Open-Graded Emulsion Mixtures: 25 Years of Experience

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Open-graded emulsion mixtures (OGEM) have been used extensively as road surfaces for low-volume roads in the Pacific Northwest since 1966. They consist of open-graded aggregate (20 × 6 mm) and 5 to 7 percent of a cationic mixing graded emulsion (CMS-2 or CMS-2h). This paper presents the results of several agency experiences indicating that OGEM usually performs as well as or better than conventional dense-graded asphalt concrete in most applications. It also includes mixture properties (modulus, changes in gradation with time, etc.) to illustrate that conventional test procedures are not appropriate for evaluating this product and layer equivalencies that have evolved during this period, as well as guidelines for use of OGEM. Well over 16 000 km (10,000 mi) of roads has been surfaced with OGEM during this period.

Open-graded emulsion mixtures (OGEM) have been used extensively in the Pacific Northwest since 1966 (*1*). Aggregates used for OGEM generally pass the 25-mm (1-in.) sieve, with 0 to 10 percent passing the 2-mm (No. 10) and 0 to 2 percent passing the 0.074-mm (No. 200) sieves. The emulsified asphalts normally used have been CMS-2 or CMS-2h. Well over 16 000 km (10,000 mi) of two-lane roads has been constructed using an open-graded aggregate with CMS-2 or CMS-2h emulsions. The first performance survey of OGEM was conducted in 1976 and evaluated several projects throughout Oregon and Washington (*2*). Each project was rated for ride quality using a passenger car driven at normal speeds. Close-up inspections were made to identify types of distress and to arrive at an overall evaluation for each project. In general, all pavements surveyed were in good condition (an overall rating of 7.9 out of 10). The types of distress observed included rutting (less than 9.5 mm), alligator cracking, raveling of the surface treatment, and poor ride quality. The poor ride was generally attributed to roughness built in during construction. Construction information, traffic data, and materials information were obtained for each project. Cores were taken from each project to determine the resilient modulus, aggregate gradation, and residual asphalt content and properties. On the basis of the 1976 survey, it was concluded that several factors other than traffic affect performance, including environment, quality control during construction, subgrade and base type, and drainage.

Similar surveys were completed in 1981 (*3*) and 1986 (*4*). Several significant findings resulted from these surveys:

- There was little change in performance for most roads, although distress in the form of thermal cracking began to appear on projects in the colder regions of Oregon and Washington.
- The ride quality of open-graded emulsified asphalt pavements was as smooth as that on hot-mix pavements. However, if proper construction practices are not followed, the mix can prematurely stiffen, producing a rough surface during laydown.
- Mix modulus increased with pavement age; calculated asphalt penetrations decreased with age. However, the data were scattered due to variations in core density, void content, asphalt content, climate, and surface seal conditions.
- Cores with high asphalt penetrations gave low moduli or stiffnesses. The converse was not always true. Several cores with low moduli also had low calculated asphalt penetrations.
- Projects with high calculated asphalt penetrations (greater than 20 dmm) had a lower incidence of distress than those with penetrations of 20 dmm or less. The incidences of distress were about equal between projects having high and low mix modulus.
- Structural layer coefficients calculated from this survey indicate open-graded emulsified asphalt pavements have a thickness equivalency of 0.9 to 1.0 when compared to hot-laid asphalt pavements.

Objectives

The purposes of this study were to

- Review and update the performance of projects constructed by three agencies in the Pacific Northwest;
- Present typical mixture properties for these mixtures;
- Compare the performance of OGEM with conventional hot mix asphalt concrete, including the development of layer equivalency factors; and
- Present the general guidelines for use of OGEM adopted by each agency in the Northwest.

Performance of OGEM

Historical Perspective

Three performance surveys have previously been conducted to evaluate the relative performance of OGEM. In July 1986, 19 projects were surveyed, including the 12 projects surveyed in August 1976 and September 1981. The survey technique was identical to that employed in 1981. Cores were taken to determine the density, modulus, aggregate gradation, and residual asphalt content and properties.

Construction Information

Table 1 summarizes the construction data for each of the 19 projects surveyed in 1986. As indicated, projects were constructed by a number of agencies and ranged from less than 1 to 20 years in age. A sample of 236 km (147.5 mi) of open-graded emulsified asphalt pavements was surveyed. In all cases, the open-graded mix was placed as the wearing surface with thicknesses ranging from 5 to 23 cm (2 to 9 in.). Chip seals were added later to improve the resistance to raveling and to provide waterproofing. The projects surveyed included mixes used in new construction as well as for overlays.

Traffic Data

Traffic data for each of the 19 projects were collected from the responsible agency. These data were used to calculate the number of 80-kN (18,000-lb) equivalent single-axle loads (ESALs). The procedure used for calculating the ESALs is provided by Hicks et al. (*4*). Most of the roads surveyed had ESALs of less than 1 million, with maximum ESALs of about 4 million.

Performance Data and Maintenance History

All projects were rated for overall evaluation, ride quality, and type and severity of distress. The overall evaluation for most of the projects was "good" to "very good" with only a few of the projects rated as fair. Though most of the projects gradually dropped in rating with time, a chip seal generally restored the overall evaluation to "very good" (*4*).

