Improving Durability of Open-Graded Friction Courses

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Open-graded friction course mixtures were evaluated in the laboratory to determine the potential for stripping. A boiling test was used to measure the potential for stripping in mixtures containing three asphalts used in New Mexico with and without both liquid antistripping additives and hydrated lime. Mixtures were also evaluated with the same three binders after modification with a polymer. All testing was conducted on mixtures after the optimum binder content was determined by using the open-graded friction course mix design procedure described by FHWA. Results of this study indicate that optimum asphalt content of open-graded friction course mixtures varies depending on the asphalt, antistripping agent type, and quantity and whether the binder is polymer modified. Stripping potential as measured by the Texas Boiling Test was significantly reduced after addition of antistripping agents to the asphalt or aggregate and after polymer modification of the binders.

Open-graded friction course (OGFC) mixtures [NMSHD (New Mexico State Highway Department) Standard Specification Section 404] have been used successfully for surfacing asphalt concrete pavements in New Mexico for many years. These mixtures provide skid resistance through course surface texture and drainage, reducing the potential for hydroplaning accidents. Although chip seals can provide similar safety, OGFC mixtures are placed by using conventional paving machines, eliminating the hazards and difficulties associated with chip seal construction on high volume facilities.

The open grading of these mixtures is intended to create high permeability such that rain water can drain away from the pavement by flowing through the mixture rather than over the surface, as in conventional asphalt concrete. Often, this theory works well, reducing water on the surface, effectively eliminating hydroplaning potential, and increasing visibility by reducing spray from tires.

However, during service the permeability of OGFC mixtures can be reduced by a tendency of aggregates within these mixtures to migrate together under traffic loading. This reduction in permeability causes rain water to remain within the OGFC for days or weeks after the rain has stopped. The water that remains within the OGFC is placed under very high pressures by vehicular tires traversing the surface. The water not exuded from the mixture by the tire loading moves within the mixture through remaining permeable air voids. If sufficient permeable voids are present to receive this water volume, little, if any, damage results. However, as permeable voids in the mixture are reduced, water attempts to fill voids in the mixture or aggregate particles coated with the asphalt cement binder. As water enters the aggregates, asphalt is displaced or removed entirely from the aggregate surface. This "stripping" of the asphalt film by water causes aggregates to become dislodged from the mixture, eventually causing failure of the OGFC and sometimes of the underlying asphalt concrete.

Hydrated lime has been found effective in reducing stripping potential of OGFC mixtures and is required by NMSHD specifications for construction of such pavements. However, on certain NMSHD projects, this method may not be working. Recent inspection of OGFC surfaces in New Mexico revealed raveling distress on some projects. Raveling can be attributed to the stripping mechanism, and therefore, the effectiveness of hydrated lime as an antistripping agent in these OGFC surfaces should be studied.

BACKGROUND AND SIGNIFICANCE OF WORK

Liquid antistripping agents and hydrated lime have been found effective for reducing the potential for stripping in asphalt mixtures. However, neither of these products or procedures is always effective with all mixtures or aggregate sources. Therefore, use of one method to reduce stripping distress for all aggregate sources, in all mixtures, is not practical.

Recently, NMSHD has constructed OGFC mixtures by using polymer modified binders. Although hydrated lime was used as a component of these mixtures, no evidence of raveling is present in these pavements, while in other OGFC mixtures containing lime, raveling distress is present.

An experimental program is required to measure the effects of hydrated lime, liquid antistripping agents, and polymer modified asphalt on the stripping potential of OGFC mixtures.

MATERIALS

Binders evaluated included three paving grade asphalts routinely used in New Mexico. These asphalts were tested alone and in combination with a liquid antistripping agent at two levels of concentration and with a polymer modifier at one level of concentration. In addition, hydrated lime was added to the aggregate in slurry form prior to mixing with asphalt. The complete factorial arrangement of variables is outlined in the Experiment Design section.

Asphalts

Three paving asphalts available for use in New Mexico were studied. The sources of these asphalts are

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- Chevron, located in El Paso, Texas, grade AC-10;
- Cosden, located in Big Spring, Texas, grade AC-10; and
- Navajo, located in Artesia, New Mexico, grade 85-100.

Liquid Antistripping Agent

A liquid antistripping agent was evaluated at two levels of concentration in each of the asphalts. The aliphatic polyamine material marketed by the Carstab Division of Morton Thiokol is called "Pavebond Special" and has been used routinely in New Mexico to reduce potential for stripping in asphalt mixtures.

