15.1 Scope
This performance guide covers the use of asphalt emulsion in the construction of open-graded pavements. The attention given to materials, design, and workmanship is intended to aid those with little or no experience with open grade asphalt emulsion mixes by providing basic information and references for more detailed study. This is a guide only and is not intended to take the place of the construction specification, which governs, and takes into consideration local practice and conditions.

NOTE:
The conceptual approach to open-graded mix, which has been developed in the USA during recent years by the Federal Highway Administration and the Forest Service has resulted in strict requirements to achieve certain end results. This guide follows the FHWA concept. However, since established practices regarding open-graded mixes often differ from place to place from the FHWA requirements, a note has been added to 15.2 Description to describe some of these differences.

15.2 Description
Open-graded mixes are designed to provide high air void capacity and when needed, pore size or drainage channels large enough to permit heavy rainfall to drain and escape, thus minimizing the danger of hydroplaning due to water buildup at the road surface.

By selection of aggregate gradation, geometry, and hardness, together with percent and grade of residual asphalt, the desired results can be achieved.

Open-graded mixes are also characterized by a thick film of binder on the aggregate. It should also be mentioned that the air voids in open mixes aid the curing of the emulsion.

Open-graded base, intermediate, and thick surface courses, placed 50 to 200 mm (2 to 8 in.) in depth are generally made from aggregate with less than 10% passing the 2.36 mm (No. 8) sieve, less than 2% passing the 0.075 mm (No. 200) sieve, and having 20 to 30% air voids after compaction. (A 2% maximum passing the 0.075 mm (No. 200) sieve has been suggested where cationic emulsions are used, and up to 5% with anionic emulsions having good mixing stability.)

Open-graded friction courses have a compacted thickness of 16 to 19 mm (5/8 to 3/4 in.). When laid on an existing hard surfaced pavement, they provide an anti-skid sur-
face, and renewal of the surface of aged, weathered pavements. A 9.5 mm (3/8 in.)
top size aggregate is used, with 15% air voids after compaction is recommended for
these thin friction courses.

Crushed stone, crushed gravel, or slag of a polish resistant type and which have good
roughness or microtexture should be selected for surface or friction courses.

The advantages, or reasons, for selecting open-graded mixes for surface courses (ei-
ther hot or cold mix) are:

1. Improved skid resistance at high speeds during wet weather.
2. Minimization of hydroplaning effects during wet weather.
3. Improved road smoothness.
4. Minimization of splash and spray during wet weather.
5. Minimization of wheel path rutting in open-graded layers.
6. Improved visibility of painted traffic markings.
7. Improved night visibility during wet weather (less glare).
8. Lower highway noise levels. All open-graded courses have the advantages of:
9. Material and hauling cost savings due to greater spread or yield per ton of mix.
10. Good flexibility of pavement layer.

And in the case of asphalt emulsion mixes the additional advantages of:

11. Lower construction costs.
12. Lower cost mixing plant (portable pug without aggregate driers).
13. Less air pollution from dust.

**NOTE**

The above cited requirements for minimum air voids and pore size to
allow heavy rainfall to drain through the pavement and escape are
not always deemed necessary or advisable by some authorities. In
Canada and other locations, open grades mixes are used as thick
surface courses over granular bases. Over thirty years ago much
open-graded emulsion mix was being laid in thick layers through mo-
tor pavers as a resurfacing course on existing secondary roads. In
many regions, good durable roads have been built on granular base
by the penetration macadam method using high viscosity, rapid cur-
ing emulsion. The wearing surfaces of the above cited roads were
(and are) usually sealed tight to achieve good drainage from the sur-
face. In such cases it is usually not considered necessary to con-
struct a waterproof membrane on the subbase as recommended in
**15.7.3 Preparation of Subbase** of this guide. Also it is felt that even
though these coarse mixtures are sealed, good skid resistance and
most of the other advantages cited above are retained.
15.3 Applicable Documents

15.3.1 ASTM Documents
- C131 Resistance to Degradation of Small-Size Course Aggregate by Abrasion and Impact in the Los Angeles Machine
- D244 Test Methods for Emulsified Asphalts
- D977 Specification for Emulsified Asphalt
- D2397 Specification for Cationic Emulsified Asphalt
- D3515 Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures
- D3628 Practice for Selection and Use of Emulsified Asphalts
- D4215 Specification for Cold-Mixed Cold-Laid Bituminous Paving Mixtures

15.3.2 AEMA Documents
- A Basic Asphalt Emulsion Manual (BAEM)

15.4 Asphalt Emulsion

15.4.1 Asphalt Emulsion for Open Graded Mixes
The four characteristics which are especially desired in an asphalt emulsion for open-graded mixes:

1. Coating Ability — The emulsion should have sufficient fluidity to facilitate mixing and coating the project aggregate and should have good attraction or wetting power for the aggregate surface. (It should be noted, however, that many operators report that the mix sometimes leaves the mixer with the appearance of not being adequately coated. By the time it exits from the paving machine it appears well coated apparently due to the additional handling and manipulation.)

