These calculations show that a 30 ft. fill may produce loads on a 48 in. pipe ranging from 10,500 lb. per lin. ft. to 28,300 lb. per lin. ft. depending upon the nature of the installation conditions.

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BITUMINOUS PAVEMENT INVESTIGATION IN UTAH AND COLORADO

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SYNOPSIS

The failed spots in nine bituminous paving projects in Utah and fifteen in Colorado were examined to determine, if possible, the causes of failure. The method of study consisted of group observations and discussions supplemented by detailed information and laboratory tests on quality and thickness of base and subbase courses, character of subgrade soil, drainage and moisture conditions, quality and condition of bituminous surface mixtures. The effects of traffic and maintenance were considered.

It is stated that the extent of the investigation did not permit positive conclusions on the causes of the observed defects. However comparisons of the test data with specification requirements indicates that construction control was deficient on many of the projects.

Among the discrepancies are excess of fines, wide variance in bitumen content of samples from the same projects and lack of correlation between bitumen content and the proper amount for the aggregate in use.

Some distortion in the wheel paths indicates insufficiency of support due to inadequate design.

During early June 1949, nine typical bituminous paving projects in Utah and 15 in Colorado were examined in an attempt to obtain information on the causes of any failures observed. Most of the pavements in these States are of the low cost or intermediate bituminous type, and while most of them are in excellent condition and have given very satisfactory results, there have been enough local failures to warrant investigation. These projects varied in age from one to ten years and in most cases were old enough to show evidence of failure if such failures were to develop, yet they were not so old as to have been built under entirely inadequate design standards for the traffic. It was planned to make the investigation as early as possible in the season in order to observe the more adverse moisture and drainage conditions at that time.

Most bituminous surfaces in the two States are of the dense-graded road-mixed type about 2 in. thick, generally employing an MC-3 asphaltic material, although many of the older surfaces were mixed with an SC-3 type. In recent years, there has been a definite trend toward the hot plant-mixed type using paving asphalts, particularly on the more heavily traveled routes. The bituminous surfaces on the plant-mix projects are generally 2 to 3 in. thick using 85–300 penetration asphalt cements.

Traffic on the projects studied varied from 350 to 6800 vehicles per day with the commercial traffic percentages varying from 5 to 26 as shown by Table 1.

It was hoped the investigation would show any weaknesses in design methods, specifications, or construction control so that improvements might be made on future work. As it turned out, the main weakness discerned was in construction control. Since representatives of the State Highway Departments of Utah, Colorado and New Mexico were present and took an active part in the investigation, it was felt any conclusions reached at the time could be put to immediate use in each of the States. Many of the conclusions reached in the field could, however, be only tentative since they were subject to revision on completion of the subsequent laboratory tests. In general, however, the conclusions reached in the field were corroborated by the later laboratory tests.

TABLE 1
TRAFFIC DATA

Project	Test Holes No.	Average Vehicles per Day	Commercial[a]
			%
Utah FAP 60-C	1, 2, 3	1620	25
Utah FAP 60-B	4, 5	1620	25
Utah FAP 103(2)	6, 7	2550	23
Utah FAP 49(2)	8	2550	23
Utah FAP 218(2)	9, 10	1925	16
Utah FAP 33(5)	11, 12	1655	22
Utah FAP 134-C	13, 14, 15, 16	485	25
Utah FH 4-B4	17, 18, 19, 20, 21	782	26
Utah FAP 187-A.	23	782	26
Colo. FAP 150-D(3)	1, 2, 3	800	16
Colo. S-0121(1)	4, 5	350	17
Colo. S-0121(2)	6	350	17
Colo. FH 29-B3, C2, etc.	7, 8, 9A, 9B	825	5
Colo. SN-FAP-44-A(1)	10, 11	1400	24
Colo. FI-44(4)	12, 13	700	24
Colo. FI-44(3)	14	700	24
Colo. SN-FAP-67-A(2)	15, 16	3500	5
Colo. SN-FAP-67-A(3)	17	3500	5
Colo. SN-FAP-67-A(4)	18	1800	5
Colo. FAP 116-A(4) & B(3)	19, 21, 22	6800	11
Colo. S-46(3)	23	100	16
Colo. S-46(4)	24	100	16
Colo. FI-2(15)	25	1900	12
Colo. FAP 2(8)	26	1900	12

[a] In Utah these percentages are for pickup trucks or larger. In Colorado they are for dual tired trucks or larger (equivalent to 1½ ton trucks or larger).

PROCEDURE

Projects to be studied and sampled were selected in advance and all available information on the design and construction assembled. Sheets carrying this information were typed and made available to those participating in the study.

Since past experience indicated that bituminous pavement behavior is most frequently dependent upon such factors as quality and depth of base course and subbase, character of subgrade soil, and drainage, it was planned to obtain as much information about these parts of the highway substructure as time and facilities permitted. However, it was felt the principal value of the investigation would be obtained by the group observations and discussions supplemented by such simple sampling and testing as time would permit.

On each project, stops were made to observe areas where the bituminous pavement was showing distress, and for comparison, at areas which appeared to be adequately carrying the loads. At each stop, notes were made on the general pavement condition, topography, drainage, or any other factors which might serve to affect the service given by the road. At most locations, test holes were dug through the bituminous surface, base, and subbase (if any) into the subgrade. (See Fig. 6.) Samples for later tests were taken of each layer of material so encountered. Notes were made on the depth of each layer as determined by measurement and on the general nature, appearance, and condition of the various materials and of the pavement itself. Samples were placed in tight cans for moisture determination. In the case of the bituminous surface itself, samples were obtained for extraction and moisture tests and grading of the aggregate.

