A Study of Factors Which Influence Type IV Sand Mix Performance

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EXECUTIVE SUMMARY

HAE Type IV Sand Mix has been used with success in Indiana since 1958. Starting in 1978 sand mix began experiencing a number of performance problems on interstate highways. In an effort to correct the problems, the mix specifications were modified. Each change in specification has either created a new problem or failed to solve the old problem. Through in-place field and laboratory testing, this report will offer evidence of the cause and solutions for each problem.

The results of this report indicate that sand mix depends strongly on permeability to reduce hydrodynamic pressure on wet pavements and maintain high skid resistance. A correlation is established in the report between permeability and baghouse fines.

The report concludes that baghouse fines are a major contributor to reduction of permeability in sand mix which results in lower skid numbers. Evidence is also given that baghouse fines are responsible for some of the other performance problems in sand mix.

HISTORY

Sand Mix has been used in the State of Indiana since it was first tested experimentally in 1958. K. E. McConnaughay who was instrumental in the development of this concept was looking for an economical mix which could give good skid resistance as well as riding quality. The Indiana Department of Highways was looking for a replacement for Kentucky Rock Asphalt which was known for its good skid resistant qualities. The results of the tests were good and Type IV Sand Mix went on to become the major surface type used in the State of Indiana with approximately 6,000 miles of road surfaces currently in use.

Until 1978 sand mix had virtually no performance problems to its record. However, in 1978 a particular type of pavement distress called delamination was discovered on two Interstate projects, I-65 and I-69. An investigation[1] of the problem by the Indiana State Highway Commission, K. E. McConnaughay, Inc., and the Joint Highway Research Project, School of Civil Engineering, Purdue University was undertaken in 1979 and 1980. In 1983, under some pressure from the Federal Highway Administration to do something about the problem, a change in specification was made. Based on this work, the Indiana State Highway Department proposed a gradation change in the specification. The modified gradation[2] eliminated any further delamination problems on interstate projects. However, due to difference in test results between wet and dry sieve gradations, some of the mixes produced were high in filler. The filler decreased the number of interconnected air voids in the mix. The result was a new pavement distress called blistering. This occurs when a non-permeable mix is placed over an open graded binder containing moisture. As pavement surface temperatures increase the moisture trapped in the binder forces itself out as a blister at the surface. Asphalt stripping of the sand and binder were evident in these blisters. As soon as the pavement cools, the blisters would disappear. This venting pattern continued until the water in the binder escapes. I-64 and I-69 both experienced blistering. A second problem with the gradation modified mix were lower skid numbers as in the case of I-70 east of Indianapolis. A very plastic filler used in achieving gradation made the mix virtually non-permeable and the plastic filler tended to remain in the asphalt film. The non-abrasive properties of the filler contributed to the low skid numbers. It should be noted that a number of jobs were laid using gradation modified sand mix which are performing well today in every respect. The concept for preventing delamination was good and should be recognized as such. It was difficult to predict at the time that large differences between dry and wet gradation would create such problems. Secondly the quality of the fillers were not understood or controlled at the time.

In late 1983 a committee to study sand mix performance was formed. The committee was a joint effort of emulsion producers and the IDOH Division of Materials and Tests. The committee was active in the study of I-64 blistering and made recommended changes to the specification in August of 1984.[3] The recommendations of the report were as follows. The first was to remove any fillers especially plastic materials from the mixes which were added to meet gradation. Secondly, in order to not have delamination the mixes needed to be strenghthened by increasing the keying action of the mix. This involved adding crushed washed stone sand rather than agg lime to the mix. Also an air void, and Marshall criteria were added to the mix requirements to ensure a mix that was both permeable and having enough strength not to delaminate. Because the change occurred in the middle of the paving season, a number of active jobs were redesigned using the new specification. It was also decided at the meeting that a much more thorough investigation of sand mix should be made. It has turned out that none of the Marshall design mixes have delaminated as of the present. However, because of the low skid numbers encountered on the gradation modified mixes it was felt the new Marshall mixes should be checked as early as possible. The initial skid test results taken in the fall and spring of 1984 and 1985 indicated that Marshall mixes average in the 40's which is typical of regular surface mixes, but far below the average sand mix of 60. Because of the lower than expected skid number and the continued concern for performance, the research initiated by the committee to study the problem was completed. The research program involved taking cores from a number of roads which had excellent performance and skid resistance as well as from roads which had poor performance. The study[4] concluded the following in November of 1984.

Mixes which delaminated all had an unusual characteristic of having large difference in air voids from the top to the bottom of the sand mix layer. This difference was due to the gradation of the sand used which resisted compaction. The kneading action of high speed truck traffic was sufficient to further compact the top half of the lift. This created a shear plane within the surface layer which delaminated the mix with traffic. To prevent this, a Fineness modulus requirement was placed on the sand. Air voids, low levels of limestone, and insolubles requirements were placed on the mix to guarantee skid resistance.

Because of concern over poor skid numbers and the past performance of every new change, it was decided that the new fineness modulus mixes would be placed in a research program[5] through the IDOH Division of Research and Training. The participants in the study are the: IDOH Districts; Division of Research and Training; the Division of Materials and Tests; the Joint Highway Research Project at the School of Civil Engineering, Purdue University; and Heritage Research which represents the emulsion producers.

The 12 projects in the research study include the use of fineness modulus mixes, slag sands, HAC sand mixes, and non-fineness modulus designed mixes such as Marshall and Florida bearing controlled mixes.

Four of the projects have been completed and skid tested currently. Again as in the case of Marshall mixes, the initial skid numbers appear low, averaging around 40 for regular sand and 47 for slag sand. One of the four projects, an F.M. design on I-74, has already exhibited a pavement distress in the form of rutting. Skid resistance was also much lower in this area. Testing on the distressed areas indicate that the mix failed to meet gradation and asphalt content criteria. The mix, however, was not so far out of specification as to expect so severe of a problem as encountered.