2. Workability — without stripping from the time the mix is made until it is laid in place.

3. Resistance to Drain Off — with the emulsion designed with high enough viscosity or thixotropic characteristics to permit handling and placement without flowing off the aggregate.

4. Setting or Curing Time — which provides resistance to wash off from rain within one hour after placement and permits slow traffic within one to two hours after compaction, and normal traffic within 24 hours under average curing conditions of temperature and humidity (70° F and 50% relative humidity). Asphalt emulsions have the advantage that they are susceptible to control of the desired performance factors and can be tailor made for aggregates, seasonal conditions, etc.

15.4.2 Grades of Asphalt Emulsion
The most widely used grades of asphalt emulsion for open-graded mixes are ASTM Grades MS-2, MS-2h, CMS-2, CMS-2h, HFMS-2, and HFMS-2h. (ASTM designations D977 and D2397)
15.5 Aggregates

Aggregates shall meet the requirements for grading size and type specified. The aggregate may be from a single source or blended so as to conform to the 4.75 mm (No. 4) sieve job mix formula. That fraction passing the 4.75 mm (No. 4) sieve in the base and intermediate courses, and that fraction passing the 2.38 mm (No. 8) sieve in thin surface courses provide a stabilizing action for the coarse aggregate fraction, and also aids the retention of a thick film of asphalt on the coarse aggregate. Therefore it could be said that as much of this sand should be in the mix as can be allowed without reducing the air voids below the specified minimums mentioned below. Sharp and angular sand type material is the most effective.

The aggregate shall be crushed stone, crushed gravel, slag, or sand which meets the requirements of ASTM D3515, Table 2 or AEMA BAEM, Table VII-4. Aggregates which are known to polish should be excluded from the coarse aggregate fraction.

The coarse aggregate shall show wear by ASTM C131 of not more than 50% for base course and 40% for surface course.

The air void content after compaction shall not be less than 15% for a thin course, and 20 to 30% for a base course. Aggregates should have 75% (by weight) with two or more fractured faces and 90% with one or more fractured faces. Aggregates should preferably be surface dry.

15.6 Design

15.6.1 Mixtures

The aggregate shall be representative of the project materials and have compatibility with a grade of asphalt emulsion used for open-graded mixes. Good asphalt dispersion (coatability) is essential to achieve proper bond between aggregate particles (cohesion) and reduce the degradation of some aggregates by traffic and climatic action. In general, the asphalt emulsion content used for an OGAEM has been the maximum amount possible without producing appreciable runoff (drainage).

For the thin open-graded friction courses, empirical equations have been developed to determine an asphalt content as a basis for trial laboratory mixes. A surface constant (Kc) using a modified State of California test method is measured for the predominant aggregate size fraction (retained on No. 4 sieve) and used in an equation with a further adjustment based on the asphalt content of the emulsion to determine the percent emulsion in the mix. Besides achieving good asphalt emulsion coating, a further requirement is that the mix after compaction have an adequate void capacity to serve as lateral water drainage channels (15% or more air voids).

For the thicker layers, (intermediate or base open-graded mixes involving coarser aggregates), design procedures may include a mixing test to evaluate coating (spoon and bowl or mechanical), runoff test, and a wash off test to evaluate early rain resistance (ASTM D224). The afore-mentioned tests are conducted on trial mixes at several asphalt emulsion contents with the range based on aggregate size.
Field adjustments to the laboratory mix design asphalt emulsion content may be necessary as construction progresses to obtain good coating without significant asphalt drainage and maintain good film thickness of the binder.

15.6.2 Structural Thickness

Factors considered in selecting the OGAEM layer thickness include traffic (equivalent 18K axle loads), subgrade soil type and strength, drainage and the possible waterproofing of the subgrade, thickness, and characteristics of already existing pavement layers, and environmental factors such as curing conditions and pavement temperatures. Initial traffic is estimated along with the anticipated growth rate during the pavement design life. The subgrade strength can be measured directly by CBR, R-Value or tri-axial modulus testing (preferable), or roughly predicted from soil classification.