Ride quality was rated as "fair" to "very good" on most projects. The older projects received "fair" ratings, while the newer projects received "very good" ratings, giving smooth quiet rides. Most of the sections receiving "fair" ratings were rough shortly after construction due to laydown difficulties; they have not changed much since. Observations of particular interest include the following:

- The most common type of distress noted was minor pitting or raveling of the surface. This is normally corrected with the use of a chip seal.
- Most of the remaining projects showed little change in appearance from that observed in 1981.
- Performance is generally better than hot mix in the eastern parts of Oregon and Washington (*2–4*). Specifi-

TABLE 1 Construction Information on OGEM Surveyed in 1986

Project	Responsible Agency	Date Constructed	Project Length (km)	Mix Thickness (cm)	Emulsion Type
Lewis River	Gifford Pinchot National Forest	1970	25.1	17.5 to 23	CMS-2h
Hermiston-Meadow Valley Interchange	ODOT Region 5	1969	7.2	7.5	CMS-2h
Blue Mountain-Elgin*	ODOT Region 5	1983	26.7	10	CMS-2
Palmer Junction*	FHWA (WDFD)	1985	13.5	10	CMS-2h
Elgin-Minam	ODOT Region 5	1981	14.5	10	CMS-2
Vance Creek Rest Area-Cottonwood Creek*	ODOT Region 5	1984	31.2	6	CMS-2
Logan Valley	Malheur National Forest	1971	17.9	10	CMS-2h
Dayville-Flat Creek*	ODOT Region 5	1984	9.8	5	CMS-2
Painted Hills-Mitchell*	ODOT Region 4	1981	10.5	10	CMS-2h
FHWA-Ochoco Summit*	FHWA (WDFD)	1981	7.4	10	CMS-2h
Hogback Summit	ODOT Region 4	1976	12.2	7.5	CMS-2s
Diamond Lake Bypass	FHWA (WDFD)	1977	10.5	7.5	CMS-2h
Indian Caves-Medicine Creek	Umpqua National Forest	1971	10.9	20	CMS-2h
Umpqua Community College	Douglas County	1967	1.9	7.5	CMS-2h
Cow Creek Canyon	Douglas County	1973	11.9	6	CMS-2
Clarks Branch Road	Douglas County	1976	3.7	5	CMS-2h
Smith River	Douglas County	1967	5.3	6	CMS-2h
Mapleton	FHWA (WDFD)	1978	7.4	19	CMS-2h
Decker Road*	Benton County	1979	9.7	10	CMS-2
Total Kilometers			237.4		

*New Projects
1 inch = 2.54 cm
1 mile = 1.61 km

cally, OGEM provides better resistance to fatigue and thermal cracking and to water-related distress (e.g., stripping).

Oregon DOT Projects

The Oregon Department of Transportation (DOT) constructed the first OGEM pavements in the late 1960s. Since that time, more than 650 km (404 mi) has been laid, accounting for more than 1.8 million tons of mix (this does not include work by counties). Although the performance of the early jobs was very good, the use of OGEM was sporadic until the mid-1980s. This was primarily due to a belief that the material was structurally inferior to dense hot-mix asphalt (DHMA). It was also caused by some jobs' exhibiting poor ride quality.

In the early 1980s, the Oregon DOT began to use OGEM at a much higher rate. This was due to the past excellent performance, low cost, environmental benefits, and changed structural design criteria. Oregon DOT engineers found that the early OGEM jobs had experienced less fatigue and thermal cracking and less moisture damage than their DHMA counterparts. The jobs completed in the late 1960s performed well for more than 25 years before they were finally overlaid. All other OGEM projects constructed since the early 1970s are still in service and are in fair to good condition.

The early design criteria used by the Oregon DOT assigned layer coefficients to OGEM that were 10 to 15 percent less than those for DHMA. However, around 1984, the design procedure was modified to allow equal structural layer coefficients for these materials in all new works. For overlay designs, the Oregon DOT also began to allow a significantly higher tolerable deflection for OGEM overlays than for DHMA overlays, in recognition of the excellent fatigue and reflective crack resistance experienced on early projects. The increased structural credit in conjunction with low initial construction cost has resulted in more jobs being constructed with OGEM. Currently, the Oregon DOT is placing more than 300,000 tons (270 000 tonnes) of OGEM per year. These projects are primarily conducted on low- to medium-volume highways [with average daily traffic (ADT) of less than 5,000] in the eastern half of the state where the environmental conditions are most extreme. The typical low winter temperatures in this portion of the state range from −1°C to −3°C and can be as low as −4°C locally. OGEM resists thermal cracking in this environment very well.

Construction practices have also improved for OGEM. Although some jobs were constructed with poor ride quality, in most cases the ride quality on OGEM is comparable to DHMA. The Oregon DOT is in the process of implementing a new smoothness specification for asphalt concrete pavements, which uses a California-type profilograph to measure smoothness. This specification will apply equally to OGEM and DHMA. Both pavement types must be constructed with a profile index of 11 cm/cm (7 in./in.) per mile or less to receive full pay.

Washington DOT Experience

The first open-graded emulsion pavement constructed in Washington was by change order on a 1975 project near the town of Moxee in the central part of the state. Table 2 summarizes the Washington DOT projects using this material through 1991. Several counties within the state have also used this material for many years, but their projects have been less well documented and are not included in the listing.

As seen in Table 2, the Washington DOT had a fairly aggressive start using this material in 1976 when over 50,000 tones (45 000 tonnes) were placed in four contracts. Unfortunately, a recurring inability to obtain a smooth ride on all of the projects somewhat discouraged the use of the material. Several years elapsed before the state began using OGEM again. By the mid-1980s, the very good performance of this material in resisting rutting, fatigue cracking, and thermal cracking renewed interest in its use, and the number of contracts using OGEM increased markedly after 1984. With more attention given to basic construction details on the part of the state, contractor, and emulsion suppliers, the ride quality of OGEM has improved on most of the subsequent projects.

A few OGEM projects had poorer performances than the rest of the OGEM projects. These projects were located on routes with higher truck traffic volumes that seemed to have been constructed with somewhat lower emulsion contents. Project personnel have subsequently been encouraged to keep the emulsion rates up just short of having runoff problems. The districts are also now encouraged to fog-seal all OGEM pavements every 5 years similar to hot mixed open-graded friction courses.