SKID RESISTANCE

Because the continuing low skid numbers for sand mix are a concern for everyone, a study of what factors influence skid resistance was undertaken. A review of the literature indicates the following factors impact largely on skid resistance of wet pavements:

1. **Surface Macrotexture —** The coarse aggregate in a bituminous mixture can influence skid resistance greatly. This is because the coarse aggregate is the major contact point between the road and the skidding tire. The height of the coarse aggregate can affect the surface channeling characteristics under the tire allowing water pressure not to build up and cause hydroplaning. In the case of sand mix, macrotexture is not as significant because aggregates height is small due to aggregate size.
2. **Surface Microtexture —** The microtexture or fine scale texture of a pavement relates to the fine grained aggregate. The fine grained aggregate can influence skid resistance by its chemical makeup. Fine grained sand may for example abrade away rather than polish. Moyer[6] in 1933 was one of the first to point out the importance of the sand paper type finish for achieving skid resistance. In sand mixes the use of acid insolubles to ensure a sufficient amount of non-polishing silica has always been specified.
3. **Channeling Characteristics —** Dense graded mixes (Air Voids around 4.0%) have historically achieved skid resistance from macrotexture or surface channeling because water cannot penetrate the surface. Pop corn mixes or open graded mixes which have been designed to increase the air voids in the mix allowing water to be pushed through the mix so that water pressure does not build up under the tire. Kentucky Rock Asphalt is also known for its excellent long term wet skid resistance. Hutchinsons, Kao, and Pendley[7] studied Kentucky Rock Asphalt and found that it had the ability to reduce hydrodynamic pressure by allowing water to pass through the interior of the mixture. The work used permeability equipment to measure how fast water could be pushed through the mix. Microtexture in the form of a fine grained silica which abraded away like sand paper also aided in maintaining high skid resistance for Kentucky Rock Asphalt.
4. **Wet Film Thickness —** One of the findings of the Florida Skid Correlation Study of 1967 — Skid Testing with Trailers[8] was that skid resistance results varied greatly with the water film thickness. The amount of water sprayed on the road before skid testing could give a variety of results. The study recommended rigid standardization of skid trailers. Under actual road conditions wet film thickness is critical. If wet film thickness is greater than tread depth on dense graded mixes, then hydroplaning can occur as low as 40 mph.

5. **Surface Geometry** — The profile of the road also had an effect on skid resistance. The crown of the road and how fast water is drained to minimize water film thickness are important factors in maximizing skid resistance. These factors generally are not considered from a skid testing standpoint, but are nonetheless important for driver safety. Galloway[9] summarized a number of important features on skid resistance in an AAPT symposia in the following way: "It has been shown by extensive laboratory and field tests that non-skid pavements must have microtexture, grittiness or small scale surface roughness whatever the vehicle speed used during the friction measurements. Additionally that surface in combination with the tire must exhibit ample and quick drainage of the water from between the tire contact area and the road surface, if this non-skid property is to prevail at high speed. Water escape may be effected by open cannels available in the pavement macrotexture and/or the tire tread or water escape into or through the top inch or two of the surface layer may be provided."

SKID RESISTANCE AS A FUNCTION OF TIME

After a review of the literature concerning skid resistance, the question remaining is why have the skid numbers on sand mix decreased in recent years. In order to answer this question, a better understanding of how skid numbers for sand mix change as a function of time was necessary. Two studies from the IDOH Division of Research and Training were obtained. The first was Optimizing Indiana Pavement Surface[10] and the second was the 1983 Executive Summary of Inventory Friction Trends.[11] Both studies indicate that sand mix in general has excellent initial skid numbers with a slowly decreasing skid number with accumulated ADT. The studies, however, did not investigate how sand mix skid numbers changed early in pavement life. A third study was also obtained from IDOH Division of Research and Training on Friction Testing of HAE IV and Slag Modified Mixes in the LaPorte District.[12] This study gave detailed information on a number of roads which were skid tested regularly. By comparing the average skid resistance of the Type IV Sand Mix versus time an interesting feature appears in Table A. A plot is listed in Graph A.

The plot shows that skid can increase significantly early in the life of the pavement. It should be cautioned that these roads were generally of low to medium ADT. If skid number was plotted against accumulated ADT, the peak skid number would occur around one million vehicles. The results of the study indicate that early skid information should be viewed on sand mix with a note of caution because skid numbers could increase greatly after the initial reading.

Graph A. LaPorte District Type IV Sand Mix. Skid Resistance vs. Pavement Age

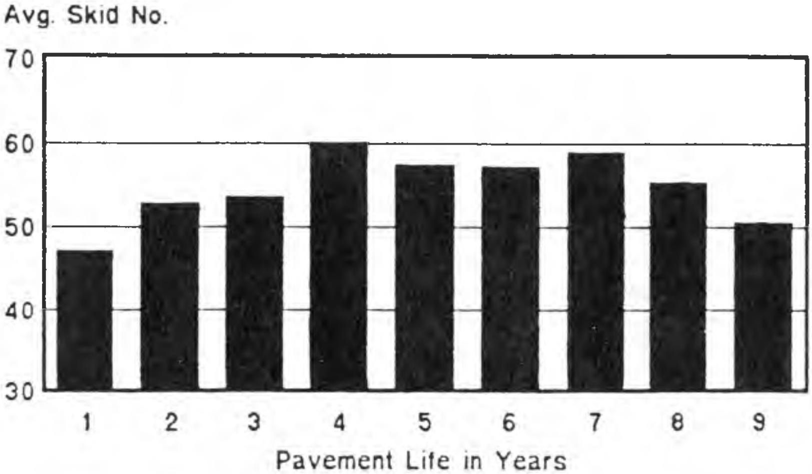


TABLE A
LA PORTE DISTRICT TYPE IV SAND MIX
SKID RESISTANCE VS. PAVEMENT AGE

Pavement Age Years	Skid No. (SN40)	Standard Deviation	No. of Jobs
1	47.3	± 5.8	12
2	52.9	± 6.4	12
3	53.8	± 8.2	9
4	60.1	± 7.7	12
5	57.5	± 6.2	16
6	57.4	± 4.7	9
7	59.1	± 6.0	5
8	55.4	± 6.1	4
9	50.7	± 0	1