Subsequent laboratory tests on the samples collected were made by the highway laboratory of the State in which the samples were collected. These tests included for each material the following:

Subgrade—Soil classification by Highway Research Board method and moisture content.

Subbase—Mechanical analysis, Liquid Limit, Plasticity Index, Classification, and Moisture Content.

Base Course—Mechanical Analysis, Liquid Limit, Plasticity Index, and Moisture Content.

Surface Course—Extraction (bitumen content), Moisture Content, and Mechanical Analysis of residue.

In some cases, the CBR test was run on subgrade, subbase, or base course materials. While it was realized that more comprehensive sampling and testing would have been desirable, this was not possible if the duration of the grade supporting power were responsible for the failures observed.

Total Depths of Granular Cover over Subgrade—As a guide to the adequacy of the total depths of subbase, base, and wearing course found at the various test holes, the depths were compared with those recommended by Mr. D. J. Steele in the Highway Research Board *Proceedings* for 1945. On this basis, conditions shown in Table 4 were found for the Utah and Colorado projects studied.

Quality of Subbase Materials—Subbase materials were not generally found on the Utah projects sampled but were the rule on the Colorado projects. These materials were usually of the selected material type from natural deposits of sand and gravel. Results on the subbase materials sampled are shown in Table 5 and summarized in Table 6.

TABLE 6
SUMMARY OF TESTS ON SUB-BASE MATERIALS

	Utah	Colorado	Combined
No. of samples tested	5	15	20
Avg. liquid limit	25	24	24
[a]Avg. plasticity index	8	1	3
Avg. pass No. 200—per cent	25	20	22
Avg. moisture—per cent	—	6	6

[a] Non-plastic considered as 0

TABLE 7
COMPARISON OF SUB-BASE MATERIALS WITH STANDARD SPECIFICATIONS

	Percentage of Samples Tested		
	Utah	Colorado	Combined
1. With more than 25 per cent passing No. 200	60	33	40
2. With plasticity index greater than 6	60	13	25
3. With liquid limit greater than 35	0	0	0

If it is considered that satisfactory subbase materials should contain not over 25 percent passing the No. 200 sieve, have a plasticity index not greater than 6 and a liquid limit not greater than 35 (as commonly called for by the specifications) the subbase materials tested qualify as shown in Table 7.

The most common defect in the subbase materials tested was the high percentage of the minus No. 200 size frequently found, although the few Utah subbase samples also averaged quite high on the plasticity index.

Quality of Base Course Materials—The base course materials were, in all cases, of the dense-graded type from natural deposits of sand, gravel, and soil binder, with the oversize gravel in the pits crushed to size. Results of tests on base course material are given in Table 8. To conform to standard specifications, a satisfactory base course material should contain less than 15 percent passing the No. 200 sieve, have a liquid limit not greater than 25, and a plasticity index not greater than 6. On this basis, the base course materials compare with standard specifications as shown in Table 9.

Base courses on the Colorado projects show a generally higher percentage passing the No. 200 sieve, but are somewhat better than the Utah projects on the liquid limit and considerably better on the plasticity indexes. Moisture contents of the Colorado bases were consistently low enough so that the bases should have been in a stable condition at the time of the investigation.

Tests of Micaceous Leveling Course—Samples of the micaceous leveling course used on a Colorado Forest Highway Project (see Figure 1) were tested to determine the modulus of elasticity and rebound under repeated loading. Tests were made on typical micaceous samples from this project and also on a similar A-2-4 soil which was non-micaceous. All samples were compacted to 95 percent of maximum dry density at optimum moisture, compaction being by static load in the CBR mold.

From the tests it was found that rebound under repeated loadings of 100 psi. was twice as much for the micaceous samples as for the non-micaceous one. Modulus of elasticity for the micaceous samples was 2021 psi., and for the non-micaceous material 7000 psi. This elastic property does not appear to show up in routine soil tests. However, it is a property which may well account for some of the pavement cracking observed on this project as well as on other projects where micaceous materials have been used.

Quality of Bituminous Surfacing Mixtures—Tests on bituminous surfacing samples are listed in Table 10. For purposes of comparison it is assumed that a satisfactory bituminous surface (of the dense-graded type as was the case on all of the projects examined) should conform to the following requirements:

(a) Have a bitumen content within the normally accepted range for the grading of aggregate involved. (Various formulas, Bureau of Public Roads, Colorado and New Mexico, were used in determining this normally accepted range of bitumen content. All of them are based primarily on the surface area of the aggregate).

(b) Contain not to exceed 15 percent passing the No. 200 sieve.

(c) Contain not to exceed 2 percent moisture (as generally called for by the specifications, although only those mats containing in excess of 2.5 percent moisture were consistent failures, as will be shown later).

On the basis outlined above, the bituminous pavement samples tested qualify as shown in Table 11.