WSPMS is a project-specific pavement management system that uses annual pavement condition surveys, collected on the entire state highway system grouped by project length segments, to predict pavement performance and project rehabilitation timing. The pavement condition is represented by a pavement structural index that uses the severity and extent of fatigue cracking, transverse cracking, and patching in a weighting system that produces a scale of 0 to 100. The scale is calibrated for flexible pavements so that a value of 100 indicates no visible distress. A value of 50 indicates the classical level of 10 percent fatigue cracking, with additional small amounts of transverse cracking and patching similar to a present serviceability index (PSI) of 3.0. Values approaching 0 represent an accumulation of severe levels of all distress similar to a PSI of between 2.0 and 1.5. In Washington State, the construction program is based on resurfacing or rehabilitating most pavements when they reach the level of 50. This system identifies the service life of any pavement section as the number of years from last construction or resurfacing until it reaches the structural condition index (SCI) of 50. Four categories of pavement condition are used by the state DOT to describe pavement condition. These descriptions are "good," "fair," "poor," and "very poor," which describe pavements with a condition rating from 100 to 75, 75 to 50, 50 to 25, and 25 to 0, respectively.

The average service life to an SCI of 50 for asphalt concrete pavement (ACP) in District 5, where most of the emulsion projects are located, is 11.2 years. An evaluation of the WSPMS data for the first eight OGEM projects constructed between 1975 and 1982 indicates that the service life to a rating of 50 ranged from 12 years to 21 years, with an average life of 14.1 years. Thus, the average service life of the first eight OGEM projects constructed in Washington was 25 percent longer than the average service life for ACP in the same area. Since the state's pavement structural index primarily indicates fatigue performance, rut depth and ride values were also checked for each of the eight projects. The maximum rut depth measured 6 mm (0.25 in.) with little or no rut indicated on most projects. There was also no discernible change in the ride values measured since construction on any of the projects at this time.

The first several OGEM projects were designed using normal design procedures, except that a thickness equivalency of 1.15 compared to 1.00 for ACP was used. In subsequent projects, the thickness equivalency

TABLE 2 OGEM Projects in State of Washington

Cont. No.	Dist. No.	SR No.	Project Name	Section Length, mi	Tonnage	Year Paved	1993 Condition
9689	5	24	Moxee Vicinity	1.37	8,665	1975	Fair
9941	5	97	Klickitat County Line to Dry Creek Bridge	6.37	13,800	1976	Chip sealed in 1983
0180	5	97	Dry Creek to Oak Springs Road	0.99	4,720	1976	Overlaid in 1991
0232*	5	12	Patit Creek to Willow Creek Hill	5.43	17,430	1976	Chip sealed in 1991
0240*	6	272	Colfax to Idaho State Line	5.40	16,500	1976	Chip sealed in 1993
0425**	5	970	East Cle Elum I/C to Teanaway River	5.66	22,500	1978	Fair
1982	5	24	SR-241 to BPA X-ing	3.64	3,420	1981	Good
2262*	6	127	Dodge to Meadow Creek Summit	6.02	18,577	1982	Good
2716	5	22	Yakima County Line to SR-82	6.32	26,598	1984	Good
2736	3	121	SR-12 in Rochester to SR-5	3.40	5,230	1985	Fair
2875	5	395	SR-260 to Adams County Line	6.42	28,000	1985	Fair
3885	5	221	Sellars Road to County Well Road	3.42	10,130	1985	Poor
2927	5	17	Adams County Line to M.P. 12	9.40	37,886	1985	Poor
2980	4	14	Klickitat River to Horse Thief Canyon	10.44	19,397	1987	Good
3080	5	12	Airport East I/C to Weight Station	1.03	4,990	1987	Good
3232	5	221	Prosser Hill	2.83	8,822	1987	Good
3263	2	17	West Foster Creek Bridge to East Foster Creek	5.58	8,920	1987	Fair
3280	5	970	Teanaway River to SR-7/Virden	4.66	11,160	1987	Overlaid in 1991
3284	5	12	Vansycle Canyon to Nine Mile Canyon	2.86	5,247	1987	Fair (with winter snow plow damage)
3289	5	12	Fairview road to M.P. 416.8	3.30	2,700	1987	Good
3269	4	12	Slide Br. to Yakima County Line	3.30	14,920	1988	Good
3357	5	410	Bumping River Road to Lower Nile Road	4.09	6,204	1988	Fair
3427	5	12	SR-261 to Archer Road	4.30	12,236	1988	Good
3419	5	12	M.P. 319.34 to Lower Dry Creek Road	5.41	11,850	1988	Fair
3562	5	124	Ash Road to M.P. 17.50	6.32	18,445	1989	Good
3808	5	12	Mud Creek Road to Road 1275	2.91	7,960	1990	Good
3927	5	12	SR 730 to Van Sycle Canyon	3.79	8,300	1991	Good
3915	5	97	Vic. Bridge 97/102 to M.P. 38.1	2.67	9,546	1991	Good
3813	5	97	M.P. 38,09 to M.P. 41.27	3.18	8,200	1991	Good
3884	5	221	Lenzie Road to Sellards Road	7.18	25,170	1991	Good
3875	6	28	Lamme to Harrington	14.6	43,800	1991	Good
			Total	152.29	441,323		

*Was resealed.
**Was overlaid with 12 mm (½ in.) depth friction course at the end of the project to correct roughness.
1 mi = 1.61 km

