OPEN GRADED EMULSION MIXES FOR USE AS ROAD SURFACES

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This paper describes the development of structural layer coefficients for open graded asphalt emulsion surfacing layers which can be used with the AASHTO pavement design method, as modified by the U. S. Forest Service, Region 6. A field survey conducted to document the history, performance and material characteristics of in-service pavements is described and this information, together with a survey of experienced users, is used to determine the most important factors affecting the design thickness for the pavements. Traffic, base type, temperature and drainage design all are important to determine the pavement thickness. Two procedures used for the development of structural layer coefficients are described. The first procedure uses the information from the performance survey and the AASHTO pavement design method to determine appropriate layer coefficients for three in-service roads. The second procedure is a fundamental approach based on layered elastic theory and using information from the field survey. This procedure is useful for the analysis of the pavement in the fully cured or partially cured state. Although a conservative approach was used for both procedures, the developed layer coefficients are greater than the values used in the current design procedure. This indicates that modification of the current values is appropriate. A tabled presentation of layer coefficients is proposed which considers only those factors found to be important for the determination of design thickness.

Open graded asphalt emulsion mixes (OGAEM) are mixtures of open graded aggregates and emulsified asphalt. An open graded aggregate is an aggregate with a low percentage of fine particles. An OGAEM is characterized by high void contents on the order of 20 to 30 percent, and typically less than 10 percent of the aggregate material passes through a No. 10 screen (1). Three typical gradation specifications used in the Pacific Northwest for OGAEM are presented in Table 1, along with a U. S. Forest Service gradation specification for a dense graded asphalt mix.

Pavements constructed with OGAEM are cold-mixed and cold-laid with conventional paving equipment. Using OGAEM with conventional equipment generally results in less pollution and lower construction costs. Construction costs are reduced because of the elimination of the operations of heating and drying the aggregate, aggregate screening and maintaining the asphalt temperature. Eliminating the aggregate dryer eliminates both a primary source of air pollution and a fire hazard and results in an energy savings by reducing fuel costs. Using damp aggregates with lower percentages of fine particles reduces the nuisance of dust (1). Asphalt emulsions are less polluting and less hazardous than solvent solutions of asphalt.

An OGAEM project constructed by the Douglas County Road Department of the State of Oregon in 1966 was one of the first projects in the Pacific Northwest. The success of this project and others prompted the U.S. Forest Service Region 6 to construct an OGAEM project in the Ochoco National Forest. Since this time, the U.S. Forest Service has become one of the largest users of OGAEM materials.

In recent years, however, the U.S. Forest Service has not been entirely satisfied with the performance of OGAEM pavements (2). As a result of apparent problems, the U.S. Forest Service, Region 6, contracted with Oregon State University to develop an improved procedure for designing pavements using OGAEM materials through proper selection of layer coefficients (a-values). The U.S. Forest Service currently uses a modified AASHTO design procedure (3). The factors considered in the determination of the structural layer coefficients for OGAEM include traffic, asphalt type, aggregate plasticity index, aggregate quality and to a limited extent "curing conditions, traffic control, compaction requirements, stockpile or aggregate uniformity requirements, etc." (3). The U.S. Forest Service recognized the limitations of the current design procedure for OGAEM materials and wished to develop a procedure to establish layer coefficients which gives consideration to laboratory stiffness tests of these materials. This report is a description of recent efforts to develop improved layer coefficients. The purpose of the report is to describe the development of a method of establishing layer coefficients, which considers laboratory test results and those factors which affect the thickness design of OGAEM pavements.

Performance of Open Graded Cold Mixes

At the time the project was initiated, there was considerable confusion as to whether or not OGAEM were performing in an acceptable manner. Some engineers indicated all cold mix jobs were 'falling apart while others indicated they provided acceptable, if not excellent, performance. Further, no clear-cut evidence was available as to which factors most affect the performance of these type mixes. To clarify this confusion, extensive field and questionnaire surveys were conducted.

Field Performance Survey

Fourteen projects throughout Oregon and Washington were selected for survey. They included variations in geographic region, traffic, climate, and responsible agency. Because the primary purpose of this survey was to observe different types of distress and to provide information for development of layer coefficients, random sampling techniques were not considered necessary. For each project ride quality, pavement condition and drainage conditions were rated. A standard survey form was developed to assure complete collection of the data and facilitate the compilation.

Each project was driven at normal speeds in a passenger car. Each evaluator independently rated the riding quality and overall evaluation (ranging from very poor to very good). Roughness or patching due to slope failures was not considered in the evaluation process. For each project the following pavement conditions were rated: percent cracking (alligator and longitudinal), depth and amount of rutting, degree of ravelling (presence of potholes would be severe), percent maintenance patch, percent surface seal retained, surface texture, drainage conditions, and amount of asphalt observed by visual inspection.

