioning of each product, uniformity, and consistency of the mix. The machine should be inspected and calibrated before beginning a project.

Figure 38 Mix paver

6.3.2 Cold mix compaction

Compaction of cold mix differs from compaction of hot mix asphalt. Compaction of hot mix asphalt must be completed before it cools. With cold mix asphalt, compaction should occur after the emulsion has broken and begun to cure. It does not hurt the mix to compact it immediately, but it makes it more difficult for the water to leave the mix.

Compaction of cold mixes can be accomplished using a static steel wheel roller, a vibratory roller, or a pneumatic–tired roller in conjunction with the static steel wheel or vibratory roller.

Open–graded cold mixes have a higher percentage of stone–on–stone contact. They do not require a great deal of compaction. Open–graded cold mixes are often chipped with a small coarse aggregate (usually a 1A stone) at about 4 to 7 kg per square meter (9 to 15 lbs per square yard), after they are placed to keep the mix from picking up under traffic. These chips are sometimes referred to as keystone and are usually applied sometime during the compaction process.

Dense–graded mixes, on the other hand, require a much greater effort to achieve the specified density. Pneumatic–tired rollers are often needed in combination with steel wheel rollers to achieve the desired density.

It is important to establish a rolling pattern, sequence, and number of passes that will be used to achieve the desired compaction. This rolling pattern is a starting point. It should be maintained as long as you are obtaining the desired density. As weather conditions change throughout the day the roller pattern may have to be modified.

Rolling should begin at the lower side of the lane, staying 150–300 mm (6 to 12") from the edge to minimize shoving of the mix. Roller passes should overlap the previous pass and progress towards the center of the road. The outer edge, which is unsupported, should be rolled last, sometimes at the end of the day. When placing the abutting lane, roll the longitudinal joint first and then progress out, rolling the unsupported edge last. It is usually advisable to complete or “finish roll” the surface the following day.

6.3.3 Pavement sealing and surfacing

It is highly recommended that cold mix pavement, especially open–graded mixes, be sealed or surfaced after placement and curing. Cold mixes usually have fairly coarse gradations with high void contents that allow surface water into the mix if not sealed or overlaid. Cold mixes that are not sealed initially and kept sealed after placement are very susceptible to raveling, stripping, and failure.

Cold mixes should be allowed to properly cure before sealing. The curing time is a function of the weather and time of year, but generally a minimum of seven days. The longer the better. Mixes that are sealed too soon entrap water, solvent, and unbroken emulsion resulting in tender pavements that can severely rut and deform. It is important that cold mix surfaces be placed between mid–June and mid–August to take advantage of the best curing conditions.

Open–graded mixes are base and binder courses and should, as a minimum, be single or double surface treated depending on the traffic conditions, economics, and desired finished surface texture. The most common practice on low–volume roads is to chip seal using asphalt emulsions and 1A stone. A better, recommended practice is to use 1ST stone.

Higher volume roads can be overlaid with dense cold mix or hot mix asphalt. These processes are more expensive initially than surface treating, but give the surface increased thickness, better rideability, and usually outperform the surface treatments. Cold mixes make great bases for hot mix asphalt.

Dense–graded cold mixes can be used for base, binder, or top. When used as base or binder courses, the mix should be sealed or overlaid like open–graded cold mix. When dense mixes are designed properly and used as top courses, they do not have to be sealed. However, sealing enhances their performance. Sometimes dense tops are fog sealed at 0.45 to 0.70 liters per square meter (0.10 to 0.15 gallons per square yard) using a diluted tack coat material without cover aggregate to seal the surface voids of the mix.

Routine maintenance of cold mix pavements must be done to keep surface water out of the mixes. Sealing or overlaying must be done to maintain the integrity and durability of the mix.

6.3.4 Curing of emulsions

After emulsions are applied to aggregate, they go through a breaking and curing period. First, the water separates (breaks) from the emulsion leaving the asphalt film on the aggregate for cementing and waterproofing; but with the water still remaining in the pavement. Then, the remaining water evaporates (cures) over a time period and we are left with a durable asphalt film on the aggregate.

6.3.4.1 Breaking time

The breaking time for an emulsion is controlled by the formulation of the emulsion. RS emulsions for surface treatments are designed to break upon contact with the road and application of the cover aggregate within a period of one to two minutes.

For MS–type emulsions, the break time is delayed to permit mixing and laydown. The breaking or coalescence of the emulsion can be visually seen as the emulsion turns from a brown color to asphalt black. In addition the emulsion changes from a fluid material to an asphalt residue which is very viscous, cohesive, and sticky. If breaking occurs prematurely in cold mixes the mixture becomes very stiff and difficult to place, and may be susceptible to poor coating and stripping. If the emulsion is over stabilized with emulsifiers, the emulsion stays brown, leaving the mixture tender, slow to cure or set, and susceptible to drain down and severe runoff in the event of rain. Breaking of the MS emulsion should occur within 20 minutes on cold mixes.

6.3.4.2 Curing time

Curing of emulsion is the process of the evaporation and removal of the water and any solvent in the emulsion after the breaking or water separation occurs. Total curing can take 7 to 14 days depending on the mix type, emulsion used, aggregate type, and environmental conditions. In warm weather, 90 percent of the water is usually evaporated within the first 24 hours.

Breaking and curing of the emulsion are primarily a function of the emulsion formulation. A slight change in the formulation can greatly change the breaking and curing characteristics. In addition, breaking and curing time of emulsion are a function of the following:

- Atmospheric conditions such as temperature, humidity, wind, and time of year
- Aggregate characteristics such as gradation, amount of fines, surface area, amount of moisture in the aggregate, mineral type, and absorption
- The mechanical forces of mixing, placing, and compaction
- Asphalt emulsion and stone compatibility
- Amount and type of solvent, if used

6.3.5 Quality control/quality assurance

Quality Control procedures are performed by the contractor in order to produce an 'in-specification' project. Quality Assurance procedures are performed by the owner/agency to satisfy themselves that they are getting what they paid for – an 'in-specification' project.

Before staring a project, samples of all aggregates to be used in cold mixes should be analyzed for conformance to the specifications, and a mix design developed by the contractor or asphalt supplier. A pre–paving meeting should be scheduled with all parties to review the project and clarify responsibilities, construction procedures, and quality control/quality assurance procedures. An inspection should be made of the equipment to be used, and the mixing equipment must be calibrated. Prior to the start of the project, aggregate gradation certificates should be obtained for all aggregates.

During the project each load of asphalt emulsion should be accompanied by a certification of compliance to the specifications. The owner should sample the materials. Random samples should be taken of each aggregate. Each load of emulsion asphalt and each day's mix should be sampled. These samples should be taken according to standard methods, labeled, and retained. Emulsions should be stored in clean plastic containers and kept from freezing. The owner may opt to test all or a portion of samples to assure quality.