TABLE 8
BASE COURSE MATERIALS

Test Hole	Depth	1 in.	No. 4	No. 10	No. 40	No. 200	L.L.	P.I.	Moisture	Remarks
	in.								%	
Utah										
1	7	94	35	29	16	8	19	NP	12	
2	7	94	49	40	25	14	20	4		
3	9	60	33	28	18	10	20	3		
4	7½	69	46	41	18	10	19	NP		
5	9½	63	42	37	19	9	18	NP		
6	7	96	50	42	35	15	21	4		
7	7½	93	49	37	32	15	25	7		
8	12½	83	46	38	30	13	21	4		
9	5	97	52	34	22	15	26	9		
10	4½	92	49	34	23	17*	26	9		
11	17	86	31	22	15	11	24*	6*		
12	4	86	36	29	25	22*	32*	14*		
13	4	100	69	59*	38	26*	30	12		
14	2½	100	54	37	22	14*	22	3		
15	4	100	56	48*	35	27*	30	11		
16	2½	100	58	49*	39	31*	29	11		
17	3½	100	49	39	31*	17*	29*	12*		
18	4½	100	40	30	23	12	12	12*		
19	3½	100	44	37	30	11	17	NP		
20	3	100	48	39	32*	16*	20	NP		
21	6½	100	53	48	35*	26*	21	NP		
23	5	95	48	36	22	15	22	4		
Colo.										
1	7½	63	36	30	23	11	18	NP	5	
3	5	93*	56	46	35	15	15	NP	5	
4	4	83*	53	45	32	24*	23	NP	7	
5	8	78*	50	43	30	19*	25	NP	7	
6	4	63*	35	28*	13	5*	25	NP	6	Specs.—No. 200 = 7-15%
7	2	97	81	72*	50	24*	28	NP	9	
8	4	99	90	81*	56	33*	30	8*	6	CBR = 7.4%
9A	5	99	94	84*	57	21*	25	NP	8	
9B	5	99	92	84*	57	21*	26	NP	8	
10	8½	98	68	56*	39	21*	28*	NP	5	
11	10	82*	61	53	36	22*	24	NP	5	
12	3½	100	91*	87*	67	33*	22	NP	5	
13	4	100	59	47	29	15	24	NP	4	
14	4½	93*	60	51	35	19*	25	NP	3	
15	4	89*	57	47	27	16*	29*	11*	6	
16	3	100	65	51	28	15	—	—	7	Oil in sample
17	2½	84*	64	57*	38	22*	25	NP	8	
18	8½	86	46	39	23	13	23	NP	5	
19	2	100	77	65*	44	26*	29*	13*	8	
	7	100	92	72*	40	14	21	NP	6	
21	2	100	81	56*	24	11	25	NP	5	
22	3	100	67	47	19	7	23	NP	3	
25	6	100	44	32	22	4*	19	NP	5	Specs.—No. 200 = 5-15%
Average										
Utah	6	91	47	38	27	16	23	6	—	
Colo.	5	92	66	56	36	18	24	1	6	
Comb.	6	91	57	47	31	17	24	4	6	

* Outside Specifications Limits
No base course at Test Holes Nos. 2, 23 and 24. (Colorado)

From Table 11, it appears that proportioning of the bituminous material is inaccurate under field construction conditions. The Colorado projects tended to be too lean but with a relatively high percentage of moisture. Of the Utah samples tested, a considerable proportion contained an excess of bitumen, but all were quite low on moisture content. While the Colorado projects generally had an appearance of greater "richness," the test results indicate this rich appearance resulted from an excess of moisture rather than an excess of bitumen. The Colorado projects also contain a definitely higher average percentage of the minus 200 size than the Utah projects. There

TABLE 9
COMPARISON OF BASE COURSE MATERIALS WITH STANDARD SPECIFICATIONS

	Percentage of Samples Tested		
	Utah	Colorado	Combined
1. With more than 15 percent passing No. 200	36	54	46
2. With liquid limit greater than 25	36	30	33
3. With plasticity index greater than 6	46	9	27
4. Avg. moisture content of bases	—	5.6	—

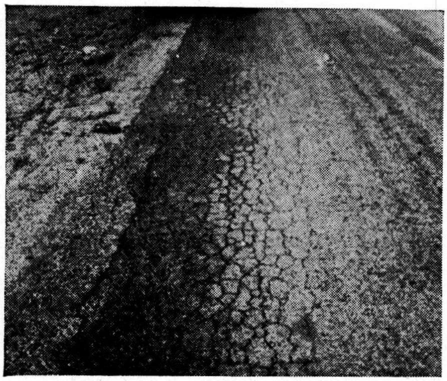

Figure 1. Colorado Test Hole No. 7: Typical Cracking over Micaceous Base Course

appears to be some correlation between high minus 200 size in the pavement and the percentage of moisture contained therein, as indicated by Figure 2. It was found that all of the mat materials having moisture contents above 2.5 percent had failed. However, the converse (that all failed mats have moisture contents above 2.5 percent) is not at all true since, of course, bituminous pavements may fail from causes not connected with the pavement itself.

It would be expected from the results of laboratory trial mixes that the lean mixes would tend to absorb more moisture than the rich ones. This did prove to be the case in the Utah samples but not in the Colorado samples, as indicated by Table 12.

There are, of course, numerous other factors influencing the amount of moisture contained in a sample of bituminous surfacing. One factor, as already brought out, is the amount of fines (minus No. 200) in the mix. Another is the availability of moisture (dependent on climate and drainage conditions), water tightness of seal coat, or whether the mat has become broken from unstable foundation conditions or other causes.