PROCESS CHANGES IN MANUFACTURING HOT MIX

Looking back over the last five years certainly raises a number of questions. The first is why after so many years of success has sand mix all of a sudden become such a problem. It could easily be argued that sand mix was never exposed to the Interstate much before this time and simply cannot stand up to the traffic volumes and truck loads. This, however, does not hold up because there are a number of U.S. routes and state roads which carry traffic volumes and truck volume which approximate interstates. Also, a number of Interstate projects have per-formed well with sand mix. A second question to be raised is what has changed in recent times which might explain the inconsistencies or differences in performance between good and poor skid resistance in sand mixes. Poor skid resistance being not necessarily unsafe, but anything less the expected average of about 60. Some of the more prevalent changes in process of manufacturing sand mix are listed below.

PLANTS

Hot mix plants previous to 1970's were primarily batch plants. With the Interstate construction boom of the 1970's, drum plants became popular because of high production. Joe Sudal with IDOH Division of Research and Training raised the question of whether drum mix plants gave adequate mixing time as compared to batch plants. To find out if there were significant differences, Ted Lucas of Contractors United, Inc. was asked to check mixing time on drum mix plants. After discussion with plant manufacturers and actual testing, it was found that mixing time on three different drum plants was between 80-100 seconds. Batch plants have a minimum mixing time of 70 seconds so there is little difference between the two on a time basis. It could be argued that the type of mixing is different so the mixing is not the same.

AIR POLLUTION CONTROL

In the early 1970's EPA became a powerful influence on plant design through regulations on particulate from hot mix plants. The newer type baghouse collector could trap particulate fines more efficiently than wet scrubbers. The compactness of baghouse collectors made them more desirable for portable mix plants and because baghouse fines are returned to the mix there was no need of water and pits to dispose of the fines as in the case of wet scrubbers. Most new plants sold are of the drum baghouse combination because of the reasons outlined above. This is in sharp contrast to the plants of a decade ago and earlier which were mainly batch wetwash permanent plants.

FUEL TYPE

Over the past decade a change in the use of fuels has become evident. The use of reclaimed oils and very recently coal in some plants has become popular. The major reason for the changes have been economic ones. The question is whether these fuels could be having adverse effects on hot sand mix or in more general terms on hot mix. This problem has been investigated in two ways. The first was an experimental test sponsored by EPA to determine the burning efficiency of hazardous waste. The testing occurred at a Contractors United, Inc. plant earlier this year. A reclaimed #4 fuel oil was used at the time of the test. During the study small quantities of hazardous solvents were added to the reclaimed fuel and measured for destruction at the stack. If the fuel burned inefficiently then the solvent might not burn. The final report is not complete, but the overall tests indicated very low emission from the stack. The preliminary results indicated excellent destruction of the hazardous waste and complete burning of the reclaimed fuel.

A second method of investigating if fuel is efficiently being burned is to study baghouse and wet scrubber fines. If fuels remain unburned, the fuel will tend to be captured on the particulate dust passing through the plant. It is well known that wet scrubbers condense volatiles better than baghouse because of the temperature drop through the scrubber. This has been proven in stack tests which shows more volatiles in the stack of plants using baghouses than wet scrubbers. It is expected then that wet scrubbers should show more volatiles in the fines than baghouses. The volatiles can be from two sources either unburned or partially burned fuel or from the asphalt. In order to separate the two sources, a control test using natural gas was made. Since natural gas does not hve a volatile fraction then any volatiles would have to come from asphalt. These test results of the fuel study are listed in Table B. The results would indicate that a plant burning reclaimed fuel with a baghouse is showing virtually no unburned volatiles on the material captured by the baghouse. If the baghouse is returning 2-4% of the total mix, the overall effect on the asphalt would be too small to measure. In the case of wet scrubbers, it appears over half of the volatiles are from asphalt. The overall loss is less than 0.1% of the total mix. The #4 reclaimed fuel did have a slightly higher volatility than the natural gas. Again, the overall effect is extremely small, accounting at the very most for 0.05% total mix. It should be remembered that wet scrubber fines are not returned to the mix so the condensable volatiles do not end up in the mix.

TABLE B

Test	Plant Type	Pollution Equipment	Fuel Type	Volatiles %
1A	Drum	Wetwash	Natural Gas	2.4
1B	Drum	Wetwash	#4 Reclaimed	3.5
2A	Drum	Baghouse	#4 Reclaimed	0.30
3A	Batch	Baghouse	#2 Fuel Oil	0.25

SKID RESISTANCE VERSUS PLANT TYPE

In order to determine if plant type and pollution control equipment have an effect on skid number, a number of sand mix jobs which skid and plant type information was available were located. The information was limited because plant type and pollution equipment are never compared to skid number. Also skid information after five years cannot be compared equally to skid after ten years. The skid information was on roads after about one year of placement. The results can be found in Table C and a graph of the results is given below in Graph C.