As part of the contractor or supplier's quality control, samples of aggregates, asphalt emulsion, and the cold mix should be taken once each day, at a minimum, and analyzed for compliance. These test results should be made available to the owner within 48 hours of sampling.

6.3.5.1 Record keeping

Appendix B contains a cold–mix project data sheet that can be used to summarize the data for a cold–mix project. Appendix C shows a mixer calibration sheet to be used for the initial mixer calibration. A cold mix daily data sheet to check yields on a daily basis can be found in Appendix D. It is of utmost importance that these records be kept on a daily basis and reviewed each day to ensure that what is being manufactured and placed conforms to the mix design.

6.4 Hot mix paving equipment

Using proper equipment, placement techniques, and compaction in a hot mix asphalt paving project are critical to its success. A thorough understanding of proper paving practices is essential to the owner and agents in monitoring and inspecting the paving project.

6.4.1 Hauling equipment

Trucks used for hauling HMA should have clean, smooth, tight metal beds. It is important that the truck beds be relatively smooth without excessive indentations or depressions. These uneven areas provide areas for the truck bed release agent to accumulate and this could create problems with the placement of the HMA. Any debris from the previous load hauled should be removed.

Figure 39 Typical hauling unit

The inside of the truck box should be coated with an approved release agent. The minimum amount necessary should be used. Excessive release agent could create placement problems. An updated list of NYSDOT approved release agents can be found on their website, refer to *Technical Services-Materials- Approved List -Release Agents for use on HMA Hauling Equipment*. These release agents are available for customer trucks at NYSDOT approved HMA plants.

Petroleum products (fuel oil, diesel fuel, kerosene, gasoline) or solvents should **not be used**! These products can cause the PG binders to take on different and undesirable properties causing soft spots where potholes will occur. In addition, use of these petroleum products can contribute to environmental problems.

Trucks should be equipped with waterproof covers that totally cover the load of HMA. Flexible covers should overlap the sideboards and tailgate of the truck. The front of the tarp should be attached to prevent wind from getting under the tarp during the transport. Even for the shortest hauls and warmest days, tarps should be used.

6.4.2 HMA pavers

HMA pavers should be self–propelled with a receiving hopper, transfer system such as feed chains, and an activated screed. Skid boxes that are pulled by another piece of equipment, usually the truck loaded with the HMA, are not generally acceptable for highway paving. The paver should be able to spread the HMA in lane widths, to the proper grade and slope, and to the desired thickness. If it is necessary to extend the screed for main line placement, screed extensions should be of the same design as the main screed. The capacity of the receiving hopper shall be of sufficient capacity to allow a uniform layer to be placed. The paver should be equipped with automatic flow controls that will deposit the HMA mixture uniformly in front of the screed without segregation. The paving unit should be capable of moving ahead at a speed that will result in a smooth uniform placement of the HMA mixture.

6.4.3 Rollers

There are three basic types of rollers used to compact HMA pavements: vibratory, static steel wheel, and pneumatic (rubber) tired rollers. It is important that all rollers are in good mechanical condition, free from oil leaks, and able to slow, stop, and reverse direction smoothly without backlash.

Vibratory rollers should be specifically designed for HMA compaction. They should be equipped with a speedometer to indicate the roller speed.

Figure 40 Vibratory roller

Static steel wheeled rollers should be self–propelled and generally about 8 to 10 tons in weight. Vibratory rollers run in a static mode and can be used as a static steel wheel roller.

Pneumatic (rubber) tired rollers should be self–propelled and consist of two axles on which multiple pneumatic tired wheels are mounted so that the front and rear wheels do not follow in the same tracks. The wheels should be mounted so that they oscillate, and the tires must be smooth and the same size, have the same ply, and the same tire pressure.

Figure 41 Rubber tired roller

6.5 Weather limitations

It is not desirable to place HMA on wet surfaces or in weather conditions that would inhibit the proper placement and compaction of the HMA mixture. The temperature and seasonal guidelines of NYSDOT Section 402-3.01 of the Standard Specifications (Table 402-1/Table 11) are a good reference.

Table 11

TABLE 402-1 TEMPERATURE REQUIREMENTS	
Nominal Compacted Lift Thickness	**Surface Temperature Minimum**
≤ 1 in	50°F
1 in < Thickness ≤ 3 in	45°F
> 3 in	40°F

NYSDOT also provides guidance on Seasonal limits and warranty information as outlined here:

B. Seasonal Limits. **Place HMA Top Course on mainline and shoulders between April 1 and November 30 for the counties of Dutchess, Orange, Putnam, Rockland, Westchester, Nassau, Suffolk, and the City of New York. For all other counties, place HMA Top Course between April 15 and October 31. When placing Top Course HMA outside the seasonal limitations, provide a limited warranty against defects in such work. Perform the warranty work in accordance with Materials Procedure (MP) 402-01, *Warranty Requirements for Hot Mix Asphalt (HMA) Top Course*. Unless specified elsewhere in this specification or contract documents, these seasonal limits do not apply for any other HMA course placement.**

The thicker the lift of HMA, the colder the minimum surface temperature allowed. The limiting factor here is the amount of time before the HMA mixtures cool to a temperature where density can no longer be increased. The thicker the lift, the longer it retains heat, giving more time to achieve the desired density.

The decision to start paving is fairly clear–cut. If the surface is **dry** and the surface temperature meets the requirements of NYSDOT Standard Specifications 402–2 (Table 11), there is no reason not to go.

Making a decision, when weather conditions change during the day is a little more complex. As a general rule, if paving has begun and it starts to rain heavy enough that the surface becomes wet, production should be halted. It is standard practice to place all the material that has been produced at the time that the plant has been notified to stop production. If there is a heavy downpour, it may be advisable to wait until it lets up. All trucks should be covered so that loads are well protected.

When placing HMA in the rain, the paving rate should be slowed to allow the roller train to be close to the paver. Rollers need to roll the mat as quickly as possible and make more passes to achieve the density required. The object here is to achieve the desired density before the mix cools to where density can no longer be increased.

6.6 Conditioning of existing surface

Hot mix asphalt should be placed on a clean, dry surface that has a uniform grade and cross slope. The existing pavement surface should be cleaned and cracks filled. Care should be taken not to be excessive with the filler material. Excess filler material can cause the HMA mixture to slide under compaction, or it can build up through the HMA lift. If the pavement surface has ruts, fill the depressions with HMA prior to placing a truing and leveling course. If the existing surface needs to be leveled place a truing and leveling course at a minimum depth with an appropriate mix to bring the surface to the correct grade and slope. A good choice for very thin shimming operations or shallow ruts is HMA Type 5 Shim found in Section 401 of the NYSDOT Standard Specifications. Type 5 Shim is a fine –grained mix that can be placed up to 3/4” thick, but can also be feathered out to nearly nothing.