PAVEMENT SETTLEMENT IN WHEEL PATHS

One pronounced type of bituminous pavement distortion noted, especially on roads carrying a considerable volume of heavy truck traffic, was a settlement or dishing in the wheel paths. (See Fig. 3.) It was usually more severe in the outer wheel path. Apparently, this more pronounced distortion in the outer wheel path is largely due to a higher moisture content in the base, subbase, and subgrade in that area although the higher load concentration due to the crown of the road might also be a slight factor.

While the source of this distortion is apparently variable and could not be determined by the investigation, samples of the bituminous pavement on Utah FAP-187-A, Heber-Fruitland, indicated that some of the consolidation occurred within the bituminous surface itself. The specific gravity in the wheel path was 2.21 while at the centerline it was 2.18.

EFFECT OF HEAVY TRUCK TRAFFIC

The effect of heavy truck traffic on pavement distortion might be illustrated by comparing Utah FAP-60-C with Utah FAP-134-C, as shown in Table 13 and Figs. 3 and 4.

The volume of truck traffic shown in Table 13 does not tell the whole story since a considerable portion of the trucks on FAP 60-C are heavy, high speed freight trucks. Those traveling FAP 134-C are generally of a smaller, lighter type and because of the curvature of the road are necessarily restricted to a slower speed. Both projects were showing distress but there seemed little doubt at the time of the inspection that FAP 134-C would fail rapidly if subjected to any heavy volume of truck traffic.

TABLE 10
BITUMINOUS SURFACING

Test Hole	Depth	Per Cent Passing					Bitumen Content		Type Used	Moisture	Remarks, Pavement Condition
		1 in.	No. 4	No. 10	No. 40	No. 200	Req'd [a]	Actual			
	in.									%	
Utah											
1	3	100	58	49	24	10	4.1–4.9	4 8	SC-6	0.4	Cracked, subsided
2	3½	100	60	49	24	9	4.1–4.9	5.3	SC-6	0.6	Cracked, wet
3	3	100	54	44	27	11	4.3–5.2	4.6	SC-6	0.4	Good
4	3	100	53	45	21	9	3.9–4.9	6.0	SC-3	0.4	Cracked, subsided
5	2½	100	61	51*	24	11	4.2–5.1	4 8	SC-3	0.2	Good
6	3	100	44*	34	25	10	4.1–4.9	2.7	SC-6	0.9	Pattern cracking
7	2½	100	44*	33	26	12	4.2–5.0	5.8	SC-6	0.6	Good
8	2½	100	48	36	27	12	4.3–5.2	4.2	SC-6	0 6	Cracked
9	2½	100	56	29*	11	7	3.4–4.4	2.8	200–300	0 4	Badly cracked
10	3½	100	51	26*	11	7	3.5–4.4	6.0	200–300	0 2	Fair
11	2½	100	55	37	23	17*	4.5–5.4	5.7	200–300	0.2	Badly distorted
12	2½	100	53	35	23	19*	4.6–5.5	5.5	200–300	0.3	Cracked, settled
13	3	100	48	35	20	13	4.2–5.0	7.0	SC-3	0.5	Cracked, distorted
14	3	100	48	36	24	15	4.4–5.3	4.1	SC-3	0.9	Satisfactory
15	4	100	66	55*	37	20*	5.2–6.0	3.5	SC-3	1.3	Satisfactory
16	4	100	58	47	29	16	4.6–5.5	4.2	SC-3	1.4	Cracked, raveling
17	2	95*	32*	22*	15	7	3.5–4.4	5.0	200–300	0.4	Failed
18	2½	100	51	36	26	11*	4.2–5.0	4.4	200–300	0.3	Satisfactory
19	2	(No sample taken)									Cracked, settled
20	2½	100	61	44	31	13*	4.4–5.3	7.8	200–300	0.6	Cracked, distorted
21	3	(No sample taken)									Satisfactory
23	2	100	54	40	29	18	4.7–5 6	3.7	SC-3	0.7	Slight settlement
Colo.											
1	2½	100	65	54	43	22	5.4–6.3	6.4	SC-3	2.9	Cracked, distorted
2	2½	100	61	51	40	22*	5.3–6.2	5.1	SC-3	2.1	Satisfactory
3	2½	100	63	52	41	22*	5.4–6.3	6.1	SC-3	1.6	Cracked
4	2½	100	54	37	18	9	3.7–4.7	4.1	MC-3	1.2	Distorted
5	2¼	100	52	36	18	8	3.7–4.7	3.3	MC-3	1.1	Satisfactory
6	1¾	100	58	42	21	10	4.0–5.0	5.3	MC-3	1.2	Satisfactory
7	2½	100	68*	58*	35	16*	4.8–5.7	3.1	MC-5	3.1	Pattern cracked
8	2½	100	66*	54*	34	15*	4.7–5.6	3.8	MC-5	2.8	Badly cracked
9A	2¾	100	60	50	31	14*	4.5–5.4	3.1	MC-5	0.3	Failed area
9B	2¾	100	68*	58*	36*	16*	4.8–5.7	4.6	MC-5	0.4	Satisfactory area
10	3½	100	68	55	36	21*	5.2–6.1	4.4	SC-3	1.0	Reprocessed
11	4	100	65	51	28	15	4.5–5.4	3.8	SC-3	1.0	Reprocessed
12	2½	100	65	52	33	20*	5.0–6.0	4.2	MC-3	1.7	Excellent
13	3½	100	66	49	24	13	4.3–5.2	3.9	MC-3	0.8	Excellent
14	3	100	64	50	28	16*	4.6–5.5	4.0	MC-3	1.0	Excellent
15	3	100	76	64*	35	17*	4.9–5.8	8.5	MC-3	1.7	Reprocessed
16	5½	100	71	58	34	18*	4.9–5.8	4.9	MC-3	2.6	Wet, plastic
17	2½	100	64	51	30	15	4.6–5.5	5.6	MC-3	1.3	Reprocessed
18	2½	100	66	54	29	11	4.3–5.2	3.6	MC-3	1.7	Good
19	6	100	81	62*	36	21*	5 2–6.2	5.5	SC-3	3.7	Settlement
21	5	100	85	64*	30	14	4.6–5.5	5.2	SC-3	0.4	Cracked, rich
22	4	100	83	61*	31	16*	4.7–5.7	6.2	SC-3	1.1	Good
23	2	100	93	77	41	24	5.6–6.7	3.5	SC-3	6.0	Slight settlement
24	2½	100	99	87*	34	14	4.8–5.9	4.8	SC-3	1.3	Good
25	2	100	58	46	30	13	4.4–5 3	4.2	MC-3	1 4	Excellent
26	1¾	100	46	37	25	11	4.2–5.1	2.6	MC-3	1.0	Failing
26	3¾	100	69	55	37	18*	5.0–5.9	6.4	SC-3	2.7	Failing
Average											
Utah ..	3	100	53	39	24	12		4.9		0.6	
Colo.	3	100	68	54	32	16		4.7		1.7	
Comb.. ..	3	100	62	48	28	14		4.8		1.2	