Graph C. Plant Type vs. Skid Number

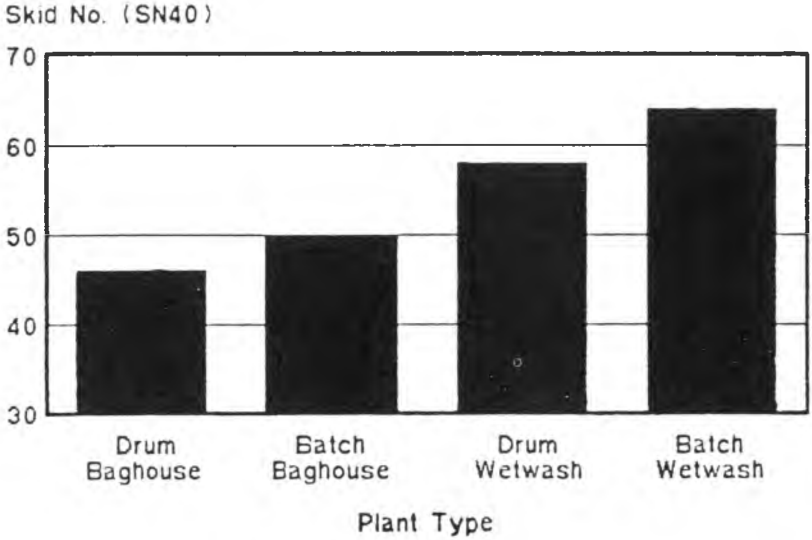


TABLE C
PLANT TYPE VERSUS SKID NO. (SN40)

	PLANT TYPE				
	Baghouse		Wetwash		
PROJECT	Drum	Batch	Drum	Batch	MIX TYPE
R-14046				71.6	Fineness Modules
R-10127		58.8			Regular Type IV
R-10930		52.6			Regular Type IV
R-10932		38.7			Regular Type IV
R-11239				55.4	Regular Type IV
R-11295		57.0			Regular Type IV
R-12970		41.0			Regular Type IV
R-12382			54.0		Regular Type IV
R-14815				67.7	Marshall
RS-14924	53.0				Marshall
RS-14818			62.4		Marshall
RS-13723		61.0			Regular Type IV

TABLE C (Continued)
PLANT TYPE VERSUS SKID NO. (SN40)

	PLANT TYPE				
	Baghouse		Wetwash		
PROJECT	Drum	Batch	Drum	Batch	MIX TYPE
RS-13756		46.0			Regular Type IV
RS-13773		46.9			Regular Type IV
RS-14051		49.6			Marshall
RS-14216		38.5			Marhsall
RS-14249	42.0				Marshall
R-14284	40.0				Marshall
R-14294	40.9				Marshall
R-14298		46.4			Marshall
R-14300		48.0			Marshall
R-14507	37.0				Marshall
R-14815				67.0	Marshall
RS-14924	53.0				Marshall
R-14705				68.7	Fineness Modulas
RS-14818			57.0		Marshall
RS-13943	38.4				Marshall
RS-14051		43.0			Marshall
R-14284	45.5				Marshall
R-13724	57.0				Gradation Modified
R-14734				68.4	Fineness Modulas
R-13773		49.1			Gradation Modified
R-14031				68.8	Fineness Modulas
R-14932				73.5	Fineness Modulas
R-10365		39.4			Regular Type IV
RS-11063		40.0			Regular Type IV
RS-11374		62.6			Regular Type IV
RS-11520		49.5			Regular Type IV
RS-11770				62.0	Regular Type IV
RS-11841				56.9	Regular Type IV
RS-12037				53.2	Regular Type IV
RS-12339	45.3				Regular Type IV
RS-12340	53.8				Regular Type IV
RS-14294	48.0				Marshall
R-14298		62.0			Marshall
R-14300		60.1			Marshall
R-14625		42.7			Marshall
R-14507	40.5				Marshall
RS-12423				57.6	Regular Type IV

TABLE C (Continued)
PLANT TYPE VERSUS SKID NO. (SN40)

	PLANT TYPE				
	Baghouse		Wetwash		
PROJECT	Drum	Batch	Drum	Batch	MIX TYPE
RS-12527		59.0			Regular Type IV
R-12549				53.3	Regular Type IV
R-12580				66.2	Regular Type IV
RS-12847	43.9				Regular Type IV
RS-12848	50.3				Regular Type IV
RS-13419		63.8			Regular Type IV
TOTALS					
Avg. Skid	45.9 ± 6	50.2 ± 8	57.8 ± 4	63.5 ± 7	
No. of Jobs	15	23	3	14	

The graph would indicate that baghouses have a detrimental effect on skid number. It also indicates that there is a difference between batch plants and drum plants with drums giving lower results.

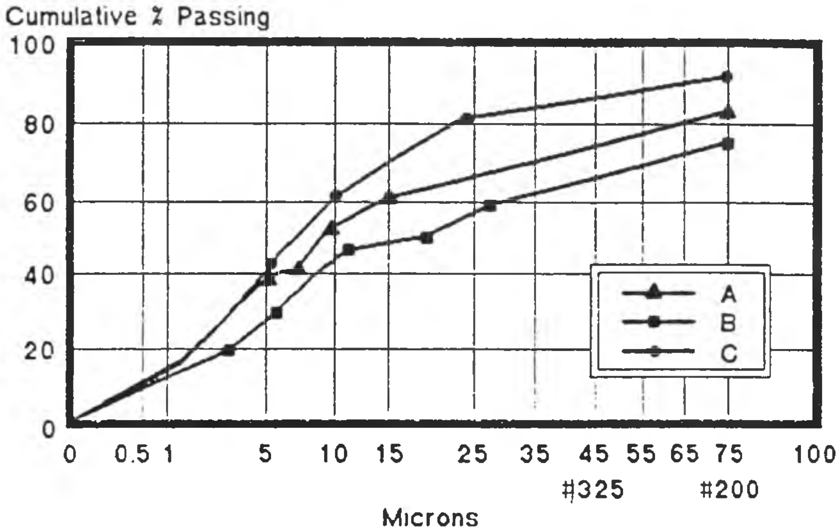
In order to understand why these differences exist, a more detailed study of the differences in each plant configuration is in order. One major difference is the fact that wetwash systems remove fines from the mix and baghouses re-incorporate the fines into the mix. A second difference is that the baghouse fines in a batch plant return with the aggregate and are mixed before asphalt is added to the pugmill. In drum plants, the baghouse fines return near the inlet of asphalt where they can be precoated with asphalt before mixing with the aggregate or be recaptured by the dust collection system. Finally, it should be noted that the data on drum wetwash combination is limited due to the low number of plants of this type in the state.