6.7 Tack coat

A thin, uniform layer of tack coat should be applied to all contact surfaces of existing HMA and portland cement concrete pavements. Areas such as curbs, gutters, manholes or adjacent pavement edges should also be tack coated.

Tack coat is usually an asphalt emulsion that has been diluted to provide an emulsion with 28–40 percent asphalt. This diluted emulsion is generally applied at a rate of 0.12 to 0.40 liters per square meter (.03 to .10 gallons per square yard). Paving should not start until the emulsion has broken or is tacky to the touch. The breaking of the emulsion occurs when the water and the asphalt separate. This can be seen when the color turns from brown to black. The water is still there as it has not evaporated yet. This small amount of water will have no affect on the paving process. Paving can proceed as soon as the emulsion has broken.

Weather conditions can cause a tack coat to break more quickly or more slowly. Generally, the more humid the day, the longer the time the tack will take to break. When paving at night it will generally take longer for the tack coat to break.

Excessive tack coat may cause the HMA to slip on the pavement or it could flush through the HMA to the surface. However, when handled properly, tack coat is very beneficial and can help prevent some of the distresses discussed in Chapter 4. NYSDOT now requires tack coat between all pavement layers, even on new construction.

6.7.1 The difference between break time and set time

Tack coat is usually a diluted asphalt emulsion that when first applied is a brownish color. A short time after application the tack coat will “break” and turn from brown to black in color. The asphalt and water are separating and the water is evaporating. The rate of evaporation is dependent on a number of factors: the type and grade of emulsion, the rate of application, the environmental conditions and pavement characteristics. The tack coat is referred to as having “set” when all the water is evaporated.

It is not necessary to wait until the tack coat is “set” to start paving. There is no harm when HMA is placed on tack coat that is broken, but not “set” and even on tack coat before the break has occurred. When the hot HMA is laid on the tack coat the “break” will occur immediately. The water will evaporate and escape as steam from the uncompacted mix. The amount of water, about 0.30 liters per square meter (0.08 gallons per square yard), is not enough to significantly reduce the mat temperature.

6.8 Hot mix paver operation

The HMA is deposited directly into the paver hopper by the hauling unit. The truck driver should back his truck and stop just short of the paver. Once stopped, the brake should be released so that when the paver comes forward and picks up the truck, there is as little disturbance as possible. When a tandem axle or tri–axle is used the box should be raised enough to “break” the load before the tailgate is released. This is done so that the mix slides from the truck to the paver hopper in a mass and avoids segregation. It is best to keep the hopper full and not let it run out of material. The less opportunity the HMA has to “break and run,” the less chance for segregation to occur. The same concept should be followed with live bottom trucks. Avoid dribbling the mix into the hopper.

The best way to end up with a high quality smooth pavement is to place the mat at a consistent rate, without stopping the paver. This is not always possible, but the closer you can come to this ideal, the better the end result.

The tendency of most paving operations is to unload a truck of HMA as quickly as possible. It is much better to adjust the speed of the paver to try to allow for a truck to always be waiting to unload. To most paving crews this seems to be painfully slow. It will require discipline to maintain a consistent, steady pace.

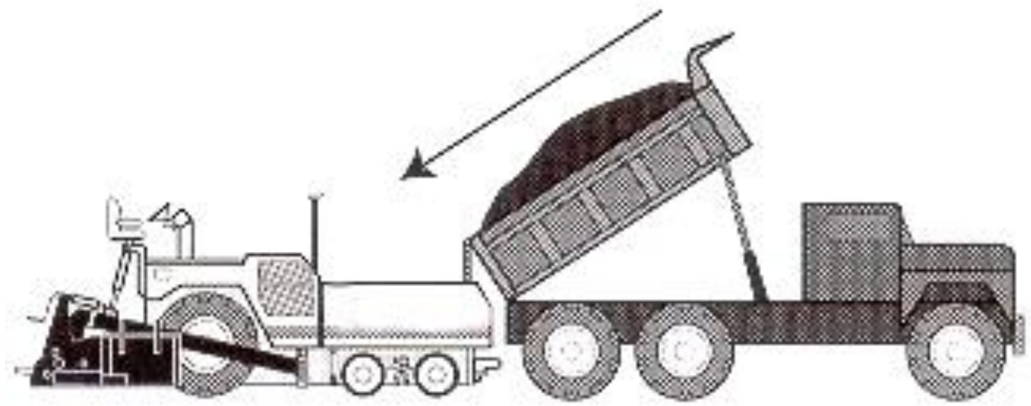


Figure 42 Mass movement of hot mix asphalt

The level of material in front of the screed should be kept at a constant temperature and level. The appropriate level should be about to the middle of the auger. Maintaining this constant head or level of material is a big factor in the resultant smoothness of the pavement.

The screed of the paver is used to strike off the HMA to the proper depth and grade. Most pavers today have screeds that can be controlled by automation as well as manually. Under manual control the thickness is controlled by cranks or screws. As the mix passes under the screed the operator can adjust the angle of attack of each side of the screed to change the depth of the mat. The most common mistake made by screed operators is to constantly adjust the screed angle causing the depth to change accordingly. Since it takes about the length of the paver for any change to show up at the screed, the operator tends to chase the screed changes up and down.

Automated operation of the screed eliminates this problem. Automated screed controls keep the elevation of the screed at a predetermined elevation relative to a reference such as a long "ski." As the ski moves over the existing grade, the deviations in the surface are averaged. The screed is adjusted based on this moving average.

Generally, automated control of the screed will produce a smoother pavement than manual control. However, because the automatic control levels out the pavement over the length of the ski, the thickness will vary. This almost always results in a higher yield than neat line calculation would indicate. If your project is restricted by a predetermined quantity of HMA, it is important to closely monitor the yield.

6.8.1 Segregation

With the implementation of Superpave mixes came an increased sensitivity to segregation. This is due partly to the coarser nature of the mixes along with the lower asphalt contents encountered. Because of this, HMA producers and contractors need to be especially vigilant in watching for segregation throughout the whole process of the project.
Segregation can happen any time the HMA is moved from one place to another. This includes the manufacture and loading of the material at the plant. At the paving operation, segregation can occur in the paver hopper when the material is dumped into the paver, or at any location in the feed system, and in the augers.

Constant alertness to possible segregation by all members of the paving crew and the owners' agents can help to overcome segregation problems. A helpful resource to detecting and eliminating a segregation problem is the National Asphalt Pavement Association (NAPA) publication, *Segregation: Causes and Cures for Hot Mix Asphalt.* It contains a very handy diagnostic chart that can help detect the causes of different kinds of segregation.