The actual thickness of emulsion mix was measured at each stop. A rut-depth meter was used to determine the depth of rutting. Where possible, the types and causes of distress, as well as the reasons for no distress, were documented. A summary of selected data from the survey is given in Table 2. The ride quality ratings of the surveyed pavements ranged from 4.2 to 9.2 with an average value of approximately 7.6 (scale of 0 to 10 where 10 is excellent). The average overall rating averaged approximately 7.9 out of 10.

The types of distress observed in the open graded mixes included distortion in the form of rutting, alligator cracking, ravelling, and poor ride quality. Rutting was observed up to depths of 1.3 cm (1/2 in.) with an average value of 1 cm (3/8 in.). The only section which exhibited considerable cracking was a thin 5 cm (2 in.) section. Other projects exhibited only small amounts of local cracking which could often be attributed to drainage problems. Ravelling of the surface treatment was observed on several of the projects. The poor ride quality observed for some projects was attributed to built-in roughness, or cracking caused by thin sections or drainage problems.

For each project surveyed, construction information, traffic data, materials type and materials properties were also obtained. The average age of the projects surveyed was five years and the most recently constructed project surveyed was two years old. There has been mention of projects constructed in Region 6 which have apparently failed in less time. None of these jobs were included in this survey.

Ten cm (4 in.) diameter cores of the OGAEM were obtained at all project sites in order to determine the resilient modulus, gradation, and residual asphalt content and properties (4). The resilient modulus tests were conducted using a diametral repeated load test system (5). The results of the tests indicate the average modulus to be on the order of 1380 to 2760 MPa (200,000 to 400,000 psi).

Based on the variable performance observed in the field survey, it was concluded that several factors other than traffic affect the performance of open graded emulsion mixes. These factors include environment, quality control, subgrade and base type, and drainage. Weather or climate have the greatest effect on emulsion mixes during the curing stage of the mix. Curing studies (6) conducted at Oregon State University and reported in the literature have shown that cooler temperatures tend to retard curing. However, the temperature dependency of the open graded emulsion mixes results in high modulus values at cool temperatures (6). This fact may account for the observed success of the roads constructed in cooler climates. Rain falling on an unbroken mix also can cause problems by washing the emulsion out of the mix (2). This is typically only a problem if a heavy rainfall occurs during the laydown process or before the emulsion breaks.

The need for improved quality control was observed on several of the projects. Non-compliance to specifications was observed for thickness, aggregate gradation and emulsion content. The open graded jobs are usually subject to less quality control than a typical hot mix job.

Materials varied for the projects surveyed. Cleanliness of the aggregate was the most noticeable difference, with the cleaner aggregates exhibiting better coating. Variations between design and extracted emulsion contents were as much as 2 1/2 percent, indicating the level of quality control experienced with these types of projects. The effect of emulsion type was not treated in this study. All were manufactured by Chevron U.S.A. and all were either CMS-2 or CMS-2h.

Subgrade and base type also appear to greatly influence the performance of open graded emulsion mixes. Both Lewis River and Merrill Lake (Section 1) roads have been subjected to considerable traffic; however, both projects show very little distress. This could be attributed to the very good subgrade and base layers (average R values of 64 for Lewis River and 69 for Section 1 of Merrill Lake) that were observed by the rating party (4).

Distress was also observed wherever drainage problems (standing water or springs) existed. Thus it is apparent that removal of water from beneath the pavement is a necessary part of design for open graded emulsion mixes, just as it is with the design of conventional hot mixes.

The survey was not of sufficient size to rank the importance of the factors which affect performance. This was accomplished by interviews with experienced users of OGAEM materials.

Factors Affecting Performance

To assess the relative importance of the factors which apparently affect performance of OGAEM materials, a questionnaire was distributed to experienced users to rank the importance of the factors affecting performance and to evaluate how the various factors might be accounted for through pavement design.

The literature review and field survey yielded twenty-four factors which apparently affected performance. These factors were listed in two questionnaire forms and sent to user agencies, contractors and researchers to rank the relative significance of each factor and to indicate how these factors could be accommodated through improved design.

The initial questionnaire resulted in twenty-three factors verified as affecting performance. The factors found to affect open graded emulsion mixes more than hot mix include seal coat application, curing temperatures, rainfall during curing, and humidity. Free draining characteristics and ravelling problems of open graded mixes generally require a seal coat to be used. The latter three factors listed are environmental factors which demonstrate the different nature of the two materials. Hot mixes "set" upon cooling, whereas emulsion mixes cure with time.