Hydrated Lime

Type N hydrated lime conforming to the requirements of ASTM C207 was mixed with water at a 50:50 by volume ratio to produce a slurry prior to mixing with the OGFC aggregates.

Polymer Modifier

Each of the three paving grade asphalts (Chevron, Cosden, and Navajo) was modified with 3 percent by weight block copolymer and processed by using the "Styrelf" procedure.

Aggregates

Mineral aggregates were obtained for New Mexico Engineering Research Institute (NMERI) by New Mexico State Highway and Transportation Department (NMSHTD) personnel in District 3. The aggregates were sampled from the J. R. Hale Construction Co. pit near Algodones, New Mexico. The material was being produced for open-graded friction course construction during the 1988 construction season. These aggregates were placed as OGFC during 1988 in and near Albuquerque.

Aggregates were evaluated in two conditions for this study. Aggregates were used in the condition they arrived at the NMERI laboratory and after washing. The resulting two gradations are referred to as "washed" and "unwashed," as follows:

Sieve	*Washed*	*Unwashed*
½ in.	100	100
⅜ in.	95	95
No. 4	40	41
No. 10	0	1
No. 40		0

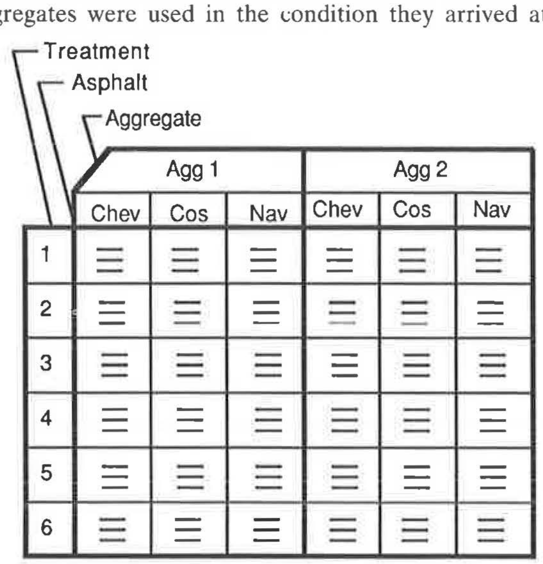

FIGURE 1 Experiment matrix.

EXPERIMENT DESIGN

The experiment was designed as a fully randomized, replicated, full factorial with fixed factors such that analysis of test results could be achieved by multiple or one-way analysis of variance (ANOVA). The fixed factor model for analysis is as follows:

$$Y_{ijk} = \mu + R_i + B_j + T_k + RB_{ij} + RT_{ik} + BT_{jk} + RBT_{ijk} + e_{ijkm}$$

where

Y_{ijk} = response of material to ith aggregate, jth asphalt, and kth treatment combination,
μ = effect on response of the overall mean,
R_i = effect on response of the ith aggregate, $i = 1,2$,
B_j = effect on response of jth asphalt, $j = 1–3$,
T_k = effect on response of kth treatment, $k = 1–6$,
RB_{ij} = effect on response of interaction of aggregate and asphalt,
RT_{ik} = effect on response of interaction of aggregate and treatment,
BT_{jk} = effect on response of interaction of asphalt and treatment,
RBT_{ijk} = effect on response of three-way interaction, and
e_{ijkm} = experimental error (random).

Independent variables in this experiment are two aggregate types, three asphalt sources, and various treatments including lime, liquid antistripping agents and polymers. Treatment combinations are as follows:

Treatment	*Description*
1	asphalt + aggregate (no lime)
2	asphalt with 3% polymer + aggregate (no lime)
3	asphalt + aggregate with 1.5% lime
4	asphalt with 3% polymer + aggregate with 1.5% lime
5	asphalt with 0.5% Pavebond + aggregate (no lime)
6	asphalt with 1.5% Pavebond + aggregate (no lime)

These data are analyzed by multiple analysis of variance (ANOVA) with factorial layout as shown in Figure 1.

The dependent (response) variable used to evaluate stripping potential is Texas Test Method Tex-530-C, "Effect of Water on Bituminous Paving Mixtures" (*1*).

It is important to note that this type of design allows comparison of the materials evaluated by this research with other materials tested by NMERI for NMSHTD.