BAGHOUSE FINES

In order to understand the influence that baghouse fines and mineral fillers have on mix, a literature review was made. An especially informative study on mineral filler was made in a review by Tunnicliff[13] which showed that mineral fillers are not actually part of the aggregate system. The bulk of the mineral filler is absorbed into the asphalt film. This swells the asphalt film. It also acts as a colloidal filler which thickens the asphalt. Anderson and Goetz[14] did an extensive study to characterize baghouse fines and found them quite similar to mineral fillers. The purpose of mineral fillers has always been to reduce interconnected air voids in the mix preventing air and moisture from oxidizing the asphalt. This extends the life of the pavement and prevents premature hardening and the resultant thermal cracking. The Asphalt Institute also published a research report[15] on baghouse fines and concluded that baghouse fines if fed back in a controlled fashion could have beneficial effects on a mix by decreasing the interconnected voids. The study also concluded that baghouse fines alter the properties of the asphalt drastically. At significantly high levels the asphalt film becomes so stiff that the mix resists densification.

In order to determine what effect baghouse fines might have on asphalt, a number of baghouse fines from various plants were tested. From the above studies particle size was considered the most significant effect on binder properties. A plot of particle size on a Fullers 0.45 power curve is listed below in Table D & Graph D.

Graph D. Particle Size Distribution of Various Baghouse Fines (Sieve, 0.45 Power)



The baghouse fines were taken from plants running sand mix when possible. The level of baghouse fines that remain in an asphalt film is related to thickness of the asphalt film. Particles the size of the thickness of the film and finer will tend to stay in the film. A typical Type IV Sand Mix film thickness was calculated to be about 20 microns. From Graph D it is clear that a substantial amount of baghouse fines remain in the asphalt film. What effect the fines have on the asphalt's physical properties can be found in Table E. The level of fines in the asphalt film plays two important roles. First it swells the asphalt film larger, acting as an extender and lowering the volume of air voids and significantly reducing

TABLE D
PARTICLE SIZE DISTRIBUTION OF VARIOUS BAGHOUSE FINES BY ASTM D422

PLANT A		PLANT B		PLANT C	
Passing %	Particle Size Microns	Passing %	Particle Size Microns	Passing %	Particle Size Microns
81.3	75	73.0	75	90.2	75
68.0	25	57.5	28.3	79.7	23.7
60.3	14.6	49.7	18.8	70.5	16.1
51.7	9.3	45.7	11.1	60.1	10.1
41.7	7.0	39.2	8.2	52.3	7.5
40.2	5.1	31.3	6.0	44.4	5.6
28.1	2.8	19.6	3.2	28.7	3.0
17.1	1.4	13.1	1.3	17.0	1.3

the number of interconnected voids. Secondly, the baghouse fines stiffen the asphalt, changing its rheological properties and making it more difficult to achieve proper mixture density. If sand mix does not rely on interconnected voids for skid resistance, then the effect of baghouse fines should be minor. Baghouse fines under this scenario would have some initial effects but after wear should achieve similar skid results.

TABLE E
IMPACT OF BAGHOUSE FINES ON ASPHALT PROPERTIES

Blend by Wgt. Asphalt %/Fines %	PEN	Viscosity @ 140°F, P.	Ductility @ 77°F, cm.	Kinematic Vis. @ 275 cSt.	TFOT % Loss
100/0	57	1887	117	392	0.10
90/10	51	1940	91	415	0.10
80/20	47	2719	131	450	0.11
70/30	41	3684	74	496	0.15
60/40	34	5907	71	625	0.17
50/50	34	10593	57	949	0.17

PERMEABILITY

Type IV Sand Mix has always had an air void level of about 10%. This was felt based on experience to be sufficient for adequate permeability for water. When air voids were measured on I-64 when it blistered, I-74 which rutted, and I-70 which exhibited such low skid numbers, the air voids in those mix were under 10% in all cases. They were not, however, so low that they would be considered unstable for a normal mix. *The problem is that air voids do not measure the level of interconnected voids.* In researching this problem, Professor Tom White of Purdue University was contacted. Professor White felt that a permeability meter used by the Corp of Engineers Waterway Experimental Station could be useful in measuring interconnected voids. Professor White obtained the equipment on a loan from the Corp of Engineers.

The permeability apparatus measures air rather than water permeability and is the only ASTM[16] recognized method for measuring permeability of bituminous pavements. Permeability used in this study is defined as the property of a porous material that permits a fluid or gas to pass through it under an induced pressure.

The apparatus works by dropping water from one vessel to a lower vessel. This creates a positive pressure as it displaces the air in the lower chamber. The water volume is measured as a function of time to measure the volume of air pushed through the pavement. By adjusting the rate of water, different pressures are achievable. The unit of measure is volume of air in cubic centimeters per minute for a 4-in. diameter area of surface. A schematic diagram of permeability apparatus is given in Figure 1 below.

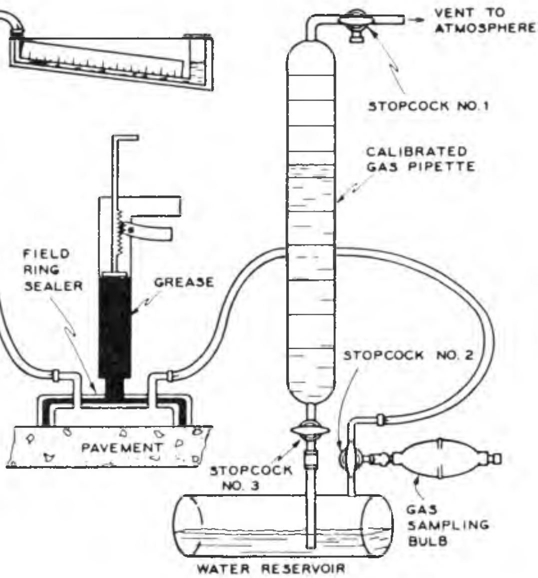


Figure 1.