TABLE 3 FHWA Projects Using OGEM

Project Name	Length (km)	Thickness (cm)	Tonnage	Date Constructed	Present Condition
Lewis River Road N-90	25.1	20-25.4	85,235	1970	Overlaid in 1990
Elk Creek Road	18.3	20	55,240	1971	N/A
Clackamas Highway	2.2	15	4980	1975	Overlaid in 1980
Cascade Lakes Highway	10.5	7.6	16,870	1976	Chip sealed in 1980
Siuslaw Highway	7.4	19	36,650	1976	Fair to Good
Moon Creek	9.0	9-23	22,075	1977	Fair
Nestucca River Road	4.8	variable	N/A	1977	Fair
Ochoco Highway	7.5	18	19,810	1981	Fair
Santiam Highway	12.8	10	19,320	1982	Reconstructed
Palmer Junction	13.4	10	26,500	1985	Fair
Burns-Izee	13.9	10	27,405	1990	Very Good
Burns-Izee	16	4	32,000	1993	Very Good

1 inch = 2.54 cm
1 mi = 1.61 km

was changed to 1.00 to 1.00. Around 1984, the layer equivalency value was changed to 0.85 to 1.00 for ACP because emulsion projects were showing little or no defects. Over the last few years, Washington State has been using a mechanistic-based overlay design method developed by the University of Washington (*5*). When using this design procedure for OGEM pavements, the shift factor for fatigue damage is adjusted to allow 25 percent more strain than is used with the normal ACP hot mix. This adjustment was based on studies in Sweden that indicated the emulsion mix tolerated much higher strain levels to comparable levels of fatigue (*6*). The Swedish work seems to be supported by Washington State's performance data for OGEM. This adjustment in the fatigue damage criteria, as used in the mechanistic-based overlay design procedure, is very similar to using a thickness equivalency value of 0.85 to 1.00 in the more standard empirically based pavement design methods.

FHWA Experience

FHWA began constructing OGEM pavements in 1970 and continued through the early 1980s. Construction and early performance problems in the early 1980s caused the agency to reevaluate its use of OGEM. New projects were constructed in the 1990s as shown in Table 3. Following is an annotated summary of the projects constructed to date.

Lewis River Road N-90

Constructed in 1970, this was the first major project using open-graded emulsified asphalt pavement in the Pacific Northwest. The pavement outperformed the calculated design life. Logging trucks in excess of 890 000 kN (200,000 lb) traveled this road. The project was widened and reconstructed in 1990.

Elk Creek Road

Constructed in 1971 this was a timber access road using 20 cm (8 in.) of OGEM directly on a clay subbase. This road is still in place today. Distress due to landslides required local corrective measures.

Clackamas Highway

Constructed in 1975, this project was a test section using three types of emulsified asphalt pavement construction. This was a national experimental evaluation project evaluating open-graded mix using CMS-2h, sand mix using CMS-2s, and a dense mix using CSS-1 emulsion. This project was overlaid with conventional asphalt mix after 5 years of evaluation. The emulsion mixes were used as a bituminous stabilized base at the conclusion of the study.

Cascade Lakes Highway

Constructed in 1976, this was the smoothest pavement constructed so far. The comparison included conventional hot-mix pavements in addition to the OGEM mixes. Due to the altitude and chain wear, a seal coat was placed on the surface about 1980. The road is still performing today.

Siuslaw Highway

Constructed in 1976, this project had a seal placed between lifts that allowed for drainage of the pavement surface to eliminate spray and minimize hydroplaning. This area has rainfall in excess of 250 cm (100 in.) per year. The pavement provided excellent drainage and has performed well. A portion of the structure was placed over floating peat bogs and vertical movement was noticeable. The pavement did not crack but warped to follow the movement of the bog.

Moon Creek

Constructed in 1977, these test sections were used to determine the layer equivalency of open-graded mixes. The sections were constructed with variable thicknesses of pavement. The thin lift sections were calculated to fail. Using traffic data, we planned to calculate structural equivalency. Due to lack of viable traffic data for the calculations, the layer equivalency was not sufficiently accurate to publish in a formal report. The data substantiated that the OGEM could be structurally designed using equal strength coefficients.

Nestucca River Road

In 1977 this road was constructed using marginal marine basalt, which does not perform well using conventional construction methods with dense asphalt systems. Short sections of conventional dense hot mix were placed for comparison to the OGEM. The OGEM performed satisfactorily, while the conventional mix was overlaid within a year. A major construction technique evolved from this project when using marine basalt: marine basalt must be used during the same construction season in which it was crushed. Initially, marine basalts were allowed to be stockpiled from one construction season to the next. This proved unsatisfactory since the gradation was altered by degradation while in the stockpile (e.g., the P200 increased over the winter from 1.5 percent P200 to about 6 percent). Therefore, it was found that encapsulating the aggregate with a thick film of emulsion as soon as practical would minimize the effects from degradation.

Ochoco Highway

Constructed in 1981, this major forest highway is still serviceable today. The road was constructed with some roughness, which was attributed to construction techniques. Though the division engineer of Western Federal Lands Highway Division was not pleased with the rough ride, the pavement performance has proven satisfactory (i.e., it is still performing well in 1994).

Santiam Highway

Constructed in 1982, this highway was totally reconstructed and the OGEM eliminated from the surface. The project required 100 mm (4 in.) of OGEM. The first 50 mm (2 in.) was placed and construction was terminated for winter shutdown. The 50-mm (2-in.) layer was inadequate for the high volume of truck traffic, and numerous sections failed during the winter. Reconstruction took place the following construction season with conventional hot mix 100 mm (4 in.) deep.

Palmer Junction

The original 1985 pavement has been reconstructed. Numerous subgrade problems were not identified in the original construction and had to be dug out. Also, the CMS-2h emulsion was manufactured in such a manner that the emulsion took over a month to break. It is important to have consistency in the manufacturing of the product so the user can anticipate what to expect in cure time.

Burns-Izee

Constructed in 1990, this project was awarded second place by the Oregon Asphalt Paving Association for smoothness and aesthetics. Another Burns-Izee project was constructed in 1993.

MIXTURE PROPERTIES

Cores were taken from most of the projects in each of the three surveys. All cores were tested for density and modulus by Oregon State University and for extraction and measurement of the binder properties by Chevron USA.