One advantage to this type experiment lies in the ability to add new information with minimal analysis errors as long as the new information is collected randomly, with replication.

LABORATORY TESTING

A laboratory test procedure was utilized that provides an indication of the stripping potential of asphalt concrete mixtures. The test simulates the removal of an asphalt film from aggregates by submersing the mixture in boiling water for a period, cooling the sample, and visually estimating the amount of uncoated aggregate particles.

Texas Test Method Tex-530-C: Effect of Water on Bituminous Paving Mixtures

The procedure for performing the test and the apparatus required are outlined in FHWA Technical Report RD-74-2 (*2*). Briefly, the procedure is as follows:

1. The mixture of the project aggregates and asphalt is prepared.
2. The mixture is allowed to cool.
3. The mixture is placed in a beaker of boiling water.
4. The mixture is removed from the boiling water and allowed to dry.
5. The resulting area of aggregate surface uncoated by asphalt after the test is judged as the percentage of stripping.

The procedure used in this research was a modification of the Method 530-C procedure. Modification consisted of preparing a 500 gm batch of asphalt and aggregates in lieu of the recommended 1,000 gm batch. Also, water boils at a lower temperature in Albuquerque than at sea level; therefore, an adjustment should be made when comparing results between laboratories.

Each of the treatment combinations shown in Figure 1 was evaluated by Method 530-C at the optimum binder content determined by a modification to the procedure outlined in the FHWA report (*2*).

Modified FHWA Open-Graded Friction Course Design

A simple laboratory technique is used to determine optimum binder content after estimating the optimum by the FHWA technique. The procedure is as follows:

1. Estimate optimum binder content by FHWA RD-74-2 technique by measuring K_c.
2. Prepare mixtures of 1,000 gm of aggregate to be used on project. These mixtures include all aggregate sizes as well as hydrated lime slurry, if applicable.
3. Mix aggregate batches with asphalt to be studied at five binder contents, so that two batches are 0.5 and 1 percent higher and 0.5 and 1 percent lower than the target obtained in the first step.
4. Place the mixtures on a clean, flat pan tilted at a 45° angle in an oven adjusted to 275° ± 1°F for 1 hr.
5. Remove the pans from the oven, and observe the mixtures for any runoff of binder from the aggregates.
6. Report the binder content 0.5 percent below that at which runoff begins as the design binder content.

TEST RESULTS: MIXTURE DESIGNS

All mixtures were evaluated to determine optimum binder content before evaluation for stripping potential. Results of the mixture designs are shown in Figures 2 and 3.

As was expected, optimum binder content varied with the treatment evaluated and on the source of asphalt.

The binder contents shown in Figures 2 and 3 for each treatment combination were used to produce the laboratory samples to be evaluated by the boiling test.

Results of the boiling test are shown in Figure 4 and presented in Figures 5 and 6. Because of the subjective nature of the boiling test, two technicians were used to evaluate the results. Differences in judgment for each technician occur and are shown in the figures.

FIELD SURVEY

Performance of five open-graded friction course projects were observed in District 1 on I-10 from the Arizona border to 54 miles east. These projects represent constructed between 1981 and 1985, with the most recent maintenance occurring in 1988. The projects were constructed by using hydrated lime, liquid antistrip of the type used in the laboratory study, and polymer modified binders.

A description of each project is described in Figure 7 with comments regarding the appearance during the field survey on November 30, 1988.

Although a variety of antistripping treatments were observed with varying levels of performance, because each project was built at different times with different aggregate sources, it is difficult to determine from Figure 7 what effect liquid, lime, or polymer modifiers have on durability of OGFC.

Antistrip Treatment
Asphalt Source
Aggregate Source

	Washed			Unwashed		
	Chv	Csd	Nav	Chv	Csd	Nav
None	6.0	6.5	5.7	6.0	5.7	5.7
Lime	6.0	6.0	6.0	6.5	6.5	6.5
Polymer	5.7	5.7	5.7	Differences in gradation judged non-significant, therefore remaining unwashed treatments not evaluated		
Poly/ Lime	7.4	6.5	6.5			
0.5% Pvbnd Spl	5.7	5.7	6.5			
1.5% Pvbnd Spl	5.7	5.7	5.7			

FIGURE 2 Optimum binder contents.