After some initial experience with the equipment, a number of sites were selected based on current skid information. Both high and low skid resistance were checked for permeability to determine if a pattern existed. Plant type and other information on the pavements was gathered. A summary of the tests are listed in Table F. A plot of the results relating permeability versus skid number was made and is found in Graph F.

TABLE F

Project	From	To	Year Const.	Mix Type	Plant Type
US-52	EB		1985	FM Sand	Drum/ Baghouse
US-52	EB		1985	FM Sand	Drum/ Baghouse
US-52	WB	SR-9	1985	FM Sand	Drum/ Baghouse
I-70	WB		1983	Grad. Modified	Drum/ Baghouse
SR-121	SR-227	Ohio St. Line	1984	Reg. Met FM[a]	Batch/Wet
US-236	SR-39	SR-75	1984	Reg. Met FM	Batch/Wet
US-36	SR-59	End	1984	Reg. Met FM	Batch/Wet
US-231	SR-52	I-65	1984	Reg. Met FM	Batch/Wet
SR-114	SR-105	SR-9	1984	Marshall	Batch/Wet
SR-25	SR-17	SR-16	1979	Reg. Sand	Batch/Wet
SR-14	SR-25	SR-19	1980	Reg. Sand	Drum/Bag

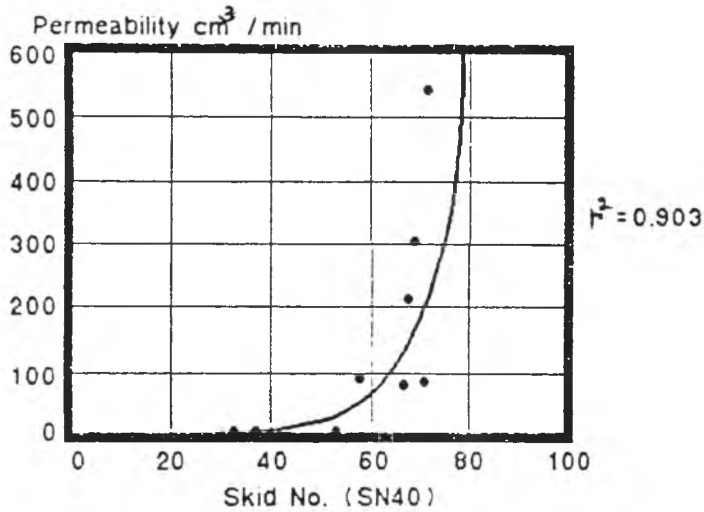
[a]These mixes were not FM designed, but met all FM criteria when placed

[b]Permeability is expressed in om^3/minutes @ 1 in. of water pressure.

Skid No /Date	Permeability[b]	Pavement Temp, °F	Comments
mid 30's (9/85)	3.1	64	Core #33124
mid 30's (9/85)	2.8	75	Core #33136
low 30's (9/85)	0.5	77	Core #33154
15 (1984)	0.5	75	Planning Site
71 (12/84)	89	97	2 mile EB
69 (12/84)	306	59	SB 2 mi.
68 (12/84)	220	64	EB
72	586	73	NB White Co. Line
67	85	77	WB Middle
53 (10/84)	6.0	79	NB
58 (10/84)	96	84	WB

so they are, in effect, FM mixes.

Graph F. Permeability vs. Skid Number (SN40) of Actual Road Jobs



A curve fitting technique using exponential curve fitting gave a coefficient of determination r^2 fit of 0.903 for the data. Considering all the other factors which influence skid resistance in a pavement, this information says that permeability is very important for sand mixes.

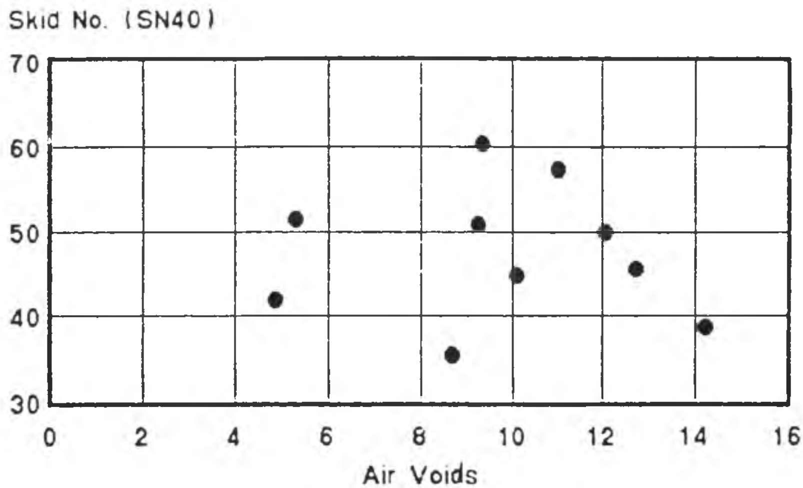
From all of this testing, it confirms that air permeability is a good predictor of interconnected voids and the ability of the sand mix to reduce hydrodynamic pressure between the tire-road interface.

Another part of this study was to determine if air void level also could predict skid resistance as well as permeability. A plot of the results are listed in Table G and is graphically displayed in Graph G.