The mixer performance is also more important for a hot mix material than an emulsion mix, because a portion of the mixing of the emulsion mix actually occurs during the laydown operations. This does not occur to the same extent for hot mixes, so mixer performance is of greater importance. A point stressed by several contractors and user agencies is the importance of aggregate gradation. A "dirty" aggregate with a high fines content has a larger surface area. This can cause problems with coating or premature breaking. The need for additional quality control of both materials and construction procedure factors was expressed by a majority of the respondents.

The results of the follow-up questionnaire demonstrate the necessity of good quality control and specifications for open graded emulsion mixes. Table 3 summarizes the areas in which improvements might be required if an unfavorable condition is encountered. Nearly every factor which affects performance is subject to improvement by quality control or specifications. The factors that could require design thickness modifications include the amount and type of traffic loads, curing temperatures, base type, and drainage design. These factors are not subject to quality control to the same extent as other factors. The designer should be able to predict these factors; thus these factors can and should be considered in a thickness design procedure.

The design thickness of a pavement layer is dependent on the number of load repetitions, the strength of the pavement material, and the strength of the pavement support. The expected amount and type of traffic can be converted to equivalent axle loads (4) to represent the number of load repetitions. The strength of an emulsion mix paving material is a function of temperature and degree of curing (6). The climate of a road location can be used by the designer to estimate the temperature effects on curing and modulus. The strength of the pavement support is related directly to the type of base material. Subgrade and base materials are usually weakened by the presence of water, so drainage provisions are an important consideration when the base strength is estimated.

Development of Improved Layer Coefficients For OGAEM

Two techniques were employed in the development of improved layer coefficients for use by the Forest Service. The first method is based on observations of in-service roads and use of the AASHTO procedure (Chapter 50) to estimate layer coefficients (3). This method is particularly useful for the estimation of minimum values for layer coefficients. The second method of layer coefficient development is based on layered elastic theory and improved laboratory characterization of materials to calculate layer thicknesses to preclude fatigue and rutting (4). These thicknesses are compared with those for dense graded asphalt concrete to establish layer equivalency factors and using these factors, layer coefficients are developed.

In-Service Roads

To evaluate the layer coefficients of OGAEM materials, three projects evaluated during the performance survey were selected for further analysis: Merrill Lake Road and Lewis River Road in the Gifford Pinchot National Forest, and Burns-Izee Road in the Ochoco National Forest.

In each project test pits were excavated for collection of layer samples, measurements of in-place densities and moisture contents, and observations of the pavement condition. Measurements of densities and moisture contents were made using nuclear testing equipment.

The material samples from all projects were analyzed to determine gradation and stabilometer resistance values (R values). CBR values were also measured for the subgrade samples obtained from the Gifford Pinchot National Forest. The resilient modulus values for the surface OGAEM materials were measured (using a diametral testing device) as part of the performance survey. The resilient modulus values for the other material layers were measured using conventional triaxial testing procedures (8).

This materials information is used along with the Forest Service thickness design procedure (Chapter 50) to estimate the layer coefficient of each surfacing layer. This procedure is useful for bracketing the design layer coefficient values. When a pavement in good condition is analyzed, the layer coefficient value determined will be less than the design value because the pavement system will support additional traffic before failure occurs. Any additional traffic will result in an increase in the weighted structural number of the pavement and a subsequent increase in the layer coefficient. In the case of a failed pavement, the determined value of the layer coefficient will exceed the appropriate design coefficient. The value determined in this case is the layer coefficient that would result if the pavement system had survived. The analysis has been conducted for the nine test pits excavated in the three selected roads. Using the measured thicknesses, the estimate of traffic, a regional factor of 2.0, and the soil support values, it was possible to determine an "a-value" for each surfacing layer.

Table 4 lists the values used for the determination of the layer coefficients of the OGAEM surfacing layers and the results. For Lewis River Road an a-value greater than 0.25 would be appropriate. An a-value between 0.33 and 0.60 is bracketed by Merrill Lake Road. The Burns-Izee Road analysis resulted in a minimum a-value of 0.39. Each of the minimum values is larger than the most optimistic value that could be derived using the current method in Chapter 50 (3).

The method used to back calculate the a-values of in-service roads is subject to errors from testing, correlations and traffic determinations. However, a conservative approach has been used so that the determined a-values are minimum values. The sample size of this investigation is not large enough for a precise determination of the range of a-values. This method is being applied to additional roads in order to refine the results. Projects approaching the point of failure are particularly useful for the method. Excavating more pits per project would reduce errors caused by materials variability and thus improve results. Accurate traffic estimates are important for this method. If the traffic history of a project is unknown, the project is not suitable for analysis.

Layered System Elastic Theory

The second approach used to develop layer coefficients is based on the concept of providing sufficient thickness to limit strain. Typically the strain limitations used are the horizontal tensile strain at the bottom of the surface layer (related to fatigue) and the vertical compressive strain at the top of the subgrade layer (related to rutting). The strains at these two points can be determined using layered system analysis techniques and laboratory test results of materials strength characteristics.