6.9 Hot mix compaction

6.9.1 Importance of compaction

Without a doubt, compaction is the most critical element in the durability of the HMA pavement. Although the new superpave mixes have illuminated the importance of adequate compaction, the importance has always been there, even with the "standard" mixes.

Before we go too far in discussing compaction of HMA, it is important to understand the terminology being used.

6.9.2 Density

The term density refers to the weight of the material that is contained in a specific volume of space. This is expressed as kilograms–per–meter cubed (kg/m^3) or pounds–per–foot cubed (lb/ft^3). This density measurement or unit weight, is an indicator of the compaction of the mix. A unit weight of 89 kg/m^3 (149 lb/ft^3) is more compact than 85 kg/m^3 (143 lb/ ft^3). When we refer to compaction we refer to the process of compressing the HMA to a higher density. As an HMA mixture is compacted, air voids in the mix are reduced, and the density increases.

In order to determine density, the per-cent air voids in the mix must be calculated. This is easily done in the laboratory or the field by comparing the Actual density of the mix to the Theoretical density of the mix. Once the air voids are calculated, the density is [100% - air void %]. So, if the air voids are determined to be 6%, then the density is [100% - 6%] or 94%.

6.9.2.1 Actual Density

Actual density of HMA is measured on a compacted sample. The sample can be laboratory generated in a Superpave gyratory compactor, or cored from a recently constructed roadway. They are typically 4" or 6" in diameter. Figure 43 shows two samples with visibly different actual densities. Note the reference that this photograph is for illustrative purposes. Under Superpave compaction specifications, binder and top are held to the same density specification requirements.

Figure 43

6.9.2.2 Theoretical maximum density

In a laboratory it is possible to measure the density of an HMA mixture with zero air voids. This is referred to as the theoretical maximum density. This number may also be referred to as the "Rice number" (the test to determine the theoretical maximum density is called the Rice test). This number is "theoretical" because it cannot be achieved on the roadway. All HMA mixtures will have some air voids in them, which is good, because it helps to prevent bleeding.

6.9.2.3 Air voids

Air voids in an HMA mix is the volume of air spaces between the asphalt coated aggregate particles. The air voids in an HMA mixture are expressed as a percentage of the theoretical maximum density.

With the move to Superpave mixes, achieving adequate compaction has sometimes become more difficult than it was with "standard" mixes. Part of this is due to the aggregate structures being coarser with an increase of aggregate angularity. This results in more stone–to–stone friction and will require more compaction effort to reorient the aggregate particles. Add to this typically lower asphalt contents in the mixes and often more viscous PG binders, and you have stiffer mixes that are more resistant to densification and require more compactive effort to achieve the proper in–place air voids.

6.9.3 Measuring density

6.9.3.1 Cores

The most accurate way to determine the density of an HMA pavement is by cutting cores out of the roadway and comparing the actual unit weight with the maximum theoretical unit weight of the HMA material.

Figure 44 Coring hot mix asphalt

6.9.3.2 Density Gauges

A nuclear density gauge is often used to monitor relative density of the pavement as it is being compacted. Relative density is measured by allowing gamma rays to be transmitted into the pavement and measuring the radiation that is reflected back. Non–nuclear gauges have recently been approved by NYSDOT for use in determining pavement densities.

The values generated by both nuclear and non–nuclear gauges are relative numbers. For them to be effectively used, they must be calibrated to actual unit weight as determined by cores. Usually these cores are taken in a test strip at the start of a paving project.

Figure 45
Nuclear density gauge

Figure 46
Non–nuclear density gauge

6.9.4 NYS density specifications

New York State specifications include four different levels of compaction. The type of construction, expected traffic loading, and size of project determine which level is chosen. Following are general descriptions of the four levels. The complete specifications can be found in Section 402-3.07 of the Standard Specifications. The roles of Quality Control personnel (contractor) and Quality Assurance personnel (owner/agency) during paving operations will be outlined in Section 6.10.3 of this Chapter:

- **50 Series –** On the first day of production, a 1,500' test strip is constructed. Before further paving can occur, four cores are taken from the mat and the density is calculated by comparing the cores to the Theoretical Maximum density in the laboratory. A statistical analysis is performed on the results, which must achieve 92% - 97% density. This same coring/calculation procedure is then followed each day of paving. Payment is based on a quality scale that can result in a bonus or penalty assessed on how well the core results meet the target range. This Series is usually specified for high traffic projects of significant size.

- **60 Series -** On the first day of production, a 1,500' test strip is constructed. Before further paving can occur, four cores are taken from the mat and the density is calculated by comparing the cores to the Theoretical Maximum density in the laboratory. A statistical analysis is performed on the results, which must achieve 92% - 97% density. Based on these results of the test strip, a Project Target Density (PTD) is determined for the remainder of the project. A density gauge is then used to monitor daily paving. A density reading from the gauge is taken every 200' and must fall between 96% and 103% of the

PTD, with the moving average of ten readings at 98%. In addition to the daily monitoring with the gauge, the Engineer will take four cores every third day to calculate the density and verify the gauge readings.

- **70 Series –** On the first day of production, a 1,500' test strip is constructed. A density gauge is used to monitor the compaction until a 'peak' density is achieved. This density should fall between 92% and 97% of the laboratory Theoretical Maximum density. The density gauge generated 'peak' density is considered the PTD. The gauge is then used to monitor daily paving. A density reading from the gauge must be taken every 200' and must fall between 96% and 103% of the PTD, with the moving average of ten readings at 98%. No cores are taken when using this Series.

- **80 Series –** For this series, neither the coring or density gauge procedures are used. It is a 'method' specification, where the number of roller passes are recommended in NYSDOT Table 402-6 of the Standard Specifications and here in Table 12:

Table 12

Pavement Courses	Static Compaction		Vibratory Compaction	
	Steel Wheel Rollers	Pneumatic Rollers	Vibratory Passes	Static Passes
37.5 Base (each lift)	**8**	**3**	**6**	**4**
25 Binder	**8**	**3**	**6**	**4**
19 Binder	**6**	**3**	**4**	**2**
12.5 Top	**6**	**3**	**4**	**2**
9.5 Top	**4**	**3**	**4**	**2**
Permeable Base	**-**	**-**	**-**	**2**

Nearly all local roads projects are 80 Series compaction. However, the use of a density gauge as a monitoring tool during compaction is a relatively inexpensive way to get a better project. Technicians can be hired locally who are familiar with the 70 Series procedures. Contact Cornell Local Roads for guidance on hiring technicians from a commercial laboratory

6.9.5 Rolling strategies

There is no "right way" to compact HMA mixes. There are many variables that have an impact on how you choose to roll the HMA mat. A few of the major variables that will dictate your rolling strategies are:

- Type of mix
- Lift thickness
- Weather conditions
- Underlying foundation

6.9.5.1 Type of mix

A dense–graded mix is generally easier to compact than a coarse–graded mix. Open–graded mixes and gap–graded mixes require a greater compaction effort to achieve the desired density. Very fine mixes can be tender and are more difficult to compact. Mixes that have a higher amount of material in the 0.60 to 0.18 mm (#30 to #80) sieve range can lack internal cohesion and be difficult to compact. These mixes have a tendency to shove out rather than compact.