* Outside Specifications.
[a] New Mexico surface area charts, Bureau of Public Roads' formula and Colorado formula used as guides in determining required percentages.

EFFECT OF MAINTENANCE

It was evident from the field observations that maintenance (generally a reprocessing by the road-mix method) of bituminous surfaces permits limited control of the composition of the resulting mat. Some of the samples taken were undoubtedly at locations which had been reprocessed at some time (although an attempt was generally made to avoid such sections) and this reprocessing probably accounted for some of the erratic results found. Figure 5 shows variable conditions resulting from maintenance operations.

INTRUSION OF SUBGRADE INTO SUBBASE OR BASE

While evidence of the contamination of the subbase course by subgrade materials was frequently found there was no way of determining just when this contamination occurred. It is believed, however, that such contamination frequently occurs during construction operations for the following reasons:

1. The subgrade is likely to be soft and wet at such times.

TABLE 11
SUMMARIZED TEST RESULTS ON BITUMINOUS PAVEMENT SAMPLES

	Percentage of Samples Tested			
	Utah	Colorado	Combined	Failing
1. With bitumen contents				
(a) Too lean	35	56	47	43
(b) Within accepted range	25	22	23	64
(c) Too rich	40	22	30	83
2. With minus No. 200 more than 15 percent	30	56	45	
3. Moisture contents				
(a) In excess of 2 percent	0	30	17	
(b) In excess of 1½ percent	0	54	26	
(c) In excess of 1 percent	10	81	51	

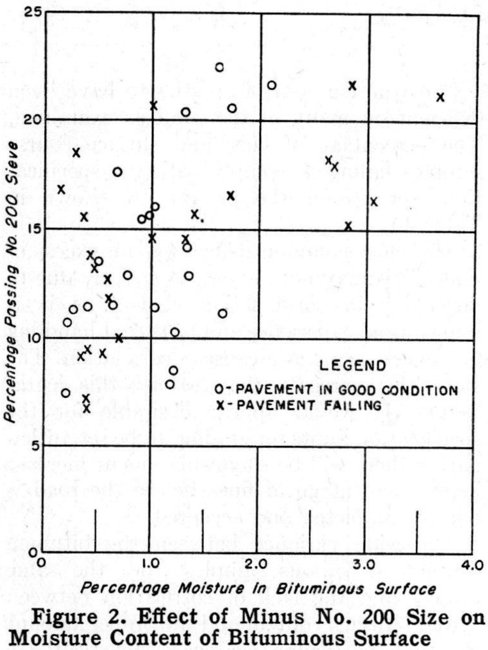

Figure 2. Effect of Minus No. 200 Size on Moisture Content of Bituminous Surface

2. The full designed depth of cover (subbase, base and surface) is not placed at one time but rather in relatively thin layers.

3. Construction equipment is generally much heavier than the traffic which will use the finished road.

4. The subbase or base course materials used are of the dense-graded type not susceptible to intrusion by the subgrade after the road is completed.