Fatigue cracking and permanent deformation in the form of rutting are the failure modes which are typically considered for this design approach (8,9). Criteria for these two modes of failure were developed as a part of this project (8). Based on the field analysis, it was determined that the failure criteria presented in Figures 1 and 2 are reasonable for OGAEM. These relationships were originally developed by Chevron, U.S.A. for dense graded emulsion mixes but seem applicable for the open graded mixes, too (8).

Layer coefficients are determined using the concept of layer equivalencies. For equivalent conditions the design thickness of hot mix and OGAEM materials are determined. The ratio of design thickness is used along with the known layer coefficient for hot mix asphalt concrete (Chapter 50), to determine the layer coefficient of the OGAEM material, i.e.

$$a_{OGAEM} = \frac{d_{Hot\ Mix}}{d_{OGAEM}} (a_{Hot\ Mix}) \quad (1)$$

where: a = layer coefficient
d = design thickness.

The method of design thickness determination using fatigue criteria is illustrated in Figures 3 and 4. The critical horizontal tensile strains based on fatigue criteria models are determined for both materials (Figure 3). The design thicknesses which limit the strains to the appropriate critical values are then determined (Figure 4). Determination of design thickness using subgrade strain criteria is similar with the exception that an identical subgrade failure criteria model is used for both types of mixes.

The layer equivalency determinations assume resilient modulus values of 2760 MPa (400,000 psi) for hot mix and 1380 MPa (200,000 psi) for OGAEM. (4). For this study three different subgrades were analyzed. The assumed modulus values of the "good", "fair" and "poor" subgrades were 205 MPa (30,000 psi), 70 MPa (10,000 psi), and 20 MPa (3,000 psi). The base modulus has been assigned modulus values equal to 1.5 times the modulus of the subgrade. A 30.5 cm (12 in.) base layer is assumed for each case and an additional case of a 60 cm (24 in.) base layer is analyzed for the "poor" subgrade.

For a given design life, design thicknesses for hot mix and OGAEM materials were determined for each subgrade condition using the fatigue criteria (Figure 1) and the appropriate strain vs. thickness relationships. The average value of the thickness ratios is 1.27, with the values ranging from 1.23 to 1.29.

Thickness ratios have also been determined for both types of mixes using the subgrade failure criteria (Figure 2). The average value of the thickness ratios is 1.22, and the values vary between 1.21 and 1.25.

The thickness ratios tend to vary slightly for the different subgrade and base strengths, with slightly lower ratios determined for the better subgrades. The variation is minimal and consideration of this factor will not be included in this portion of the development. The maximum ratio values are the controlling values considered for the development. The thickness ratios represent layer equivalencies where the ratio value times a given thickness of hot mix asphalt concrete determines an equivalent thickness of an OGAEM layer. The fatigue criteria ratio determinations result in the larger average ratio value of 1.27. The layer coefficients for hot mix materials given in Table 5 are modified using this ratio, i.e.

$$a_{OGAEM} = \frac{a_{Hot\ Mix}}{1.27} \quad (2)$$

to obtain the values shown for OGAEM, also listed in Table 5.

A comparison of these values with the values bracketed by the in-service roads shows good agreement. The layer coefficient bracketed by the Merrill Lake test pits is between 0.33 and 0.60. The layer coefficient determined using the layer equivalency concept is 0.31. The appropriate layer coefficient for Lewis River Road would be 0.25 and the in-service road analysis determined 0.25 to be a minimum layer coefficient. For Burns-Izee test pit number two, the minimum layer coefficient of 0.39 is considerably higher than the layer coefficient of 0.28 as developed using the equivalency concept. The Burns-Izee test pit number one minimum layer coefficient of 0.28 is a more reasonable value and corresponds well with the layer coefficient determined using the equivalency concept.

It is important to realize how the assumed modulus of the OGAEM surfacing layer affects the layer equivalency values for hot mix as determined using this procedure. The values presented in Table 5 assume a modulus value of 1380 MPa (200,000 psi) for the OGAEM and 2760 MPa (400,000 psi) for hot mix asphalt concrete. The OGAEM moduli correspond to the average moduli measured for the cores from the three roads used for the in-service road development of layer coefficients. Table 6 demonstrates the variation of the average layer equivalency value as the OGAEM modulus is varied between 690 and 2760 MPa (100,000 and 400,000 psi). The table shows that the layer equivalencies decrease as the modulus increases. Thus if a laboratory investigation indicates that the modulus of the OGAEM is expected to be relatively high, then a larger design layer coefficient closer to that of hot mix is appropriate.