The amount of material passing the 74 µm (#200) sieve can have a dramatic effect on the compaction of a mix. A higher percentage of minus 74 µm (#200) material will generally make a mix more difficult to compact.

6.9.5.2 Lift thickness

For many years the axiom has been that the minimum lift thickness should be twice that of the maximum aggregate size. Maximum aggregate size was defined as the first sieve to have 100 percent of the material passing.

Things have changed with Superpave. The Superpave mix designations use the “nominal” maximum aggregate size. This is the first sieve that retains 10 percent of the aggregate. The lift thickness of the Superpave mixes should be a minimum of three times the “nominal” maximum aggregate size of the mix. If the thickness of the lift is less than three times nominal, it will be very difficult to achieve desired density. In trying to achieve the density the mix can easily be damaged by fracturing the coarse aggregate particles.

A thicker lift is easier to compact to desired density because it holds the heat longer giving more time for the rollers to obtain the density.

6.9.5.3 Weather conditions

Differing weather conditions can have an impact on how a mix compacts. Sunshine, overcast, relative humidity, and temperature all have an effect on the rolling patterns used to achieve the desired density. These factors can change the characteristics of a mix not only on a daily basis, but also throughout the day. A mix that compacts well early in the morning may start shoving as the temperature rises or the humidity increases. Roller patterns may need to be modified many times during a day to reach the density levels desired.

6.9.5.4 Underlying foundation

For any pavement to have long term performance, the underlying foundation must be sound. The difficult types of underlying foundations can require different compaction methods to best achieve the desired densities. Full–depth asphalt bases may allow for heavier rollers or more aggressive vibratory efforts that could help eliminate a roller from the compaction train. There is no hard and fast rule in these cases. Experience and experimentation are the best avenues to take.

6.9.5.5 Tender zone

When Superpave was introduced with increased emphasis on field compaction, contractors and owners increasingly encountered what has been termed the “tender zone” during rolling operations. In reality, the tender zone has always been there, but with the coarser mixtures, lower asphalt contents, and the increased attention to compaction, these tender zones manifested themselves more than in the past. Not all Superpave mixes exhibit a tender zone. In fact, with the adjustments to the system described in Chapter 3, there have been fewer problems in this area. However, it does occur. The temperature range varies from mix to mix, day to day, even hour to hour sometimes on the same mix. The contractor and owner should be aware, and be ready to adjust operations at any time. Again, an experienced technician using a nuclear gauge following 70 Series compaction protocols can detect these tendencies very quickly and lend valuable information during paving & rolling operations.

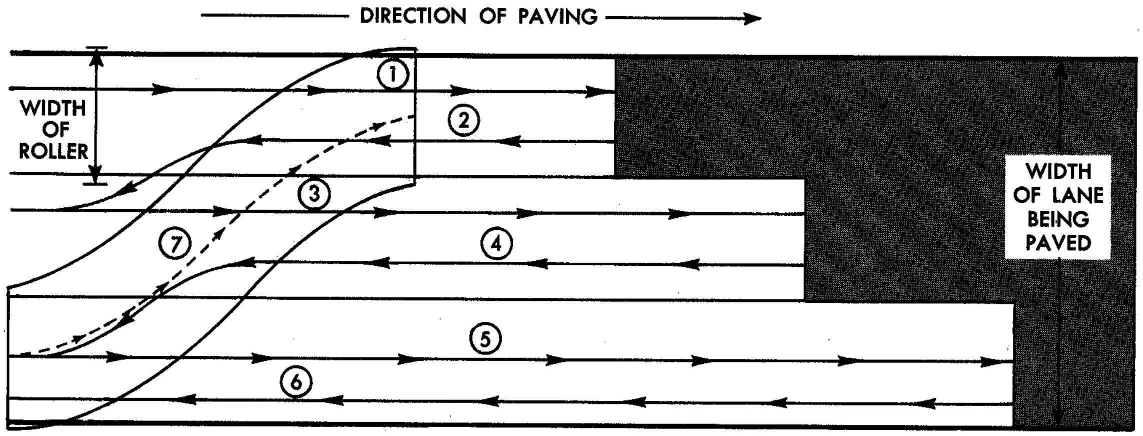
The tender zone will be noticed by the movement of the mix under the compaction effort of the roller. This will be noticed in a number of different areas.

The “bow” wave in front of a steel wheel roller will increase as the roller moves on the mat. The mat may widen out as the rollers compact the mix. The mat may shove forward and then backward with each pass of the roller. This can be described as being like a “throw rug on a hardwood floor.” When the mix is moving in front of the roller, and it encounters a change in the underlying surface such as an asphalt patch on a concrete road or excessive crack filler material, the material will hump up and leave a considerable bump.

The best way to address this tenderness is to stay off the material while it is tender. This means trying to achieve as much density as possible before the mat becomes tender, and holding back the final rolling until the mat cools down and becomes stable again.

6.9.6 Rolling procedures

For hot mix asphalt paving projects, the more you know about the compaction process and the correct construction procedures, the better you will be able to observe and inspect the contractor’s progress and the quality of the work. Following is a description of the construction procedures for hot mix asphalt rolling to use as guidelines for inspecting compaction on your projects.



This is a recommended rolling pattern. Every pass of the roller should proceed straight into the compacted mix and return in the same path. After the required passes are completed, the roller should move to the outside of the pavement on cooled material and repeat the procedure.

Figure 47 Correct rolling pattern

Basis rules for rolling:

- Decelerate and accelerate slowly and smoothly whenever switching direction. This is to avoid shoving the mat.
- Shut off vibration when slowing the roller to a stop, and start it again when the roller is moving over 0.8 km/hr (0.5 mph).
- For vibratory rollers, make sure to operate at a speed that will achieve at least 10 impacts per 300 mm (one foot) of travel.
- When ending a pass of the roller, turn the roller into a slight curve before stopping. This is to avoid leaving a transverse ridge in the HMA mat.
- Avoid sharp turns that will shove and cut the mat.
- Whenever you stop the roller, park at an angle on a cool part of the mat to avoid leaving an indentation.

In general, rolling hot mix asphalt should begin as soon as possible after lay down. The lead roller should stay as close as possible to the paver to achieve as much density as possible while the mat is still hot.