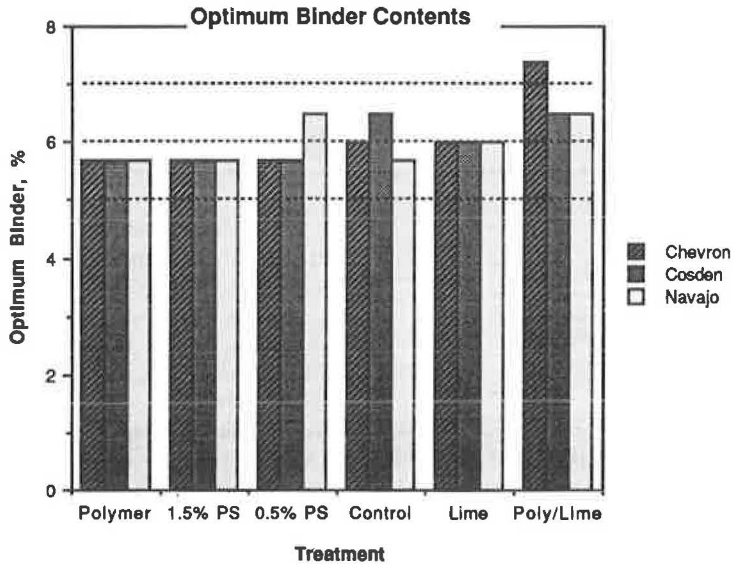

FIGURE 3 Comparison of optimum binder contents.

	Technician 1			Technician 2		
	Chevron	Cosden	Navajo	Chevron	Cosden	Navajo
Control	15	40	30	40	75	35
Lime	10	8	2	30	5	2
0.5% Pavebond	10	0.5	1	10	1	1
Polymer	3	5	5	5	10	15
Poly/Lime	0.5	1	2	1	2	2
1.5% Pavebond	0	0	0.5	0	0	0.5

FIGURE 4 Results of boiling test.

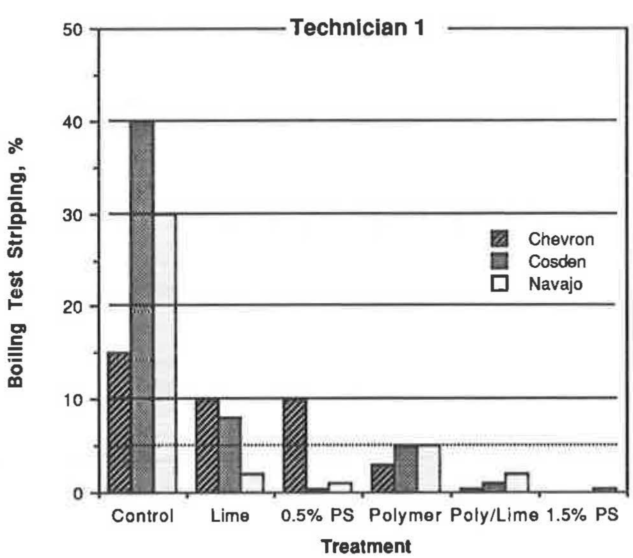

FIGURE 5 Results of boiling test judged by Technician 1.

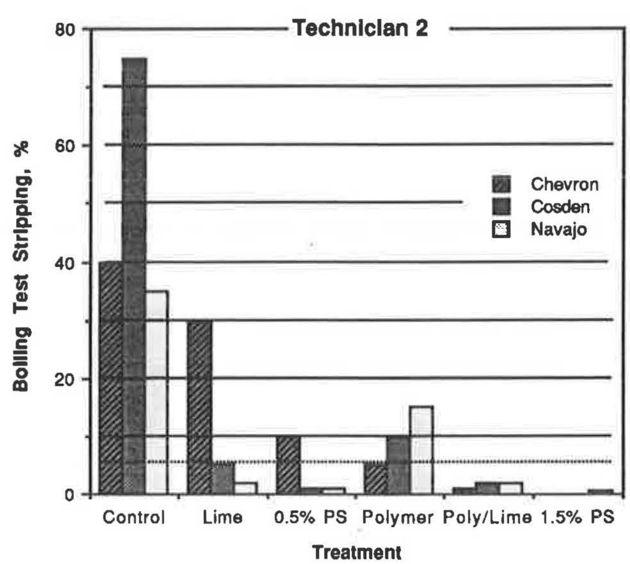

FIGURE 6 Results of boiling test judged by Technician 2.