The approach used to develop the layer coefficients is conservative because conservative failure criteria have been used, and a conservative value has been assumed for the modulus of the OGAEM. Despite this, the layer equivalencies are somewhat less than those currently used by the U.S. Forest Service, Region 6, as shown in Table 7. When comparing these values with what other agencies in the Pacific Northwest are using, one cannot directly compare hot mix layer equivalencies. This is because the a-values used for hot mix are considerably different, the Forest Service using a-values ranging from 0.30 - 0.42 and the other agencies using 0.28. Cold mixes must therefore be compared directly by a-values or by using a base layer equivalency. If we compare a-values, we find the high side of the Forest Service values approximately the same as the other agencies, values of 0.24 - 0.30 vs. 0.25 - 0.28. The Forest Service discounts these values for marginal quality aggregate, soft asphalt, and poor quality control. The design a-value can be as low as 0.18.

Early Cure Considerations

The criteria given are also useful for checking the adequacy of a design thickness before a pavement is fully cured. An estimation of the traffic expected during the early cure period (normally 3 months or less) is used to determine the allowable strain values from the failure criteria. The actual strain values during the early cure period are determined using layered theory for the design thickness and an appropriate early cure modulus. This strain value is checked to assure that it is less than the allowable strain. In the situation where the strains are greater than the allowable strains, the designer can increase the design thickness or require limitations of traffic during the early cure period. For details on the procedure for calculating additional thickness refer to references 4 and 7.

Conclusions and Recommendations

Conclusions

Thickness Design. OGAEM pavements have been used successfully in the Pacific Northwest by several agencies. The U.S. Forest Service has experienced success with OGAEM pavements used for light, medium and heavy traffic volumes in various climatic regions. The current Forest Service design procedure is based on the AASHTO design procedure which uses structural layer coefficients as a measure of the capabilities of materials in a pavement system. The factors considered in the determination of a layer coefficient principally include traffic, asphalt type, aggregate plasticity index, aggregate quality, and to a limited extent "curing conditions, traffic control, compaction requirements, stockpile or aggregate uniformity requirements, etc." (3).

This study has determined that the factors which affect design thickness include the amount and type of traffic, curing temperatures, base type, and drainage design. The other factors considered by the Forest Service such as asphalt type, aggregate quality, traffic control, compaction requirements, etc. apparently have relatively less effect on design thickness. These factors are important. However, they are more appropriately considered in the specifications for OGAEM materials and subjected to quality control.

A proposed table for the layer coefficient determinations considering these factors is given in Table 8. The layer coefficients presented in the table are estimates based on the layer equivalency development (Table 6). Extrapolation to other temperature conditions is not given at this time, but should be considered as a future study. If the majority of the traffic is seasonal, an appropriate temperature is the average temperature for the period of use. The surfacing structural number (SN_B) is the design input used to represent the base strength (good, fair, poor). A SN_B of 1.0 would represent the situation where one has a good subgrade while an SN_B of 3.0 would represent a poor subgrade.

The layer coefficients presented in Table 8 are best estimates based on data presented in Tables 5 6. Further in-service road testing is necessary to establish these coefficients for modular values outside the range of 1380 to 2070 MPa (200,000 to 300,000 psi). The in-service road investigations can also be used to define the failure criteria models. If the failure criteria are adequately defined, the missing values in the table can be filled in, and an early cure layer coefficient table similar to Table 8 could then be developed. This table would permit the determination of the thickness requirements of uncured mixes for the traffic expected during the early life of the pavement. The development of this table has been described in the preceding section.

A minimum thickness of OGAEM material is apparently required because of construction variability. The minimum recommended thickness over a good base, based on the performance survey, is 6.35 cm (2.5 in.) It should be emphasized that this applies to situations where there is a good quality base (R = 78, CBR = 80+). If the base material is of lower quality a greater minimum thickness would be necessary.

Specifications. The majority of the factors which affect the performance of OGAEM materials must be controlled with adequate specifications and quality control. The current Forest Service and other agency specifications all cover the factors affecting OGAEM performance as determined by the survey. Only minor variations in the specifications for the various agencies are noted. The performance survey did document non-compliance with specifications for items such as aggregate gradation, emulsion content, and layer thickness. It is therefore apparent that good quality control is not always practiced for the OGAEM material. Improvements in this area would result in more uniform projects which should improve performance.