Most pavement thickness design methods are based on layer coefficients which have resulted from engineering judgements and experience. Layer coefficients for OGAEM have ranged from about 0.18 to 0.30 with the value selected a function of traffic, emulsion base asphalt hardness, aggregate quality, curing conditions, etc.

Improved structural design procedures and criteria are being developed through extensive field and laboratory investigations of already constructed OGAEM pavements. This has included road condition surveys, core sampling, materials characterization using new equipment such as the diametral resilient modulus device, and the application of layer theory. With some newer design approaches, two critical elastic strains are examined in determining the proper pavement thickness. They are horizontal tensile strain at the bottom of asphalt treated layer (important relative to fatigue cracking) and vertical compressive strain at the subgrade surface (considered relative to permanent deformation in the subgrade, (i.e., rutting)). With OGAEM pavements, generally, only the strain at the subgrade surface has been considered in determining the structural section.

15.7 General

15.7.1 Pre-construction Meeting

On sizeable jobs or critical test sections, a pre-construction meeting of key personnel representing the contractor, agency and material suppliers is recommended. The engineer in charge can define areas of responsibility, resolve questions, and set up working relationships for inspection, expediting, and so on.

The emulsion supplier plays an important part in mixture design and in providing technical service. The mixture design should be determined prior to this meeting. Adjustments to the starting mix are usually made to conform to field conditions.

15.7.2 Preparation of an Existing Asphalt Surface

Holes and irregularities shall be repaired with dense-graded material to produce a tight surface. All loose and foreign materials shall be removed by sweeping. If the surface remains dusty, it should be lightly moistened with water or given an asphalt emulsion tack coat. It is very important that the existing surface be impervious to water so that
rain penetrating the open-graded mix will not penetrate further but drain laterally and not collect in the base or subgrade.

15.7.3 Preparation of Subbase

For new construction, the preparation of subbase is essentially the same as for open-graded hot mix. However, for porous pavements, a waterproof membrane is recommended to prevent the rainwater from weakening the subbase. This can be done by mixing emulsion (SS or CSS grade) into the top layer of the granular, or dense-graded subbase during blading, shaping and compaction. The top layer of the subbase can be a plant mix of emulsion with dense-graded aggregate.

15.8 Mixing

Asphalt emulsion and aggregate may be mixed in place or at a central plant pugmill. The choice of method depends on such factors as:

1. Equipment availability
2. Size of project
3. Aggregate source, type, and cost
4. Anticipated traffic volumes and loads
5. Climatic conditions

The best balance between these factors must be evaluated. Regardless of the mixing method, 100% coating of the coarse aggregate particles is not always achieved, nor is it necessary.

15.8.1 Mixing Moisture

Mixing procedures should aim at achieving a uniform dispersion of the emulsion with a complete coating of the finer aggregate fractions. Toward achieving this uniform dispersion of the asphalt emulsion, it is sometimes necessary to moisten the aggregate before application of the emulsion. The appropriate volume of water to be added should be determined by the mix design, and if required should be added prior to the incorporation of the emulsion.

Mixing of the emulsion should be done at as low a moisture content as possible, because the compaction moisture content is usually lower than the moisture content after mixing. Under poor drying conditions the removal of surplus moisture could be a costly and time consuming operation.

NOTE

Excess moisture in open-graded mixes may contribute to draindown and the reduction in asphalt film thickness which is necessary for proper performance.

15.8.2 Central Plant Mix

Central Plant Mix is recommended for projects that involve close tolerances and high production. Generally, this type of mixing is done away from the road site, and fre-
quently at the source of the aggregate. Conventional batch and dryer-drum hot mix plants can also be used to produce asphalt emulsion mixes.

The central cold mix plant consists of a mixer and certain auxiliary equipment for feeding the emulsion, water, aggregate and additives to the mixer. The asphalt emulsion central mixing plant generally has no dryer or screens other than a scalping screen to remove oversize aggregate. At the very least, the plant should consist of a pugmill, an emulsion storage tank, a metering pump, units for feeding water and additives, controls for adjusting and monitoring the various components, a conveyor, and a power source, a tachometer to aid in maintaining a constant speed on the conveyor belt, and one or more aggregate bins with belt feeders.

The mixer should be of a type that permits variation in mixing times to ensure that the aggregate is properly coated but not over mixed. Mixing times can be varied in a continuous pugmill plant by changing the angle of the paddles, by varying the height of the endgate, or by changing the location of the asphalt spray bar.