Mix Properties

The results of the tests on cores taken over the study period indicated the following:

- Core densities range from about 14.0 to 17.3 N/m^3 (111 to 137 lb/f^3).
- Air voids range from about 13 to 30 percent.
- Extracted asphalt contents range from about 3.0 to 5.8 percent.
- Percentage passing the 0.074 mm (No. 200) ranges from 2 to 5 percent with the percentage passing the 2 mm (No. 8) ranging from 10 to 20 percent.

These results indicate that there is some change in properties over time. Void contents have dropped from 25 to 30 percent to 13 percent and P20 has increased from 0 to 2 percent to 2 to 5 percent.

Modulus Data

All modulus tests were performed using a repeated load diametral test (ASTM D-4123). The results (given in Figure 1) indicate the following:

- In most cases, modulus values tended to increase with pavement age.
- Many of the older projects have modulus values exceeding 68.9 GPa (10^6 psi).
- The 1986 modulus values for selected projects (e.g., Hogback Summit and Elgin–Blue Mountain Summit) were extremely low.
- Figure 2 shows that for most projects sampled in 1976, 1981, and 1986 there is an increase in modulus, with the exception of Hogback summit.

Recovered Asphalt Data

The properties of asphalts recovered from cores obtained in the 1981 and 1986 surveys indicate the following:

- Penetration of the recovered asphalt generally decreases with pavement age (Figure 3).
- For projects sampled in 1981 and 1986, the penetration, in most cases, decreased with time (Figure 4).
- The penetration of some of the older projects is less than 20 dmm.
- The penetration for selected projects (e.g., Clarks Branch Road and Cow Creek Canyon) appears to be extremely high.

EVALUATION OF RESULTS

Properties Versus Performance

Mix modulus would be expected to increase with time as the pavements age. In general, this occurred but with a significant scatter of results, as shown in Figure 1. The scatter is not too surprising since other variables (e.g., core density, air void content, asphalt content, amount of seal over the open-graded pavement, and the climate conditions) are not equal.

The penetration of the recovered binder decreased with age, as shown in Figure 3. With the exception of results from the Cow Creek Canyon and the Clarks Branch Road projects, the correlation is quite good. Projects over 10 years old have recovered penetrations of 5 to 20 dmm, while projects under 10 years old generally produced recovered penetrations greater than 20 dmm. This suggests the importance of periodic fog seals to rejuvenate the binder.

Recognizing that other variables are not equal, mix modulus versus penetration of the recovered binder are

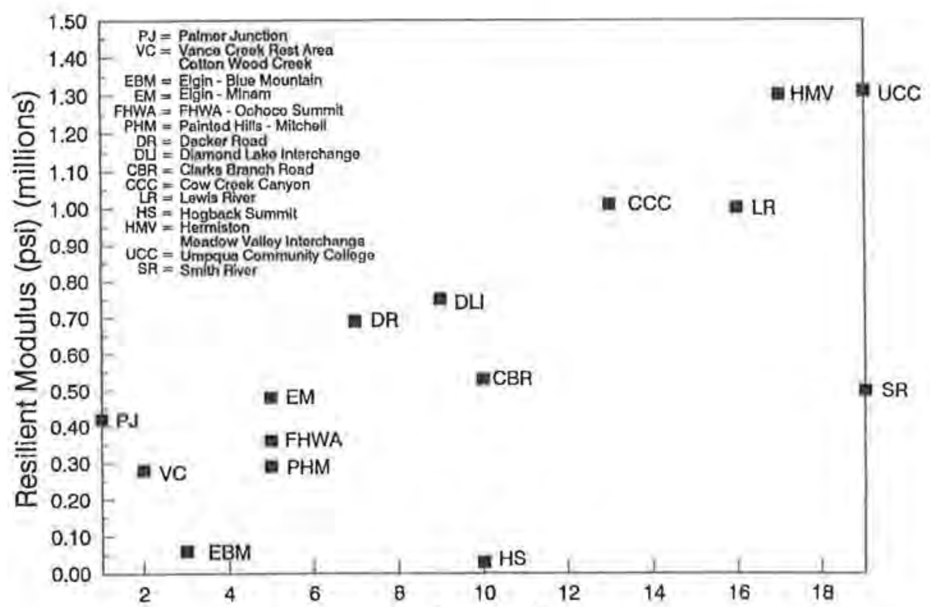

FIGURE 1 Variation in modulus with pavement age.