TABLE 12
EFFECT OF RELATIVE RICHNESS OF BITUMINOUS MIXTURE ON WATER ABSORPTION

	Percentage of Moisture in Bituminous Surface		
	Utah	Colorado	Combined
Lean mixes	0.4	1.7	1.4
Normal mixes	0.3	1.8	1.1
Rich mixes	0.4	1.8	1.0

Figure 3. Utah Test Hole No. 4: Showing Typical Cracking and Settling under Outer Wheel Path

TABLE 13
COMPARISON OF TWO UTAH PROJECTS WITH DISSIMILAR TRAFFIC

Project	Utah FAP 60-C	Utah FAP 134-C
Year built	1941	1937
Traffic volume (present)	1620	485
Truck volume (present)	405	121
Subgrade soil type	A-4(5–8), A-6(7)	A-7-6(11–13), A-6-(12)
Base—type	A-1-a	A-1-a, A-2-4(9), A-2-6(0)
depth	7 in.–9 in.	2½ in.–4 in.
Pavement depth	3 in.–3½ in.	3 in.–4 in.
Pavement condition	Generally deteriorated, distorted, and cracked. Requiring heavy maintenance.	Generally good except near edge of mat in certain locations.

To prevent contamination of subbase or base by the underlying subgrade soil during construction, it is recommended that the required depth of subbase or base not be placed until the underlying material is sufficiently firm to carry the hauling equipment without distortion. This may mean removal and wasting of soft unstable materials, or stabilization by filling with rock and other granular materials. Only after such stabilization has been accomplished should the required designed depths of cover material be placed.

Figure 4. Utah Test Holes Nos. 13 and 14: Type of Failure over Plastic Base Course and Subgrade

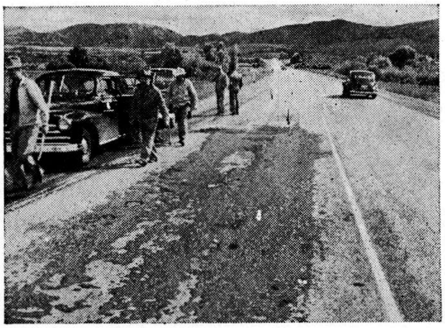

Figure 5. Utah Test Hole No. 12: Typical Conditions Showing Non-uniformity Resulting from Maintenance Operations

CONCLUSIONS

It is evident that the extent of the investigation did not generally permit any positive conclusions as to the causes of observed conditions. Where failure or deterioration of a bituminous surface has occurred, it may well be the result of one or more conditions. On the other hand if the pavement is in satisfactory condition, it is not possible to determine whether the design and construction have been adequate, or more than adequate, or whether failure may occur at some later date under more unfavorable climatic or traffic conditions, or with additional wheel load repetitions. It is emphasized that some of the conclusions listed are the conclusions reached in the field based on mutual observations and discussions and are not necessarily either proven or disproven by the limited test data. Future investigations should include cutting trench sections through the distorted bituminous surface, base, and subbase into the subgrade itself to determine by visual inspection in which of the component parts of the highway structure the distortion has occurred.

TABLE 14

PERCENTAGE OF BASE AND SURFACE COURSE SAMPLES FAILING TO MEET JOB SPECIFICATIONS

	Utah	Colorado	Combined
Base-Course	45	86	65
Surface Course	55	63	59

Construction control appears to have been deficient on many of the projects examined. The percentage of base and surface course samples failing to comply with the specifications set up for the project are shown in Table 14.

The most common defect was an excess of fines. This may not have been entirely due to deficiency in construction control as it is known from experience and tests that handling of mineral aggregate causes degradation. The softer the aggregate, the greater is this degradation. It would appear desirable for the specification limits for grading to be set anticipating there will be some subsequent increase in the percentage of fines before the road is finally completed and accepted.

The wide variance between the bitumen content of various samples from the same project and the lack of correlation between actual bitumen content and the proper amount for that particular aggregate constitutes a serious indictment of the bituminous construction control. While it might be anticipated that control of the bitumen content would be better on plant-mix work, this is the case only for the Utah projects sampled. However, the one Colorado plant-mix project represented used a rather soft, friable aggregate and it is believed extensive degradation occurred in the mixing and handling of this aggregate, thus resulting in an excess of fines and an overly lean pavement. This project is therefore not included in the summary given in Table 15.

Too much dependence should not be placed on appearance as a method of controlling road-mix operations. This is well illustrated on Colorado S-46(3), Sugar City-East. (See Fig. 6.) The bituminous surface appeared excessively rich and doubtless so appeared at the time of mixing. However, tests on samples of the pavement showed that the rich appearance was actually caused by a high moisture content (6.0 percent) rather than by an excess of asphalt and that the mix was instead deficient in asphalt. This deficiency of asphalt promotes the entrance of additional moisture even if an excess of moisture did not exist at the time the pavement was originally laid.

TABLE 15
PERCENTAGE OF BITUMINOUS SURFACING SAMPLES WITH BITUMEN CONTENTS OUTSIDE PROPER RANGE

	Utah	Colorado	Combined
For plant-mix jobs	60	—	60
For road-mix jobs	86	74	77

Figure 6. Colorado Test Hole No. 23: Good Base and Subgrade but Bituminous Surfacing contains Excessive Moisture

The percentage of the minus No. 200 size in both base and bituminous surface courses was generally higher for the Colorado projects than for the Utah projects. The moisture contents of the bituminous surfaces on the Colorado projects also averaged higher than for the Utah projects. It is believed there is a definite relationship between the high percentage of fines and a high moisture content.