Recommendations

Recommendations are listed throughout this report. In summary, these recommendations include the following:

1. Modify the existing layer coefficients used for OGAEM materials by the U.S. Forest Service to larger values. The in-service road analysis and the theoretical layer equivalency development, both demonstrate that the current values used are low.
2. Replace existing procedures for layer coefficients with a table similar to Table 8 in which only those factors which most affect thickness design are considered in the layer coefficient determination. Factors which affect the performance of OGAEM materials that can be controlled with specifications should be subject to quality control rather than thickness design considerations.
3. Improve quality control of OGAEM projects to assure more uniform results on the projects. Education of the project inspectors is appropriate to explain the different nature of asphalt emulsions as compared to other asphalts.
4. Continue in-service road analysis to develop layer coefficient values and refine the failure criteria models. Only those projects for which accurate traffic histories can be obtained should be analyzed. Roads for which the terminal serviceability index is approaching 2.0 (failure) are the most useful roads because the coefficients determined will be close to the design layer coefficients.
5. Analyze projects after construction to determine the materials variability experienced and the deviation from the expected results. This information is useful to the designer for comparison of the lab test results with the results obtained in the field, and to the construction supervisor for determining if changes in quality control procedures or specifications are appropriate. The establishment of materials variability will involve sampling several sections within a project. This procedure is also useful for definition of the stiffness development relationship for field conditions if the sampling is also done at time intervals.
6. Improve construction records to better document the history of each project. A documentation process accessible to the designers would allow

analysis of new processes and materials.

7. Improve traffic information collection to benefit the road system managers and the designers. Knowing the traffic history allows the road manager to predict the remaining service of a project and allows the designer to improve the design process.

8. Periodically inventory the pavement system for roadway management and for pavement design. The inventory would allow the history of project performances to be recorded, thus providing the information required to evaluate construction procedures or materials. A standardized inventory process should be developed to measure such things as ride quality, surface deflections, and distress. This information would not only be useful to the designer but also be useful in the development of maintenance management systems for the Forest Service.

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Table 1. Typical gradation specifications for open graded mixes.

Sieve Size	Percent Passing			
	USFS (Open)	Douglas County (Open)	FHWA (Open)	USFS (Dense)
25 mm	100	100	100	100
12 mm	45 - 70	-	-	60 - 85
9 mm	-	55 - 75	-	-
4.7 mm	0 - 20	25 - 45	-	35 - 60
2.0 mm	0 - 6	0 - 7	0 - 7	20 - 40
0.42 mm	-	-	-	8 - 22
0.074 mm	0 - 2	-	0 - 2	2 - 8

Note: 1 inch = 254 mm

Table 2. Summary of Riding Quality and Overall Rating of Projects Surveyed

Project	Ride Quality	Overall Evaluation
Lewis River #1	7.6	9.0
Lewis River #2	6.8	8.6
Canyon Creek #1	6.6	6.3
Canyon Creek #2	4.6	3.8
Merrill Lake #1	7.5	7.9
Merrill Lake #2	4.2	3.9
Ringo Butte	9.0	8.7
Hermiston	7.9	9.2
Charlois	7.9	9.1
Tipton	8.5	8.3
Burns Izee #1	8.9	8.0
Burns Izee #2	8.9	9.0
Silvies Van	9.2	8.5
Logan Valley	8.2	8.1
Smith River	8.0	8.5
Cow Creek	9.1	9.0
Indian Caves	6.4	8.2
Umpqua Community College	8.2	8.9
AVERAGE	7.6	7.9

Table 3. Improvement areas for the ranked factors which affect performance of OGAEM materials.

Rank	Factor	Method of Treatment			
		Quality Control	Mix Design	Pavement Design	Specifi-cations
1	Emulsion Grade and Type	X	X		X
2	Aggregate Gradation	X			X
3	Emulsion Content	X	X		X
4	Drainage Design			X	X
5	Emulsion Content Compliance	X			
6	Aggregate Gradation Compliance	X			
7	Curing Temperatures			X	X
8	Aggregate Water Content at Mixing	X	X		
9	Rainfall During Curing	X			X
10	Compaction	X			X
11	Base Type			X	X
12	Aggregate Quality	X			X
13	Thickness Compliance	X			X
14	Aggregate Uniformity	X			X
15	Amount of Traffic			X	
16	Seal Coat Application	X			X
17	Humidity During Curing				
18	Oversized Vehicle Loads			X	
19	Stockpiling Methods	X			X
20	Traffic Control	X			X
21	Mixer Performance	X			X
22	Lift Thickness	X			X
23	Laydown Machine	X			X

Table 4. Determination of layer coefficients of OGAEM surfacing layers from in-service roads.