Rolling should begin from the lowest edge. This lower edge will become a support for subsequent passes. Rolling lanes should be changed by making the turns on the compacted areas. All turns should be gentle to decrease the risk of cracking the mat. On a super elevated turn, start rolling at the low side edge and work toward the super elevated edge. Overlap rolling passes by 100 to 150 mm (4 to 6"). It may be necessary to stay about 300 mm (one foot) away from the unconfined edge of a lane on the first pass to prevent the material from shoving out. On the subsequent pass, the roller can roll the one foot of uncompacted material.

6.9.7 Joints

With the move to the coarser Superpave mixes, the longitudinal joint is where many pavements prematurely fail. Most often this is due to segregation of the mix at the joint and improper compaction. This problem is not new, but the move to the coarser mixes makes it easier to segregate at the joint, and the problem manifests itself more often. To produce a good paving joint, the material needs to be as close to the same consistency as possible, not segregated, and compacted to as close to the same density as the mat itself. Although the diagram for the Traditional Butt Joint here is correct, many contractors through experience have found that a 1 ½" overlap which is not struck off and left in place for the roller is beneficial.

There are two types of joints:

- **Traditional "butt" joint**
  The objective here is to produce as close to a vertical edge as possible as the material is placed with the paver for the unconfined edges. The key to this is to maintain a consistent head of material in front of the screed to prevent segregation. The end gate of the paver must be secure and extended to the back of the screed. The end gate must be adjusted to ride on the existing pavement and create as vertical an edge as possible.

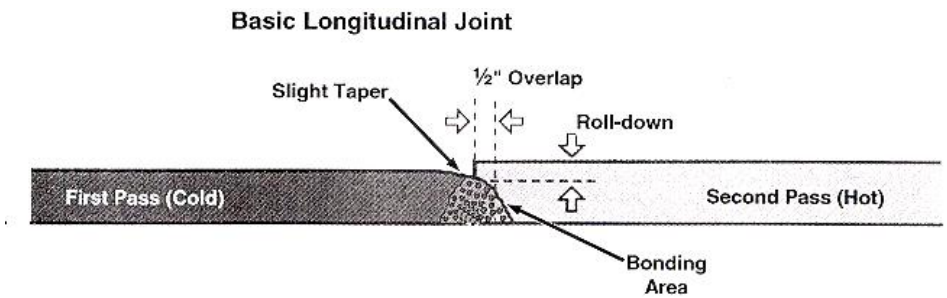


Figure 48 Traditional "butt" joint

- **"Wedge" joint**
  The "wedge" joint, or tapered joint, is a technique that has been developed and used successfully in a number of states. The edge of the first pass is tapered over a 12–inch width to produce the wedge. This is done by a tapered plate on the paver screed or with special screed extensions that extrudes the wedge and imparts some compaction to it. The second pass of the pavement extends slightly over the wedge. The heat of the overlying material helps to achieve the desired density at the joint.

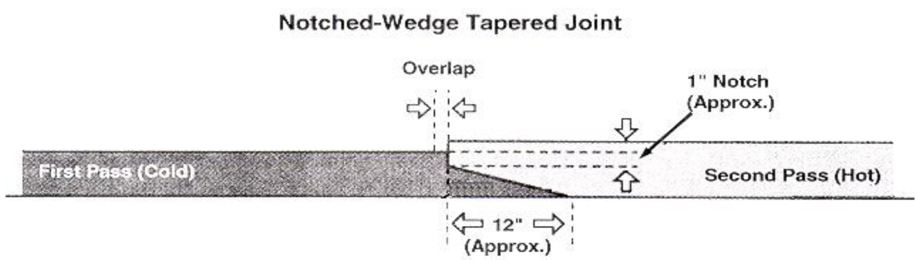


Figure 49 Notched wedge joint

A modification of the wedge joint is the "notched" wedge joint. This technique leaves a vertical edge of about 25 mm (1") at the top of the wedge. This gives the hot mat of the second pass a confining edge, and it also gives a vertical edge as a steering guide for the paver operator.

With both of these joint techniques the paver operator must steer a straight line while laying the first pass to make it easier to have the proper overlap and depth of material on the second pass. In order to mitigate joint failures, NYSDOT now specifies the use of a Joint Sealant on all projects. It is specified in Section 705-02 of the Standard Specifications and references *ASTM D6690 Types II or IV.*

6.9.8 Joint compaction

There are two standard alternatives for joint compaction:

- **Alternative A** – The joint is compacted with the roller working on the cold lane and overlapping the hot lane by 100 to 200 mm (4 to 8"). Vibration should not be used when most of the roller is on the cold lane. One of the disadvantages to this alternative is that the roller will be in the traffic lane when it makes its pass on the joint.

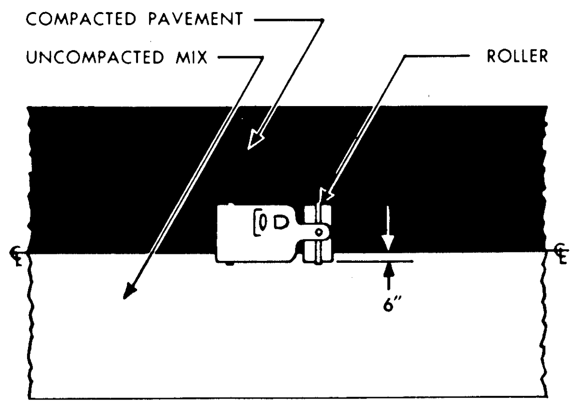


Figure 50 Rolling a longitudinal joint

- **Alternative B** – The joint is compacted with the roller working on the hot lane with a 100 to 200 mm (4 to 8") overlap on the cold lane. When using this alternative, as the mat is rolled from the lower, outside first, a berm of uncompacted material about 150 mm (6") wide can be left next to the cold mat. Then when the last pass is made, overlapping a few inches onto the cold mat, the berm material is compressed between the two compacted mats.

6.10 Quality control/quality assurance

To achieve a successful, high quality HMA pavement, both the owner and the contractor will need to address how to achieve and to assure this quality. Current NYSDOT specifications divide this responsibility into two areas: quality control is the contractor's responsibility, and quality assurance is the owner's responsibility.

6.10.1 Quality control at the HMA plant

At the plant the producer does the quality control. All NYSDOT approved plants have a quality control plan that has been reviewed and approved. This plan details how the producer will test the material produced to assure its quality. A NYSDOT certified technician employed by the producer must be present during the testing procedures. When sampling the mix, the technician will obtain two separate samples. One sample will be tested immediately, and the other kept as a referee sample. This sample is the companion sample

Figure 51 Quality control sampling

Depending on the mix being produced, the producer will test for gradation, asphalt content, and percent voids at design compaction. These tests must produce results that are within certain limits of the design criteria. The producer uses these results to adjust the manufacturing process to produce within the prescribed limits.