There has been a strong tendency to write the specifications for subbase, base, and surface course materials to fit the available materials. Frequently, these available materials contain a high percentage of fines. While the fines may be of low plasticity and therefore of satisfactory quality by the usual specifications, their presence tends to encourage a high moisture content as indicated by Figure 2. The deficiency of coarse particles also reduces the mechanical stability of the material. It is believed construction could be greatly improved by decreasing the percentage of fines in both base course and bituminous surface to give a maximum of 12 percent passing the No. 200 sieve. There are, of course, numerous cases where it would increase the cost of the aggregate if this limit were specified. However, the results should be better and in the case of the bituminous surface, the decreased quantity of asphalt required would tend to offset the extra cost of aggregate. For a normal aggregate, a decrease in the minus No. 200 size of 5 percent would cause a decrease in the required percentage of asphaltic material of $\frac{1}{2}$ to $\frac{3}{4}$ of 1 percent, or 10–15 lb. per ton of mix which would cost about $0.16–$0.25. Such an amount would pay for considerable removal and wasting of fines.

The distortion so commonly found in the wheel paths (a settlement in the wheel path with corresponding rises on either side) indicates the serious effect of heavy wheel loadings if the pavement, base, subbase, and drainage have not been designed and constructed to adequately carry the load. This distortion may lead to accelerated destruction of the pavement through increased impact and decreased resistance to the entrance of surface water. The decreased resistance to the entrance of surface water results from cracking of the pavement and from ponding in the depressions formed.

SUMMARY

1. The subgrade soils on the projects examined had average moisture contents (in their 0-No. 40 fractions) very close to their plastic limits. No relationship was found between these relative moisture contents and the occurrence of pavement failures.

2. On the projects examined, the total depths of granular cover (subbase, base, and wearing course) over the subgrade was about

adequate for the Colorado projects but somewhat deficient for the Utah projects on the basis of the Group Index design method previously referred to.

3. Subbase, base, and surface courses were all frequently found to be outside the job specifications or normally accepted ranges with respect to grading, liquid limit, and plasticity index. The most common defect was an excess of the minus No. 200 size.

4. The bituminous surfaces commonly contained bitumen contents outside the normally accepted ranges for the aggregates involved. More of the samples were on the lean side. This may have resulted from excessive fines formed in the mix during processing which would tend to make the quantity of asphalt used inadequate. The considerable number of samples failing to meet the specifications set up for the job indicates the need for improved construction control.

All bituminous surfaces having moisture contents of over 2½ percent had failed. However, high moisture contents were not necessarily the cause of the failure as they may have been one result instead. Moisture in the bituminous mixture has much the same appearance as the bituminous material itself, consequently proportioning of the mixture by appearance alone is impractical.

5. As the percentage of the minus 200 size in the pavement goes up the moisture content also goes up. It is recommended that the percentage passing the No. 200 sieve not exceed 12.

6. The frequent distortion (settlement) in the outer wheel path results from inadequate initial compaction or from lack of sufficient stability in the pavement, base, subbase, or subgrade to carry the heavy truck loads. The extent of the investigation did not permit exact determination of the extent or cause of this distortion in each case since any failure might well be a result of several conditions.

7. It was apparent that subbase or base course materials have, in some cases, become contaminated by underlying subgrade materials. Additional construction precautions are required if this is to be prevented.

ACKNOWLEDGEMENTS

Mr. B. W. Matteson, Division Engineer of the Bureau of Public Roads, Denver, Colorado, suggested the study be made. Mr. Worth D. Ross, former Division Materials Engineer, made all preliminary arrangements. Mr. D. F. Larsen, Materials Engineer, Utah State Road Commission, and Mr. A. H. Bunte, Materials Engineer, Colorado State Highway Department, were responsible for assembly of project data, providing sampling crews, and making and reporting of laboratory tests. Mr. M. L. Gordon, Assistant Materials Engineer, assembled and summarized much of the data.

DISCUSSION

HERBERT E. WORLEY, *Kansas Highway Commission:* Mr. Eager has presented an interesting report of a bituminous pavement investigation in Utah and Colorado. This discussion consists essentially of information obtained on a similar, although not an identical investigation of bituminous pavements in Kansas.

The purpose of the investigation presented by Mr. Eager was to determine weaknesses in design methods, specifications or construction control so that improvements might be made on future work. The purpose of the studies in Kansas was to correlate the present method of flexible pavement design with road service behavior.

A brief review of the history of flexible pavement design shows the progress of triaxial testing and highway construction in Kansas. The advent of modern flexible pavements in Kansas began in 1938 with the construction of about 500 miles of stabilized bases within a few years. Most of these bases were 6 in. thick, penetrated and sealed with asphalt. Variations in thickness for the earlier bases were made by comparison based on judgment and experience depending on type of base materials available, subgrade, traffic, and location. These variables were not well defined and were not evaluated numerically, and it was deemed desirable to find a method to evaluate these variables whereby each project could be designed for the conditions peculiar to it.

Several methods of testing were investigated and the triaxial compression test was selected in 1943. Samples were obtained from several projects which had been constructed and triaxial tests conducted in order to determine the coefficients required and the soundness of the formula which we proposed to use. The system was eventually approved in 1945. Since that time most flexible type construction in Kansas has been designed by the triaxial method. Improvements were made in the technique of sampling and laboratory testing and also in the calculations of required thickness of pavement. These values were correlated from time to time with projects which had been in service for a number of years. A full description of this method of design has been published in Highway Research Board Bulletin No. 8 entitled, "Design of Flexible Pavements Using the Triaxial Compression Method."