Emulsion cold mixes require shorter mixing time than asphalt concrete mixes. The tendency is to overmix asphalt emulsion mixes which may remove the asphalt from the aggregate. It may also result in premature breaking of the emulsion, causing overly stiff mixtures.

The mix produced at a central plant may be stockpiled for later use. The length of storage time in stockpile is controlled by the type of asphalt emulsion incorporated into the mix.

### 15.8.3 Travel Mixers

The purpose of the travel plant is to leave uniform, properly coated, asphalt emulsion and aggregate mixture on the roadbed. Aggregates are placed into the hopper of the mixer where they are drawn into the mixing chamber. The emulsion proportioning device is interlocked to ensure a constant blend. The emulsion is added by pumping through a spray bar mounted on the mixing chamber. This method permits the addition of all the emulsion in one application. The forward speed of the mixer should be adjusted so that the material being ejected has a uniform texture. Mixing times can be varied in a traveling mixing plant by changing the angle of the paddles, by varying the height of the endgate, or by changing the location of the asphalt spray bar.

Injecting the emulsion in one application through the mixing chamber can be done at a lower moisture content than with distributor application. The single application immediately brings the aggregate to optimum mixing moisture where as the first application with a distributor adds only part of the moisture associated with the emulsion.

The travel plant places the mix on grade with proper cross-slope to the design thickness. The mix is then ready for compaction.

### 15.9 Spreading And Conditioning

Asphalt emulsion mixes gain stability as the water evaporates. It is important not to hinder this process. Therefore, lift thickness may be limited by the rate of fluid loss.
The most important factors affecting this dehydration or curing are the type of asphalt emulsion, the mix water content, the gradation and temperature of the aggregate, wind velocity, ambient temperature, and humidity.

When multiple lifts are required, some curing time must be allowed between successive lifts. The length of this curing time is a function of the rate of evaporation, and this is a variable. However, an existing lift can normally be overlaid after from 2 to 5 days under good curing conditions.

The mixture should be spread uniformly on the roadbed, beginning at the point farthest from the mixing plant. Hauling over freshly laid material should not be permitted except when required for completion of the work.

Spreading central plant mixes is most professionally done with a self-propelled asphalt paver. However, base spreaders and motor graders also obtain good results.

The mixture should always be spread to a uniform thickness. This is to eliminate the chance that thin spots may occur in the final mat and to ensure a smooth riding surface.

Successful placement of cold laid plant mixes require the presence of sufficient fluids. Dry mixes tend to tear beneath the screen or strike-off bar. If the mixture is too dry, the mix water content should be increased. When a self-propelled paver is used, heating the screed in attempts to eliminate this tearing does not help. It actually makes the mix less workable, since it serves to accelerate the drying process. Because of these variables, local experience is likely to be the best guide in determining allowable placement thickness.

15.10 Compaction

Fat or lean spots behind the paver should be removed and replaced with good mix before rolling. Rolling should be delayed until the mixture is able to support the roller without excessive shoving. Avoid excessive finish rolling as often a single pass is sufficient.

Frequently it is necessary to apply a choke or blotter course of fine aggregate to the fresh mat. This can be accomplished through use of a sand spinner or any conventional chip spreader at the rate of 3.3 to 6.6 kg/m² (5.4 to 10 lb/yd²). This serves to reduce early traffic damage and can be accomplished either before or just following the initial roller pass.

15.11 Traffic Control

If possible, traffic should not be allowed on the mix until it will support vehicles without undue displacement. When it is not possible to close the road completely, vehicles should be controlled to minimum speeds, without acceleration, deceleration, or sudden braking. Traffic should be directed through the project with such signs, barricades, devices, flagman, and pilot vehicles as maybe necessary for absolute control.
15.12 Precautions

- Construction should begin only if the ambient temperature is 10° C (50° F) and rising. Dry weather is necessary to achieve good adhesion to the existing asphalt surface and a reasonably good set time. Construction should not begin when rain is expected or be continued after rain commences.
- Equipment should be properly maintained.
- When the mat is tender and the surface sticky in the early curing stage, it is usually remedied by spreading 3.3 to 5.4 kg/m² (6 to 10 lb/yd²) of choke or blotter stone immediately after the mix is laid or after the first pass with the roller.
- It is recommended that before attempting to lay open-graded friction courses with emulsion, the counsel of an experienced engineer or operator in this field should be obtained who can show examples of good finished work and perhaps show work in progress.
- Aggregates should not change in physical or chemical characteristics during the construction period.
- Emulsion properties should be consistent throughout the construction period to insure maximum coating, adhesion, and to minimize stripping.
- Do not mix anionic and cationic emulsions together.