6.10.2 Quality assurance at the HMA plant

During normal operations, a certified Quality Assurance technician employed by NYSDOT will randomly sample and test material. These results will be compared to the producer's Quality Control results. If they compare favorably within prescribed tolerances, there are said to validate. Once validation occurs, remaining samples are discarded and the Quality Control results are recorded. If the Quality Assurance and original Quality Control test *do not* validate, the Quality Assurance technician tests the companion sample and those results are used and recorded.

Figure 52 Quality assurance companion samples

6.10.3 Quality Control and Quality Assurance in the field

The roles of the Quality Control personnel and Quality Assurance personnel are specific to each of the compaction Series types discussed in Section 6.9.4:

- **Series 50 –** During construction of the test strip and then daily paving, the contractor will perform Quality Control using a density gauge. The job of the Quality Control technician is to use the gauge to achieve compaction density within specifications during rolling operations. Typically, this technician will direct the rolling operations based on the gauge readings. When the paving operation is complete, the owner/agency will then perform the coring/calculation procedures to determine if the density specifications have in fact been met. This is the Quality Assurance.

- **Series 60 –** For the test strip and the paving days when cores are taken again (every third day), the roles of Quality Control and Quality Assurance are identical to those in **Series 50** shown above. For all other paving days, the Quality Control technician uses the density gauge to monitor the compaction to achieve the PTD as described in Section 6.9.4. On these paving days, the Quality Assurance technician is responsible to record the density readings taken every 200' on the proper form.

- **Series 70 –** For this Series, it is the role of the Quality Control technician to use the density gauge during the test strip to 'peak' the gauge in order to determine the PTD. The Quality Assurance technician must verify the PTD and record it on the proper form. During daily paving, the Quality Control technician monitors the compaction with the gauge to achieve the PTD as described in section 6.9.4. The Quality Assurance technician is responsible to record the readings taken every 200’ on the proper form.

- **Series 80 –** In this Series, the contractor is required to compact according to the recommendations of the owner/agency as shown in Table 402-6. These are guidelines, and the owner’s representative can modify them during the project. The role of Quality Control is for the contractor to understand and follow the owner’s recommendation regarding the number of passes. It is actually an operations protocol rather than a testing protocol. The owner’s Quality Assurance duties are to make sure the contractor actually does follow the rolling recommendation.

6.10.4 Record keeping

The owner should require copies of all quality control records for both plant production and field monitoring. These records should be kept with all quality assurance records that the owner generates.

An owner’s representative at the job site should maintain a daily diary that will contain a written narrative of the entire production and lay down operations. This narrative should be as detailed as possible. There is no such thing as too much detail!

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APPENDIX B
Cold Mix Project Data Sheet

Start date ______________ Completion date ________________

1. Project name/location____
   Length ____________________Width ____________________
   Thickness: Lift 1___________________ Lift 2 ______________ Lift 3 _____________________
   Type of surface or seal ____

2. Contractor ____
   Contact ___________________________Phone ______________________________

3. Aggregate: Source / Location / Size / State Approved

Source	Location	Size	State Approved
___________	_______________________	______________	Y N
___________	_______________________	______________	Y N
___________	_______________________	______________	Y N
___________	_______________________	______________	Y N

   Were certifications provided? Y N (attach if provided)
   Were gradations checked? Y N (attach if checked)
   If blended, how? ____
   Blend proportions _________________________________ Moisture content __________________

4. Asphalt emulsion:
   Manufacturer _____________________________________ Supplier ___________________________
   Type of emulsion __________________________________ Temperature of emulsion ____________
   Were certifications provided? Y N (attach if provided)
   Date, time, load ticket of project samples _________________________________
   ____
   Were samples tested? Y N (attach results)

5. Mixer:
   Manufacturer ______________________________Model or serial # ___________________________
   Type of mixer: continuous or batch
   Length of mix after asphalt added _____________Surge hopper capacity or dimensions ________
   Type totalizing meter _______________________

6. Mix design: __________% #3 ________% #2 _________% #1 _________ % #1A
   __________% sand _______% screenings ________ % mineral filler
   __________gallons per ton _______% emulsion _________% residue

7. Mix placement:
   Paver: Make and model ____
   Properly maintained? Y N

   Preliminary curing time ______________ Rollers used ________________________________
   Initial roller pattern ____

8. Observation and comments: ____

APPENDIX C
Mixer Calibration

Date: ______________________________

1. Project name/location ____

2. Mixer:
   - Manufacturer ______________________________________
   - Model/serial # ______________________________________
   - Type of mixer: continuous or batch ______________________________
   - Length of mix after asphalt added ______________________________
   - Surge hopper capacity or dimensions ____________________________
   - Number of aggregate bins ________________________________
   - Do aggregate and asphalt feed interlock? Y N (if N, stop)

3. Aggregate feed calibration:

A. By weight:

	Run 1	Run 2	Run 3
Gate setting	_______	_______	_______
Gross weight (G)	_______	_______	_______
Truck tare (T)	_______	_______	_______
Net weight (N=G-T)	_______	_______	_______
Loading time (M)	_______	_______	_______
Feed rate (E=N÷M)	_______	_______	_______

B. By volume:

Gate setting	_______	_______	_______
Volume(cu yd) LxWxH(V)	_______	_______	_______
Loading time (M)	_______	_______	_______
Feed rate (V÷M)	_______	_______	_______

*For stone 1 cu yd = approximately 1.4 tons

4. Asphalt meter calibration:

	Run 1	Run 2	Run 3
Final meter reading (F)	_______	_______	_______
Beginning meter reading (B)	_______	_______	_______
Gallons delivered (D=F-B)	_______	_______	_______
Weight of drum and asphalt (R)	_______	_______	_______
Tare weight of drum (D)	_______	_______	_______
Weight of asphalt (A=R-D)	_______	_______	_______
Weight/gallon of asphalt (W)	_______	_______	_______
Actual gallons (U=A÷W)	_______	_______	_______

D ÷ U should be between .95 and 1.05, if error is greater than 5%, repair meter

5. Gallons required:

   Gallons required per minute = aggregate
   Feed rate (E) x design gallons per ton (P)

   GPM = E x P   GPM = _______ x _______= _________

APPENDIX D
Cold Mix Daily Data Sheet

Date ___________________________

1. Project name/lLocation ____
   ____

2. Weather conditions: Cloudy_______Sunny _______ Rainy_______
   Temperature: AM ___°F
   PM ___°F
   Relative humidity __________

3. Mix Design:
   _______% #3 ______ % #2 ______ % #1 ______ % #1A
   __________% sand____________% screenings _________ % mineral filler
   _____________% gallons per ton _____________ % emulsion