The present studies were made to correlate further the present method of flexible pavement design with road service behavior. They included sampling, sample preparation, triaxial testing, and thickness calculations. The investigation in Kansas was made in February and March of 1949. A reconnaissance inspection was made during a prolonged cold period in which the ground was frozen for several weeks in February, 1949. Seventeen road locations, totaling 248 miles in length, were selected from the southern two-thirds of Kansas for this study. A log was prepared showing the extent of each surface failure existing at that time. The present flexible surfaces on these locations, with one exception, were constructed prior to 1942 and had been in service from 7 to 11 years at the time of this investigation. These projects were constructed before the present method of thickness design had been developed for design use. Then in March, when the spring thaw was in progress we made the detailed survey. Seventeen spots were selected where the surface was in excellent condition and no failures appeared to have occurred since construction. Failures were incipient at the other seventy-one small areas. Reference was made to the February inspection log and failures which existed at that time were avoided.

Holes were dug about 1 ft. deep in the subgrade at various places. Samples were not obtained where inspection showed rock or other non-uniform conditions which could not be accurately evaluated. At each spot selected for sampling, the thicknesses of wearing surface and base course, if any, were measured and the general surface condition in each vicinity was described. The existing density and moisture content of the base course were determined using the sand density method. A disturbed sample of base course material was obtained at each spot where it occurred for gradation, plastic index and triaxial compression tests.

An undisturbed sample representing the upper ten inches of the underlying subgrade was obtained, sealed in a moisture-proof container, packed in sawdust and transported to the laboratory.

The disturbed base course samples were prepared for triaxial testing by molding them into specimens of 5-in. diameter by 12-in. height having the same moisture and density at which they were found beneath the surface of the roadway. They were then cured 4 days according to the regular procedure and tested in the usual manner. The modulus of deformation was computed for the stress difference applicable to each location according to the 1947 traffic count.

The undisturbed subgrade samples were trimmed to 2.8-in. diameter by 8-in. height and tested by triaxial compression with 20 lb. per sq. in. lateral pressure at their field moisture content and density. This procedure duplicated as nearly as possible the actual field condition and eliminated the need of applying a saturation coefficient in computing thickness requirements.

A value for modulus of deformation of 15,000 lb. per sq. in. was used in these computations for the bituminous mixtures. The thickness of bituminous surface required on each subgrade was computed for various traffic coefficients to determine which one should apply according to its situation, considering the condition and thicknesses of surfaces and base courses where they occurred. The thickness of base required in combination with the surface, if any, was computed for each place where a base existed. These required thicknesses were then compared with the actual thicknesses as a means of correlating present flexible pavement design methods with road service behavior and thereby determine whether any adjustment should be made in the traffic coefficients.

Of the 17 spots where failures had not developed, 14 had thicknesses equal to or greater than that required by the present method of design. Calculations show additional thickness required at the other three spots. A similar comparison was made for the 71 spots where failures had developed. Sixty-three had thicknesses less than that required by the present method of design and therefore, failure would be expected. Eight spots had thicknesses greater than that required by the present method of design and should not have failed. Accordingly, these spots would have been under-designed if these values were used exactly. An adjustment of coefficients might be made; however, the necessary adjustments oppose each other so any change favoring one group would increase the discrepancy in the other. When these comparisons were plotted the line of demarcation was quite sharp with the present system. Any change, in either direction, would appear undesirable. The percentage of error or discrepancy is not unreasonable.

Some additional information may be obtained by comparing data with Mr. Eager and interpreting one set in the light of the other. Mr. Eager was unable to find any consistent relationship between the stability of the subgrade (as determined by the relationship of actual moisture content to that contained at the plastic limit) and the condition of the bituminous pavement. In Kansas the moisture content of the subgrade was nearly always higher than the plastic limit at the failed spots, and where this did not occur, the density of either the subgrade or the base course was low. Where the surface was good, the moisture content of the subgrade was usually below the plastic limit. Moisture content alone does not tell the whole story, as density and other characteristics are effective. Triaxial compression tests are used in Kansas to evaluate all these characteristics together as much as possible, but sometimes this procedure does not evaluate everything.

Considerable variation has been found in the quality of bituminous surfacing mixtures using various formulas for bitumen content. Mixtures are prepared in the laboratory with a range in bitumen content of about one percent, based on that computed from a formula. Triaxial tests are run on these mixtures to determine the optimum bitumen content for stability. Absorption tests are also run to provide additional information in selecting the most desirable bitumen content and to prevent indiscriminate use of too little asphalt.

Pavement settlement in the outer wheel tracks is also a source of much difficulty and concern in Kansas. This is remedied to some extent by making certain that the subgrade is compacted adequately before the base is constructed. An additional thickness of base may be constructed near the edge of the pavement over that in the center of the roadway. Particular attention may be given to shoulder construction to make sure that water will be carried away from the edge of the road. Additional width of roadway is also beneficial in that it permits traffic, especially heavy traffic, to follow a course not so near the edge of the pavement. This permits a distribution of the load over the surface of the roadway and also gives additional lateral support to the base material which is under the wheel tracks.

The recommended procedure given by Mr. Eager regarding the intrusion of subgrade in the subbase or base may be further emphasized. Construction control is very important. The final product is what counts.

The percentage of asphalt required for various mixes may be computed by one or more formulae and in addition to this information, triaxial tests are conducted in Kansas to determine the maximum stability which may be obtained with asphalt contents within these ranges.