	Lewis River		Burns Izee		Merrill Lake				
	1	2	1	2	1	2	3	4	5
TRAFFIC HISTORY									
Applied 80 KN EAL	2,910,000	2,700,000	215,000	215,000	24,000	24,000	24,000	24,000	24,000
SURFACING (OGAEM)									
Thickness (cm)	20[a]	23[b]	17	11	4	5	10	10	13
Res. Modulus (MPa)	496	1800	1620	2379	1393	1393	1393	1393	1393
BASE[c]									
Thickness (cm)	-	43	13	20	27	42	48	35	46
R Value	-	60	68	75	76	65	77	55	55
Layer Coef., a_2[d]	-	0.04	0.055	0.085	0.09	0.05	0.10	0.03	0.03
Soil Support[d]	-	6.5	6.9	7.8	8.0	6.8	8.2	6.3	6.3
Weighted Structural No.[e]	-	3.1	1.9	1.7	1.0	1.2	0.9	1.3	1.3
SUBGRADE									
R Value	76	60	71	19	72	60	46	51	68
Soil Support[d]	8.0	6.5	7.2	5.4	7.4	6.5	6.1	6.2	6.9
Weighted Structural No.	2.6	3.1	1.8	2.4	1.1	1.3	1.4	1.4	1.2
Req. Structural No. of Surface	2.0	1.6	1.9	1.7	1.0	1.2	0.9	1.3	1.3
Min. Layer Coef. of Surfacing	0.25	0.18	0.28	0.39	0.67	0.60	0.23	0.33	0.26
Performance	Good	Good	Good	Excellent	Failed	Failed	Excellent	Cracking	Excellent

[a] Supported by 10 cm Pulvermix layer, M_R = 1169 MPa, a_2 = 15
[b] Supported by 8 cm Pulvermix layer, M_R = 6860 Mpa, a_2 = 0.50
[c] Base and Subbase Combined
[d] Determined using R-Value Test Result
[e] Assumed regional factor of 2.0
Note: 1 in = 2.54 cm, 1 psi = 8.895 kPa
1 K = 4.448 KN

Table 5. Layer equivalency development of OGAEM layer coefficients.

Total 80 KN Equivalent Axles	Hot Mix Layer Coefficient[a]	OGAEM Layer Coefficient[b]
Less than 10,000	0.42	0.33
10,000 - 60,000	0.40	0.31
60,000 - 120,000	0.38	0.30
120,000 - 350,000	0.36	0.28
350,000 - 1,000,000	0.34	0.27
1,000,000 - 3,000,000	0.32	0.25
More than 3,000,000	0.30	0.24

Note: 1 K = 4.448 KN

[a] After reference 3
[b] Hot mix layer coefficient divided by 1.27

Table 6. Layer equivalency[a] variations with variation in the assumed modulus of the OGAEM layer (4).

(a) Average layer equivalency determined using the fatigue criteria model.

Subgrade Type	OGAEM Modulus, MPa			
	690	1380	2020	2760
Good	1.33	1.23	1.11	1.00
Fair	1.60	1.28	1.09	1.00
Poor	1.68	1.27	1.08	1.00
Poor, with thick base	1.77	1.28	1.12	1.00

(b) Average layer equivalency determined using the rutting criteria model.

Subgrade Type	OGAEM Modulus, MPa			
	690	1380	2020	2760
Good	1.44	1.21	1.09	1.00
Fair	1.48	1.22	1.08	1.00
Poor	1.56	1.25	1.10	1.00
Poor, with thick base	1.50	1.23	1.09	1.00

Note: 1 psi = 6.895×10^{-3} MPa

[a] Layer Equivalency =

$$\frac{\text{Design Thickness of OGAEM}}{\text{Design Thickness of Hot Mix Asphalt Concrete}}$$

Table 7. Comparison of layer coefficients between cold mix and hot mix (4)

(a) U.S. Forest Service

80 KN Axles	Cold Mix	Hot Mix	Hot Mix Equivalency	Base Layer Equivalency
< 10,000	.24 - .30	.42	1.40-1.75	1.72-2.16
10-60,000	.22 - .28	.40	1.43-1.82	1.57-2.00
60-120,000	.20 - .26	.38	1.46-1.90	1.43-1.86
120-350,000	.18 - .24	.36	1.50-2.00	1.29-1.72

(b) Other agencies

Agency	Cold Mix	Hot Mix	Hot Mix Equivalency	Base Layer Equivalency
Oregon DOT (34)	0.25	0.28	1.0 - 1.1	1.8
Washington Highway Department (38)	0.25	0.28	1.1	1.8
FHWA Office of Federal Projects (36)	0.28	0.28	1.0	2.0

Table 8. Proposed layer coefficient table for open graded emulsion mixes, at average annual temperatures of 5 - 13° C.