I-10 Location, Mile Marker	Lane Direction	Construction Date	Asphalt Type	Antistrip Description	Comments
0 - 6	W B	1985	PAC15	1% Lime	Driving lane has redder appearance than passing lane (possibly different contracts) No ravelling; good tight matrix.
6 - 13	EB & WB	1981	AC 10	1% Liquid*	OGFC is on both main lanes and shoulder. Moderate ravelling in driving lane
13 - 21	EB & WB	1985	AC 10	1% Lime	Gray color. Tighter appearance than section adjacent to east (MP21 - 54).
21 - 34	EB & WB	1985	PAC20	None	Recently fog sealed. Striations visible in right wheel path/driving lane, texture similar to section adjacent to east (MP34 - 54)
34 - 54	EB & WB	1984	AC 10	1% Lime	Reddish color. Texture is very open, very little fine aggregate. Difficult to tell if fines have raveled or if texture was built with this appearance. Striations visible in right wheel path/driving lane.

* Records did not indicate source of additive.

FIGURE 7 Condition survey of open-graded friction courses on I-10, District 1.

DISCUSSION

Mixture Design

Optimum binder contents obtained for each of the six treatments varied from 5.7 to 7.4 percent by weight of mix. The FHWA design procedure determines optimum binder content as a function of the coarse aggregate absorption. What is assumed is that viscosity of the binder does not affect binder content. Therefore, binder contents should be equal for mixtures containing liquid antistripping agents, viscous polymer modified binders, or mixtures containing hydrated lime. However, field experience indicates that binder viscosity and minus No. 200 fraction (lime) have a significant effect on binder content. The modifications made to the design procedure were intended to measure these differences. As was expected, treatments containing a liquid antistripping agent required less binder than the control mixture because of lower viscosity and greater flow potential. However, only the Navajo mixtures containing hydrated lime required additional binder when compared with the control. The Cosden mixtures containing lime required less binder than the control when using the modified procedure. These results were not expected and could indicate modifications made to design procedures are not sensitive enough to small (1.5 percent) changes in minus No. 200 content.

The treatment containing polymer modified binder without lime required the same binder content as the treatment with 1.5 percent liquid antistrip. This was unexpected because of the significantly different viscosities of the two binders. The subjective nature of the modified OGFC mix design procedure may be somewhat responsible for this apparent anomaly since optimum binder content is related to binder flow characteristics under relatively low shear. Further work is required to determine whether the method could be modified to account for this apparent difference. However, it seems reasonable that higher binder contents should be expected, and would be desirable, for stiffer binders.

The three different asphalt sources required a variety of binder contents for certain of the treatments. However, none of the asphalts consistently presented a trend to higher or lower binder requirements.

Stripping Test

Results of the stripping test (Tex-530-C) indicated that removal of the asphalt film in the presence of boiling water could be significantly improved by use of a liquid antistripping agent, a polymer asphalt modifier, and a combination of polymer modified asphalt and lime treatment and hydrated lime slurry treated aggregates.

Results of the stripping test varied somewhat, with the visual judgment of the technican performing the evaluation and on the source of asphalt used. However, the general ranking of stripping effectiveness can be summarized as follows:

Rating of Stripping Prevention	*Treatment*
1 (best)	1.5% Pavebond
2	3% polymer/1.5% lime slurry
3	0.5% Pavebond
4	3% polymer
5	1.5% lime slurry
6 (worse)	control

Generally, all treatments provided significant improvement to stripping potential compared with the control.

Although all three control asphalts demonstrated stripping potential, the Cosden asphalt appeared to be more susceptible than either of the other two binders. However, the Cosden asphalt also appeared to benefit the most from all of the treatment conbinations used. The Chevron asphalt demonstrated the best performance as a control binder but also was affected least by the various antistripping treatments.

Summary

Five antistripping treatments and controls were compared for open-graded friction course mixtures by using a laboratory boiling test. Mixtures were compared at respective optimum binder contents as evaluated by a modification to the FHWA open-graded friction course design procedure. Optimum binder content varied with the treatment used but generally decreased when a liquid antistripping agent was added to the binder, as was expected. The expected increase in binder content due to addition of hydrated lime was not measured and may indicate that further modification of the design procedure is required.