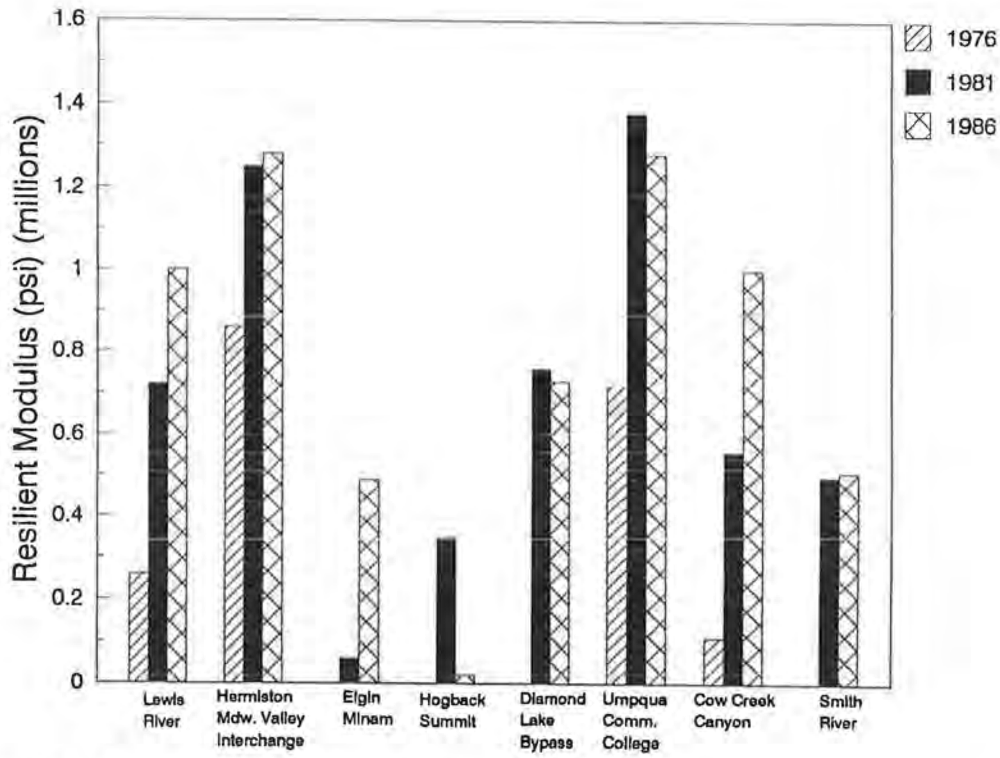

FIGURE 2 Variation in modulus with time, selected projects.

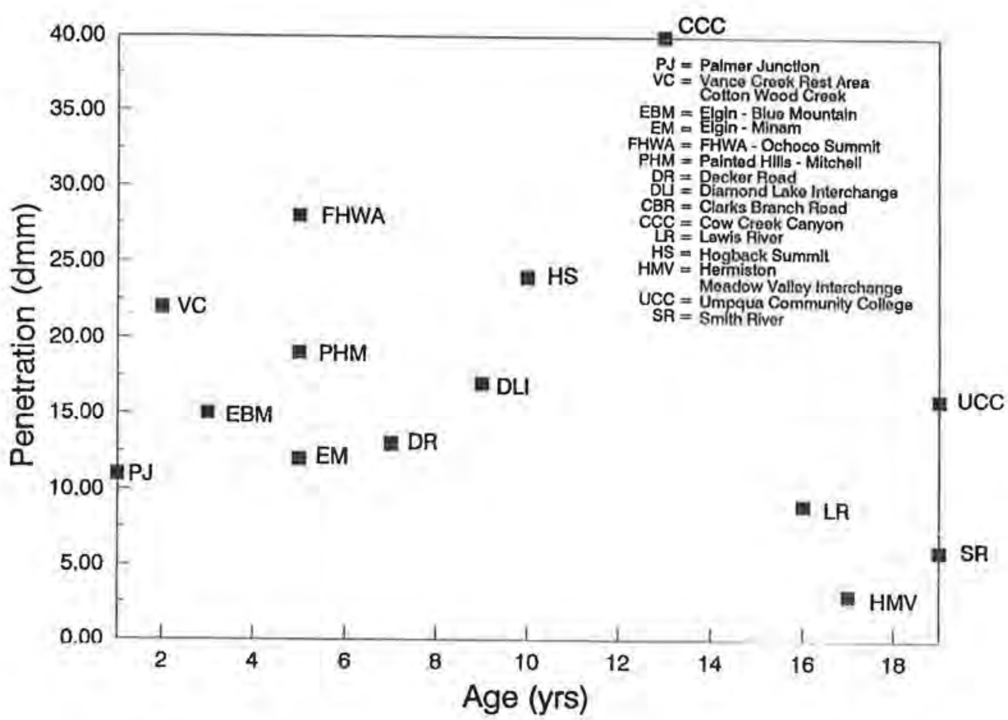

FIGURE 3 Variation in penetration with pavement age.

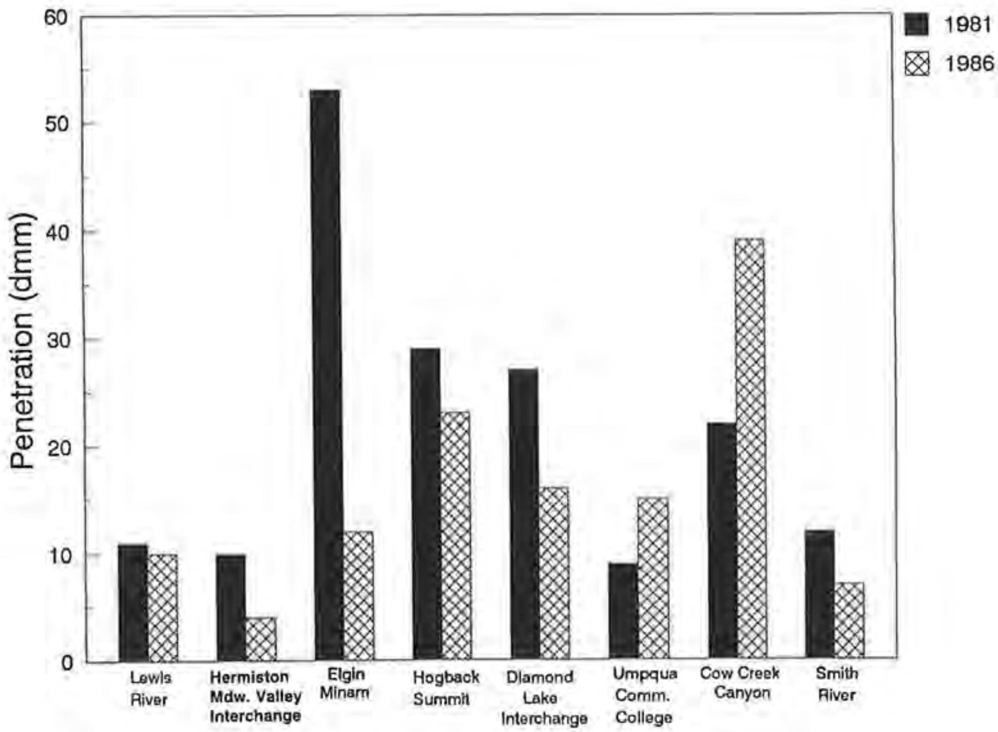

FIGURE 4 Variation in penetration with time, selected projects.

plotted in Figure 5. Cores with high penetrations have low mix modulus. However, the converse is not true. Several cores with low moduli also have low penetrations. It is interesting to note that projects with penetration values of 20 dmm or less tend to exhibit a higher incidence of cracking than those with penetrations over 20 dmm.