Surfacing Structural Number (SN_B)		1 (good subgrade)	2 (fair subgrade)	3 (poor subgrade)
Traffic 80 KN EAL	Ultimate Resilient Modulus MPa @ 23°C	Layer Coefficients		
10^4	690	0.29	0.26	0.25
	1380	0.34	0.33	0.33
	2070	0.38	0.38	0.38
10^5	690	0.26	0.24	0.23
	1380	0.31	0.30	0.30
	2070	0.34	0.35	0.35
10^6	690	0.22	0.20	0.19
	1380	0.26	0.25	0.25
	2070	0.29	0.29	0.29

Note: 1°F = 1.8°C + 32
1 Kip = 4.448 KN
1 psi = 6.895×10^{-3} MPa

Figure 1. Fatigue criteria for emulsion mixes (4)

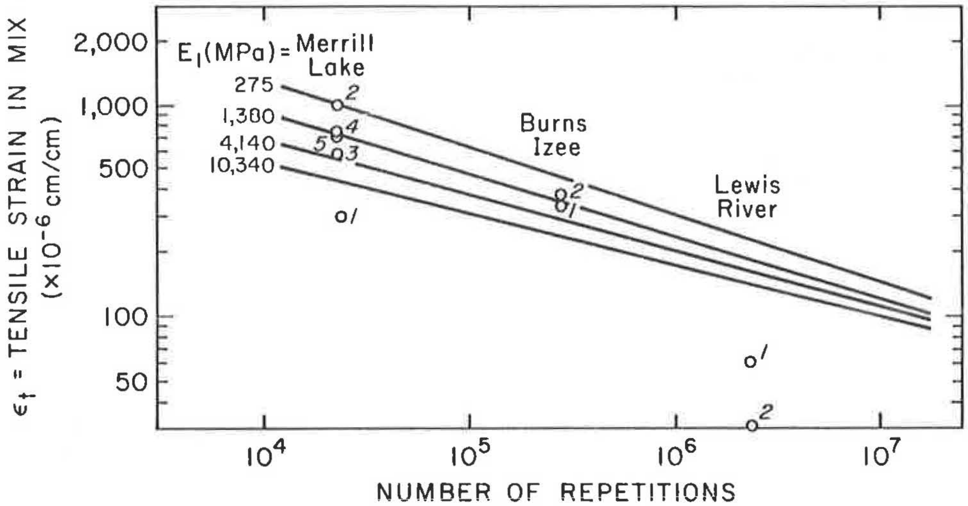

Figure 2. Subgrade strain criteria (4)

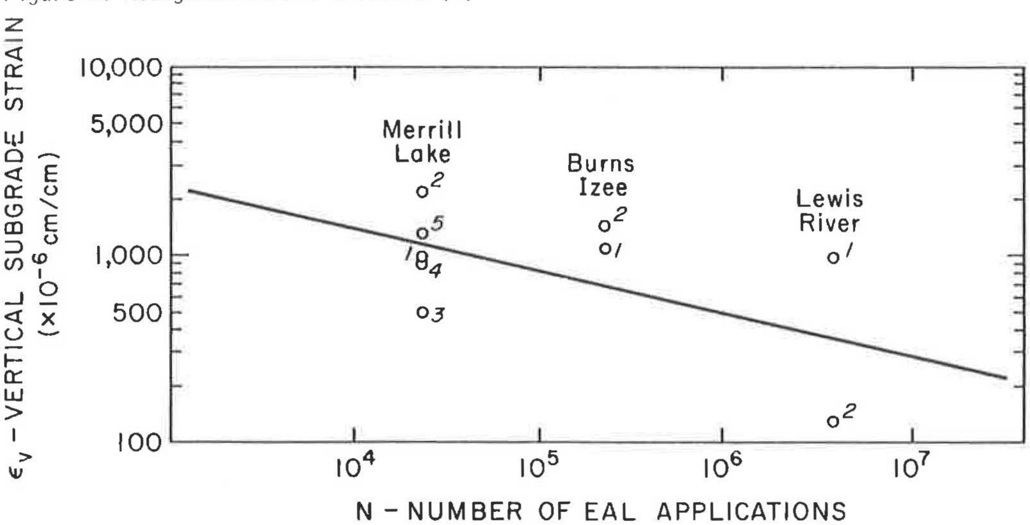

Figure 3. Determination of critical strain level based on design life

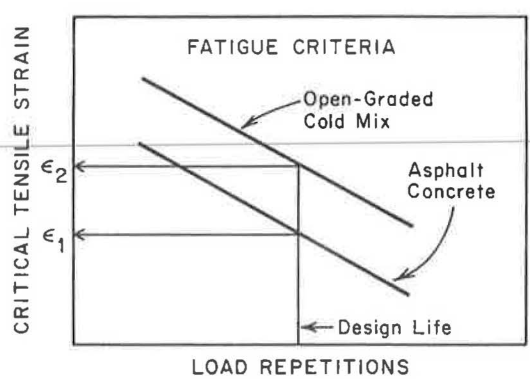

Figure 4. Determination of design thickness based on critical strain level