4. Checking gallons per ton:
   Total gallons ÷ total tons aggregate ÷ = gallons per ton
   ______÷_____= _____ gal/ton
   *Should be ± one/gallon from design

5. Checking yields per square yard:
   Determine square yards paved = length x width (ft) ÷ 9 square ft/sq yard
   Square yards = _________ft x ft ÷ 9 = _________ sq yds

   Tons laid x 2000 pounds per ton ÷ square yards = yield in pounds per square yard
   ____________x 2000 ÷ ___________= ___________ lbs/ sq yd

- Dense mixes should be 100–110 lbs/ sq yd/ inch
- Open–graded mixes should be 80–100 lbs/sq yd/ inch

APPENDIX E
Hot Mix Project Data Sheet

Start date_______________ Completion date_____________

1. Project name/location____

   Length________________________Width ____________________

2. Paving contractor:____

   Contact_____________________________________ Phone______________________

3. HMA supplier: ____

   Contact_____________________________________ Phone______________________

   Source______________________________________ Location___________________________

   Material type_________________________________ Item No.___________________________

   ESAL level___________________________________ PG Grade__________________________

   Compaction series: 50 60 70 80

   Source______________________________________ Location___________________________

   Material type_________________________________ Item no.___________________________

   ESAL level___________________________________ PG Grade__________________________

   Were certifications provided? Y N (attach if provided)

   Were samples taken and retained? Y N

   Were samples tested? Y N (attach results)

   Temperature of mix at site________ºF

4. Paving:

   A. Paver

      Make and model____

      Properly maintained (check for damage, heaters, extensions, proper crown adjustments, automation, tampers, or vibrators).

   B. Rollers

      Make and model____

      Properly maintained (check for cleanliness, damage, weight, scrapers, sprinkling system).

   C. Workmanship

      Are workers trained and qualified?____

   D. Consistency

      Are color, texture, and temperature consistent?___________________________________

5. Observations and comments:____

APPENDIX F
Hot Mix Daily Data Sheet

Date: ________________________

1. Project name/location ____

2. Weather conditions: Cloudy _______ Sunny ________ Rainy ________
   Temperature: AM______°F
   PM______°F

3. Supplier:____
   Mix type____
   Depth placed____
   Temperature of mix at paver____
   Temperature of mix at rolling____
   Morning road surface temperature____

4. Checking yields per square yard:
   Determine square yards paved = length x width (ft) ÷ 9 square ft/sq yard
   Square yards = _______ft x ____ft ÷ 9 = _______ sq yds

   Tons laid x 2000 pounds per ton ÷ square yards = yield in pounds per square yard
   ___________x 2000 ÷ ___________= ____________ lbs/ sq yd

   - HMA should be 110 lbs/sq. yd/inch

APPENDIX G
Conversions

ENGLISH TO METRIC CONVERSION TABLE					
Multipy	**By**	**To get**	**Multiply**	**By**	**To get**
Acres	0.404 687 3	Hectares	Ounce (force)	0.278 013 9	Newtons=N
Board feet	0.002 359 74	Cubic meter	Pint (liq.)	0.473 176	Liters=l
Cubic ft.	0.028 316 85	Cubic meter	Pint (dry)	0.550 61	Liters=l
Cubic yd.	0.764 554 9	Cubic meter	Pound (wt.)	0.453 592 37	Kilogram
Feet	0.304 8	Meters	Pound (force)	4.448 222	Newtons=N
Footcandles	10.763 91	Lux=lumens/m^2	Pound/sq.ft	47.880 26	Pascal=N/m^2
Ft.–lb_f	1.355 818	N≅m=joule	Pound/sq.in	6.894 757	Kilopascals
Gallon (US)	3.785 412	Liters	Quart(liq.)	0.946 352 9	Liters
Horsepower *	745.699 9	Watt=J/sec	Sq. feet	0.092 903 04	Sq. meter
* Horsepower = 550 ft–lb_f/sec			Sq. in.	645.16	Sq. mm
Inch	25.4	Millimeters	Sq. mile	258.998 8	Hectares
Inch–$pound_f$	0.112 984 8	N≅m=joule	Sq. mile	2.589 988	Sq. km
Kips	4.448 222	Kilonewton	Sq. yard	0.836 127 4	Sq. meter
Kips/in^2	6.894 757	Megapascal	Ton (short)	0.907 184 7	Metric ton
Miles (US)	1.609 347	Kilometer	Ton (short)	907.184 7	Kilogram=kg
Ounce (wt.)	28.349 52	Grams	Ton (short)	8896.444	Newtons=N
Ounce (liq.)	29.573 53	ML	Yards	0.914 4	Meters=m

For temperature conversion use: EC= 5/9(EF – 32)

METRIC TO ENGLISH CONVERSION TABLE

Multiply	By	To get	Multiply	By	To get
Cubic meter	1.308 0	Cubic yard	Liter	0.264 17	Gallon
	35.314 7	Cubic foot		1.056 7	Quart
	61,024	Cubic inch		2.113 4	Pint
	264.172	Gallon		33.814	fl. ounce
Gram	0.035 274	Ounce (wt)	Milliliter	0.033 814	fl. ounce
	0.002 204 6	Pound (wt)	Liter/m	0.080 52	gal/ft
Kilogram	35.274	Ounce (wt)	Liter/m^2	0.220 88	gal/sq.yd
	2.204 623	Pound (wt)	Lux	0.092 902	ft-candle
	0.002 204 6	Kip	Meter	1.093 6	Yard
	0.001 102 3	Ton		3.280 84	Foot
Megagram	1.102 3	Ton	Millimeter	0.039 370	Inch
(Metric ton)			Kilometer	0.621 37	Mile
Hectare	2.471 04	Acre	Micrometer	0.039 370 1	mil
	107,639	Square feet	Newton	0.224 81	Pound(f)
	11,959.9	Square yard	Kilonewton	0.224 81	Kip(f)
	0.003 861 02	Square mile	Pascal	0.020 885	lb/sq. feet
Microare	0.155 00	Square inch	Kilopascal	0.145 04	lb/sq. inch
Joule	0.737 56	Foot pound	Megapascal	0.145 04	kips/sq. inch
	8.849 5	Inch pound	Square meter	1.195 99	Square yard
kg/m^3	1.685 55	lbs./cubic yards		10.763 9	Square feet
	0.062 428	lbs./cubic feet	Square millimeter	0.001 55	Square inch
km/hr	0.621 37	Miles per hour	Square kilometer	0.386 102	Square mile
			Watt (J/second)	0.001 341	Horsepower
				0.737 56	ft–lb/second

For temperature conversion use: EF = 9/5 EC + 32