TABLE G
SKID NUMBER VERSUS AIR VOIDS

Project	Road	Air Voids	Skid Number	Mix Type
R-13943	I-70	14.2	38.4	Marshall
R-13991	US-31	12.1	50.0	Marshall
R-14284	I-74	10.1	45.3	Marshall
R-14333	US-52	8.8	35.0	F.M.
R-14298	I-69	12.7	46.0	Marshall
R-13723	I-70	9.4	61.7	Reg. Type IV
R-13773	I-69	10.5	57.0	Reg. Type IV
R-13724	I-70	9.2	52.5	Gradation Modified
R-13773	I-69	5.3	52.9	Gradation Modified
R-12970	I-70	4.7	42.8	Reg. Type IV

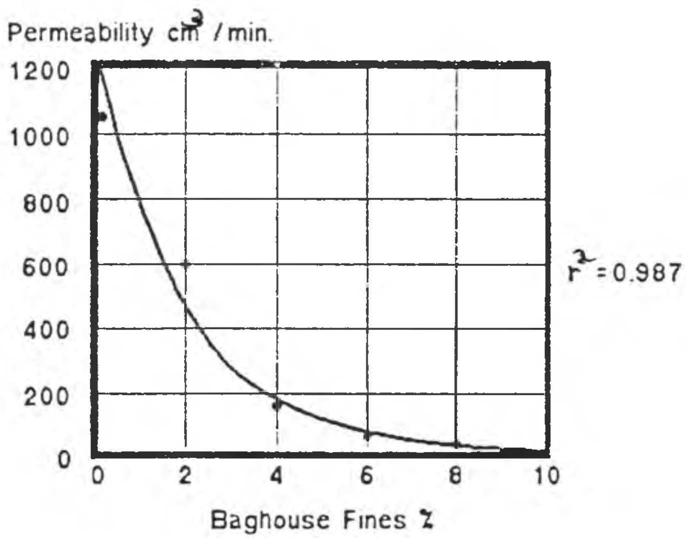
Graph G. Skid Number vs. Air Voids



The curve fitting technique shows no fit greater than r^2 coefficient of determination of 0.016. This indicates that air voids are not a predictor and can not be counted on as an indicator of permeability or skid resistance. This is clearly due to the fact that interconnected void level and pore size are more important than the total number of voids.

Now that a correlation between permeability and skid resistance in sand mixes has been established, it is important to know what properties effect permeability in mixes. As was stated earlier, mineral fillers and baghouse fines tend to swell the thickness of the asphalt film. This could be the cause of reduced permeability in sand mixes. To test this a #24 sand from American Aggregates in Richmond was sampled. Also sampled were baghouse fines from a CUI plant running sand mix for contract R-14643 on SR-27. The aggregate was checked for gradation and wet sieved to measure the level of minus #200 sieve material. The aggregate was tested as is and also washed of all #200 material to simulate a wet-wash system. Baghouse fines were added to the sand in controlled amounts and mixed with AE-60. The mixture was heated and mixed to 240°F until all moisture was released. The mixture was compacted 75 blows each side by Marshall compaction. Great care was taken to treat all samples identically. Each laboratory pill was tested in a laboratory apparatus for the permeability test. The effect of increasing or decreasing asphalt content was also tested for several of the samples. Each pill was tested for permeability at a variety of pressures. Air voids and density were also measured to determine what effect they had on permeability. The results of the tests are listed in Table H. A number of interesting facts arise from the results. The first is how permeability at constant pressure (1 in. water) changes with the level of filler in the mix at one asphalt content (7.5%). A graph of the results are listed in Graph H-1 below.

Graph H-1. Permeability vs. Filler Content on Laboratory Compacted Samples



An r^2 coefficient of determination of 0.987 indicates a strong relationship between baghouse fines level and permeability. Permeability above 200 cm^3/mn was considered to give good skid results in the field. Based on the graph, any baghouse fines level above 3.5% would be detrimental. In looking back at some of the gradation modified, Marshall, and new F.M. designed mixes, the 3.5 level was exceeded in almost all cases where baghouses were used. This is especially true of interstate work. Another plot which was interesting was asphalt content versus permeability at different levels of baghouse fines. This is listed in graph H-2 below. In this plot asphalt content has a substantial effect on permeability at low baghouse fines content and a smaller effect at high baghouse fines content. This is because asphalt is low in density and high in volume compared to filler on an equal weight basis. Another important factor is that permeability which is a measure of interconnected voids falls in a exponential fashion with baghouse fines content (See Graph H-1). As the interconnected voids decrease the effect of asphalt content is less measurable.

Graph H-2. Permeability vs. Asphalt Content
at Various Filler Levels

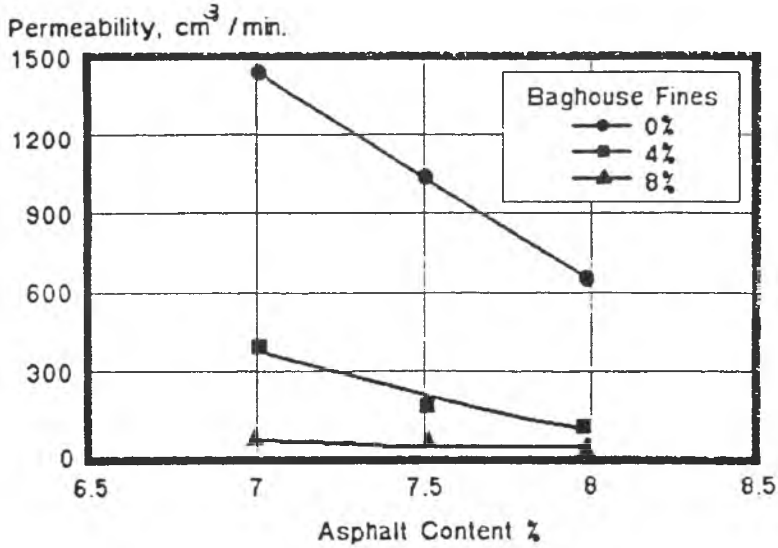


TABLE H
PERMEABILITY VERSUS BAGHOUSE FINES ON LABORATORY PREPARED SAMPLES OF HAE-TYPE IV SAND MIX

Baghouse Fines %	AE-60 Asphalt %	Permeability @ 1 in.	% Air Voids	Density lb/cu ft
0	7.0	1477	12.3	130.6
0	7.5	1048	10.2	133.8
0	8.0	663	9.3	133.9
2	7.5	592	8.4	136.4
4	7.0	414	7.8	137.4
4	7.5	148	7.1	138.4
4	8.0	122	6.5	139.3
6	7.5	71	5.0	141.6
8	7.0	56	3.8	143.2
8	7.5	28	3.8	143.2
8	8.0	13	3.6	143.5

The test results are quite meaningful because they graphically show that baghouse fines at even low levels are very detrimental to sand mix. In reviewing the literature on skid resistance and sand mixes a report was found from K. E. McConnaughay dated 12/58. In the report[17] Mac reviewed the first three experimental sand mix jobs placed in Indiana and stated the following. "Silica sand mixtures have been given credit for skid resistance; however, in many states sand mixtures are not safe in this respect. It is our opinion that when voids in the sand mixture are filled with asphalt and filler, the pavement will not be skid resistant." Based on the work in this study, it appears Mac was right.