Structural Layer Coefficients

Calculations for layer coefficients using the approach described by Hicks et al. (*3*) are included in Table 4. Basically, the layer coefficients (a_1) are back-calculated using the AASHTO design guide (*7*) for $Pt = 2.0$ and a knowledge of the surface thickness (D_1), traffic (W_{18}), regional factor (R), and the soil support of the base (SS). The a_1 values are, in most cases, minimum values since the majority of open-graded emulsified asphalt pavements are still performing well. The values shown below for selected projects are based on some evidence of distress (thermal cracking, load-associated cracking, or overlaid):

Project	*a_1-Values*
Lewis River	0.37–0.41
Hermiston-Meadow Valley Interchange	0.45
Logan Valley	0.48
Hogback Summit	0.47
Diamond Lake Bypass	0.57
Cow Creek Canyon	0.75
Mapleton	0.21

For the projects surveyed, it appears that an a_1-value of 0.40 or greater is reasonable for open-graded emulsified asphalt pavements. Average values of layer coefficient for materials used in the AASHTO road test include an a_1-value of 0.44 for dense asphalt concrete surface course. Hence, a layer equivalency of 1 seems justified for open-graded emulsion mixtures. This layer equivalency is presently used by the Oregon and Washington DOTs (*8,9*). In fact, in some cases, Washington DOT actually uses a layer equivalency of less than 1.0 for OGEM because of the excellent performance of the OGEM pavements.

Guidelines for OGEM Use

The results in this paper clearly indicate that OGEM pavements can perform well for up to 25 years. This is, in part, because OGEM has been used only for selected applications. The general guidelines in Table 5 appear

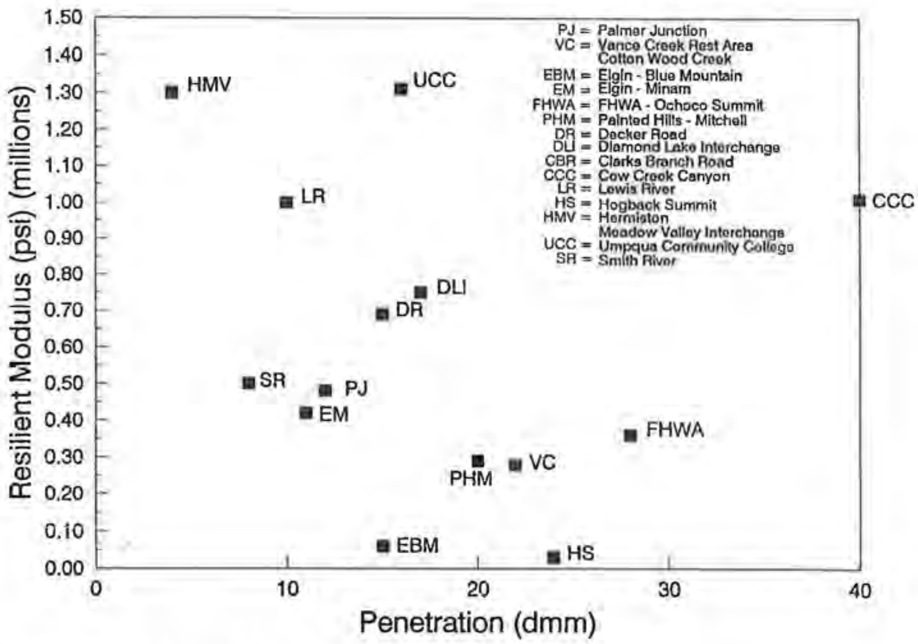

FIGURE 5 Mix modulus versus asphalt penetration.

to be appropriate for OGEM use in the Pacific Northwest (*4*). Specific guidelines by agency follow.

Oregon DOT Guidelines

Guidelines currently used by Oregon's DOT are summarized below.

1. Project selection

- Use in warmer, drier climates to facilitate curing.
- Use on projects with less than 5,000 ADT or less than 10 million ESALs.
- Use on higher-volume routes when traffic can be kept off pavement during curing.
- Use on west side where pavement flexibility is design criterion.

2. Thickness design

- OGEM possesses lower stiffness and higher fatigue resistance than hot-mix asphalt.
- Use 25 percent higher fatigue strength in mechanistic analysis. This results in a thinner OGEM layer than hot-mix asphalt but a thicker base.
- Overlay design based on tolerable deflection chart developed by Oregon State University (*4*).

3. Specifications for materials and construction

- Use CMS-2 or HFMS-2. CMS-2S can also be elected by contractor for better paving characteristics and ride and/or with dirtier aggregate.
- Fracture, gradation, aggregate quality, as specified in Section 735 in Oregon DOT specifications.
- Chip seal (6 to 2 mm typically) required on all projects.
- Mix design checks for compatibility of rock and emulsion. Emulsion content and add water are given as guide for field. Actual emulsion content used in field based on visual assessment of percentage of greybacks (all the emulsion it will hold without runoff).

In addition, it has been determined that OGEM has certain advantages and disadvantages.