All antistripping procedures evaluated provided a significant decrease in the stripping potential of the control mixtures for all three asphalt sources tested.

Because each of the treatment combinations was evaluated for stripping at the optimum binder content, no information was collected to determine the effect of binder content on stripping potential. Because binder contents may vary in the field, an evaluation to determine effect of binder content should be undertaken.

It would be desirable to compare binder contents used in the field to performance of these pavements as a means of obtaining a better laboratory mixture design procedure.

CONCLUSIONS

- Five types of antistripping treatments used in open-graded friction course mixtures were evaluated requiring binder contents ranging from 5.7 to 7.4 percent by weight.
- Required binder contents were lower for mixtures containing liquid antistripping agents when compared with control mixtures. However, mixtures treated with hydrated lime slurry did not necessarily require increased binder content.
- Although each asphalt was either an AC-10 or 85-100 grade, the source of asphalt affected the optimum binder content.
- The Cosden AC-10 asphalt appeared to be more susceptible to stripping than the other two binders when no antistripping treatment was used. The Chevron AC-10 asphalt appeared to be least susceptible to stripping when no antistripping agents were used. As a consequence, performance of the Cosden asphalt was most improved by use of antistripping treatments and the Chevron asphalt was least improved.
- Each of the five treatments studied provided reduced asphalt stripping when evaluated by using the boiling test. Although conventional antistripping agents such as hydrated lime slurry and a polyamine compound were effective in reducing stripping, a polymer modified asphalt used with and without lime treated aggregate was also found to be an effective antistripping agent. The polymer modified asphalt performed best when the mixture aggregate was treated with lime, but the polymer modified asphalt mixture without lime still performed better than mixtures treated with hydrated lime slurry and conventional paving asphalt. In fact, the lime treated mixtures containing conventional asphalt performed poorest when compared with other treatments, which may account for the differences in field performance observed by others.
- The results of the stripping test varied with the judgment of the technician performing the evaluation. Because of the subjective nature of the test, this outcome was not unexpected and indicates a standardized evaluation procedure should be developed.
- Comparison of the results of this laboratory work with field performance was not conclusive. Therefore, it is recommended that information regarding field performance of mixtures containing various antistripping treatments be collected to determine if a correlation between laboratory test results and field performance can be established.
- This study compared all treatment combinations at the theoretical optimum binder content such that differences between the five treatments could be measured. Further work should be conducted to determine the sensitivity of the mixtures to stripping as a function of binder content. The study should be an expanded version of this research such that additional combinations and types of antistripping agents are studied at a range of binder contents.

RECOMMENDATIONS

1. The sensitivity of open-graded friction course mixtures to stripping as a function of binder content should be explored. Further work should include a laboratory study to measure both the effect of binder content and the quantity and type of antistrip. Suggested treatments with at least three aggregate sources should include

- Polymer modified binders,
- Hydrated lime slurry,
- Dry lime,
- Location and method of lime addition,
- Polyamines, and
- Combinations.

Field evaluations should also be conducted where stripping or raveling is occurring in open-graded friction courses such that a comparison between the binders, antistripping agents, and results of mixture designs can be made. An evaluation of this type is important if prediction of open-graded friction course field performance from laboratory test results is desired.

2. The FHWA mixture design procedure for open-graded friction course mixtures should be further modified such that optimum binder contents predicted in the laboratory better correspond with binder contents expected to provide desired field performance.

3. A mixture design procedure should be adopted by the NMSHTD for use in determining optimum binder and gradation requirements for open-graded friction course mixtures. The design procedure should include a means of judging the water susceptibility of the mixture.

4. A full-scale experiment should be constructed such that a basis for comparison of the various antistrip materials and methods can be made with the laboratory procedures described in this paper. Ideally, the project would include several aggregate resources located throughout the state such that the effects of moisture on stripping or raveling, or both, could be thoroughly evaluated.

ACKNOWLEDGMENTS

Thanks go to the University of New Mexico Engineering Research Institute, which conducted this research under the direction of the principal author prior to his employ by the Asphalt Institute. Appreciation is also extended to Medford Pettit, District Construction Engineer in Deming, for sharing information related to open-graded friction course construction in District 1 and helping locate field projects where various types of open-graded friction course mixtures have been constructed.

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Publication of this paper sponsored by Committee on Characteristics of Bituminous-Aggregate Combinations To Meet Surface Requirements.