CONCLUSIONS

1. Baghouse fines reduce permeability greatly in sand mixes. The reduction of permeability has a direct effect on reducing skid number of the pavement. Many of the changes in the sand mix have done little to improve skid resistance because baghouse fines have such an overriding influence on the performance and skid resistance of the mix.
2. Early skid data from a pavement with less than one million accumulated ADT may not give accurate information on the eventual skid resistance of the pavevment.
3. Drum plants versus batch plants appear to have similar mixing times.
4. Other factors beyond permeability are important to short and long term skid resistance. Silica content, polishing characteristics, and road geometry all impact on skid resistance and should not be overlooked.
5. Fineness Modulus of the sand is still believed to be important in preventing delamination because of compactability. This study did not change any of the previous work in this area.
6. Blistering in sand mixes appears to be the result of adding fillers and baghouse fines in the mix over open graded wet binders. Elimination of baghouse fines and plastic fillers will prevent this from happening.
7. Rutting on contract R-14457 for I-74, was the apparent result of inconsistent return of baghouse fines. Samples of small portions of the road before removal showed clumps of high filler and asphalt. Samples as high as 14% filler and 11% asphalt were found. The low skid resistance of the section was also evidence of the nonpermeability of the mix. Removal of baghouse fines again will solve this problem.
8. Although the fuel study was far from complete, it appears that reclaimed fuels when burned properly leave little residue in the fine aggregate or asphalt film.

RECOMMENDATIONS

1. On all future sand mix work it is recommended that baghouse fines not be returned to the mix. The baghouse fines can be handled in one of several fashions. Remove and return to the aggregate source for disposal. Store in a bin and use in base mixes where they are beneficial for reducing permeability. If this is done then they should be added in a controlled fashion. Finally, if neither of the first two methods are available then dispose of the material in an appropriate landfill. For

transportation it is better to keep the baghouse fines wet to prevent fugitive dust problems.

2. On high traffic roads continue to require fineness modulus mixes.

LITERATURE CITED

[1]Rucker, A.M., "Investigation of HAE Type IV Surface Distress," IDOH Materials and Tests, 1981.

[2]IDOH Special Provisions, "Specification for Modified Type IV Sand Mix," 1983.

[3]IDOH Special Provisions, "Specification of Marshall Designed Sand Mix," 1984.

[4]Committee on Sand Mix, "Report on Type IV Sand Mix Pavement Problems," November 2, 1984.

[5]IDOH Division of Research and Training, "Study Plan for Evaluation of HAE Type IV and HAC Type D Sand Mixes," April, 1985.

[6]Moyer, R.A., "Skidding Characteristics of Road Surface," Proceedings, Highway Research Board, 13th Annual Meeting, December, 1933, pp. 3-48.

[7]Hutchinson, J.W.; Kao, T.Y.; Pendley, L.C., "Pavement Dynamic Permeability Testing," ASTM Symposium on Highway Skid Resistance, Atlanta, Georgia, September 29-October 4, 1968, ASTM STP456, pp. 159-176.

[8]Smith, L.L.; Fuller, S.L., "Florida Skid Correlation Study of 1967," ASTM Symposium on Highway Skid Resistance, Atlanta, Georgia, September 29-October 4, 1968, ASTM STP456, pp. 4-101.

[9]Galloway, B.M., "A Review of Current Methods and Mechanisms for Producing Skid Resistant Pavements," Paper presented at the Meeting of the Association of Asphalt Paving Technologists, Houston Texas, February 12-14, 1973, pp. 352-439.

[10]Kercher, K.J.; Gulen, S., "Optimizing Indiana Pavement Surfaces,' IDOH Division of Research and Training, September, 1982, Report No. FHWA/IN/RTC-82/1.

[11]Kercher, K.J.; Gulen, S., "1983 Executive Summary of Inventory Friction Trends," IDOH Division of Research and Training, July, 1984.

[12]Kercher, K.J., "Friction Testing HAE IV and Slag Modified Surfaces in LaPorte District," IDOH Division of Research and Training, July 1, 1985.

[13]Tunnicliff, D.G., "A Review of Mineral Filler," Paper presented at the Meeting of the Association of Asphalt Paving Technologists, New Orleans, Louisiana, January 29-31, 1962, pp. 118-150.

[14]Anderson, D.A.; Goetz, W.H., "Mechanical Behavior and Reinforcement of Mineral Filler Asphalt Mixtures," Paper presented at the Meeting of the Association of Asphalt Paving Technologists, Houston, Texas, February 12-14, 1973, pp. 37-66.

[15]Shook, J.F.; Erck, J.H., "The Effects of Baghouse Fines on Asphalt Mixtures," Paper presented at Canadian Technical Asphalt Association Annual Conference, Winnipeg, Canada, November 20-22, 1978, Asphalt Institute Research Report 78-3.

[16]ASTM D3637 Volume 4.03, Road and Paving Materials; Traveled Surface Characteristics, April, 1985, pp. 620-628.

[17]McConnaughay, K.E., "Skid Resistance Pavements," K.E. McConnaughay, Inc., Lafayette, Indiana, December, 1958.