1. Advantages

- Cost—one-half to two-thirds that of hot ACP.
- Uses less energy and resources. Yields more pavement per ton mix.
- Simpler system. Less equipment needed.
- Allows use of very soft asphalt that improves resistance to thermal cracking and fatigue cracking.
- Resists rutting due to high fracture and open grading.
- Not sensitive to construction variability.

2. Disadvantages

- Long curing period required—limits use under heavy traffic.

TABLE 4 Backcalculated Layer Coefficients for Selected OGEM Projects

Project	Date Constructed	Pavement Condition	Traffic — W_{18}		Thickness of Open-Graded Pavement (D_1) (cm)	Estimated Regional Factor (R)	Average Base Property			SN = f(W_{18},SS,R) P_t = 2.0	Calculated a_1 = SN/D_1
			1981	1986			CBR	R-Value	Soil Support (SS)		
Lewis River	1970	fair-good	$3.9x10^6$	$4.0x10^6$	21.6	2.0	—	60	6.5	3.3	.37-.41
Hermiston-Meadow Valley Interchange	1969	fair	$0.15x10^6$	$0.27x10^6$	10.2	2.0	—	70	7.0	1.8	0.45
Logan Valley	1971	good	$0.33x10^6$	$0.39x10^6$	10.2	2.0	31	—	7.5	1.9	0.48
Hogback Summit	1976	very good	40,000	52,500	7.6	2.0	—	70	7.0	1.4	0.47
Diamond Lake Bypass	1977	very good	88,500	$0.12x10^6$	7.6	2.0	—	70	7.0	1.7	0.57
Indian Caves-Medicine Creek	1971	good	5000	7200	20.3	2.0	—	—	—	—	—
Umpqua Community College	1967	very good	10,000	$0.31x10^6$	7.6	2.0	—	—	—	—	—
Cow Creek Canyon	1973	very good	$0.99x10^6$	$1.04x10^6$	7.6	2.0	31	—	7.5	2.25	0.75
Smith River	1967	good	$2.4x10^6$	$2.5x10^6$	25.4	2.0	—	—	—	—	—
Mapleton	1978	good	27,000	$0.10x10^6$	10.1	2.0	—	70	7.0	1.6	0.21

Note: 1 in. = 2.54 cm

TABLE 5 Suggested Guidelines for Use of OGEM

1.	ADT ≤ 5000.
2.	Do not use where sharp turns are expected.
3.	Complete paving during warm weather to insure curing.
4.	A positive seal is needed, preferably on the surface, to protect the underlying base from moisture and the surface from raveling.
5.	OGEM is useful on projects requiring good crack resistance.
6.	OGEM should not be used where high initial stiffness is required.
7.	Encourage use in locations where hot-mix plants do not exist.
8.	Encourage use where good aggregates are in short supply.

• Harder to get smooth ride due to variability of mix under screed.

Finally, the following are some general notes regarding the use of OGEM:

1. Use on Interstate for inside passing lane where cure time is adequate. Currently working with asphalt suppliers to develop a controlled set emulsion that can be used to obtain a shorter curing period and OGEM can be used under higher traffic volumes.
2. Need to experiment with OGEM without chip seals to use benefits of porous pavement.
3. Need to experiment with OGEM as porous overlay on portland cement concrete (PCC) pavement.
4. Vision for future is that OGEM will become a predominant mix in Oregon as emulsion technology improves so it can be used in cooler and wetter climates and under heavier traffic volumes.
5. Need to experiment with using OGEM for shoulders with PCC pavements.

Washington DOT Guidelines

General guidelines currently used by Washington's DOT include the following:

1. Project selection

• Use only in eastern Washington where dry climate facilitates curing.
• Use on routes with ADTs between 1,500 and 5,000.
• Use exclusively in more remote areas where portable ACP plants would be required.
• Do not use in urban areas where numerous turning movements and more critical tracking problems would occur.
• Do not use on projects where signficant grading work during the summer makes latter season paving necessary.

2. Specification and construction concerns

• Washington continues to use the federal guideline for grading and fracture. The grading of the course material does not appear to be very critical but the grading of the fine material is highly critical. Problems with early emulsion break and subsequent rough ride occur when the percentage of passing the 0.074 mm (No. 200) sieve approaches or exceeds 2.
• Washington has also had recurring problems with CMS-2 and CMS-2S emulsions from some suppliers: emulsions break early apparently from a deficiency of oil distillate. Washington now uses a modified CMS-2 specification for OGEM that requires 6 to 12 percent oil distillate by volume of emulsion, which has significantly reduced the early break problem. The standard CMS-2 specification is also modified to require a minimum viscosity that helps to eliminate runoff problems.
• All OGEM projects are fog-sealed or chip-sealed after construction to minimize potential raveling of the surface.

FHWA Guidelines

General guidelines currently used by FHWA include the following:

1. Project selection

• Use where very heavy loads are anticipated.
• Use where anticipated deflections may exceed 0.9 mm (0.035 in.).
• Use where marginal aggregates are the only economically available materials.
• Use over existing pavement structures that are flushed but are structurally adequate.
• Use where there is not an abundance of quality aggregate since a ton of materials yields more pavement structure.

2. Specification concerns

- Variability of emulsion due to manufacturing techniques.
- Specifications do not define the quality of the product.
- Specifications are too broad and allow product variability.
- FHWA specification spells out the minimum amount of oil distillate. Probably should use boiling point for the oil distillate to eliminate the slower curing materials.

SUMMARY

This paper presents a summary of the experiences with the use of OGEM in the Pacific Northwest. OGEM has performed successfully in this region since 1966. Although some construction problems occurred early on, they have generally been resolved. The performance of these mixes has been very good to excellent, particularly east of the Cascades where the climate is dry and cold. OGEM continues to be a cost-effective pavement type for low-volume roads (1,000 to 5,000 ADT) used by FHWA, state highway agencies, and counties in the Pacific Northwest.

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