Service Behavior of Asphaltic Concrete

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The design of asphaltic concrete has been based on scientific procedures for the past number of years. The two most used systems of tests, the Hveem stability and the Marshall stability, have both been proved reliable beyond question. Until the validity of the assumptions inherent in the mix design procedures has been proved by sufficient follow-up of service behavior studies and tests, there is danger of overemphasizing stability characteristics at the expense of flexibility characteristics.

Service behavior studies on asphaltic concrete in Oregon were begun in 1954 on a limited scale. In 1959 and 1960 a more extensive survey was organized. One hundred ninety-five paving projects covering 872 miles and representing 3,000,000 tons of asphaltic pavement which have been in service from one to 11 years were surveyed, sampled and tested. The data obtained from the survey, together with the results of routine tests made at the time of construction provide comparative information showing the effect of age and traffic.

The survey consisted of estimating the degree of cracking, raveling, shoving and flushing. Field measurements of wheel track depression and pavement thicknesses were made. Core samples were cut from the area between wheel tracks, in the wheel track and outside the wheel track. An 8- by 12-in. sample was cut from the shoulder or area outside the wheel track.

On arrival at the laboratory the core samples were tested for specific gravity and stability as received, which indicated the in-place condition. The cores were then compacted in the kneading compactor and retested for specific gravity and stability. Granulometric analysis and asphalt content were obtained on a portion of the cut sample. Laboratory-molded specimens, the same size as the cores, were made from the remainder of the cut sample. The molded specimens were compacted in the kneading compactor then inverted and recompacted. Specific gravity and stability were measured after each compaction.

From the analysis of the surface conditions it was found that cracking and raveling is as prevalent as flushing in the pavements surveyed. No evidence was found to indicate that wheel track depressions are caused by instability or horizontal shoving but rather by a combined compaction of pavement and base.

Analysis of the mixture before and after traffic showed a loss of asphalt content after placing in the road.

From the analysis of the results of tests on the cores, it was found that the density increased rapidly for the

first 3 years after construction, then more gradually for the next 8 years. Higher construction compaction requirements would reduce or eliminate the rapid increase by traffic immediately after construction. The density obtained from laboratory-compacted cores changes in a degree depending on the amount of traffic prior to cutting the cores. The greater the prior rolling or traffic, the greater will be the laboratory-compacted density.

From stability tests on the cores, it was found that low in-place values are not indicative of pavement instability, particularly when the mix design is such that further consolidation by traffic increases the measured stability value.

●DESIGN of asphaltic concrete has been based on scientific procedures for the past number of years. Laboratory-molded specimens composed of ingredients to be used for each project are tested to determine the most appropriate gradation and asphalt content. The two most used systems of tests, the Hveem stability and the Marshall stability, have both been proved to be reliable beyond question. Limiting values of stability have been set up for the purpose of insuring stable mixtures under traffic. The assumptions are made that the laboratory-molded specimen is comparable to the actual pavement in regard to particle orientation and density, that the test itself is comparable to traffic loading, and that the limiting value set up distinguishes between good and poor mixtures in reference to shoving and grooving. There are insufficient data available to determine the validity of these assumptions for all types of mixes. The tests and assumptions could well be valid for a sandy mixture but not for a dense but coarser mix such as the Oregon Type B mix. Unless the tests and limiting values are proved valid, there is danger of emphasizing stability at the expense of flexibility.

The presently accepted procedure for increasing the stability of any given asphalt and aggregate mixture is to reduce the asphalt film thickness either by a reduction of asphalt content or by an increase of aggregate surface area. Such a reduction in film thickness will obviously result in a loss of flexibility. If high stability values, as presently determined, are essential to prevent plastic flow under modern heavy traffic, then asphaltic concrete pavement ceases to be flexible and should not be classed as such. Since natural aggregate base materials have been found to retain a characteristic deflection under load regardless of compaction, and asphaltic concrete designed for high stability cannot be used as a wearing surface without inviting failure by cracking and raveling. Treatment of base aggregates for the purpose of reducing deflection under load to the extent that the highly stable semirigid asphaltic mixture can be safely used, reduces the economic advantage asphaltic concrete possesses when used as a flexible pavement.

PURPOSE OF PROJECT

The purpose of this project was to determine the changes in physical characteristics of asphaltic concrete occurring with age and traffic. In addition, the purpose was to determine the degree to which tests on laboratory-molded specimens conform to tests on actual pavement specimens.

SCOPE OF PROJECT

The first series of tests were made in 1954. No research survey project was set up at that time, and the samples were taken and tested whenever time and opportunity presented themselves. Approximately 100 cores were taken from 70 different projects. The results of tests on these samples, rather than providing data for definite conclusions, indicated that further study was needed on a larger scale, both in the number of tests and the pavements represented.

In 1959 the project was set up as a research survey in cooperation with the Bureau of Public Roads with Highway Planning Survey funds sufficient for employment of routine personnel during off-construction season. All the unsealed pavements in Oregon were surveyed, sampled, and tested.

In 1960 the research survey was continued and all the projects on primary highways surveyed the year before, and all those sampled in 1954 were resurveyed, sampled, and tested.

In all, 1,105 cores and 169 cut samples were taken and tested. One hundred ninety-five paving projects were surveyed and sampled. These projects cover 872 miles representing over 3,000,000 tons of asphaltic pavement, and have been in service from one to 11 years under all types of climatic conditions found in the state.

PROCEDURE

No prepared procedure was set up for the 1954 series of samples. A group of projects laid since 1950 were selected at random throughout the state. These projects were examined and sampled by routine personnel as time permitted. One or more cores were cut from the wheel track and the location noted by station or mile post. The wheel track depression was measured, and the general condition of the pavement in the area of test was noted as to indication of shoving, flushing, cracking, or raveling. Laboratory tests consisted of specific gravity and stability on the core samples as received, which indicated the specific gravity and stability in place.

For the 1959 and 1960 surveys, considerable preliminary work was done before the field crew was sent out. The construction test records were examined for each paving project since 1949, and all pavements that had not been sealed were chosen for examination and sampling. The sealed pavements were ruled out for two reasons. First, there is a possibility that the asphalt in the seal coat has penetrated into the pavement and thus both density and stability of the asphaltic concrete would be affected. Second, the visual condition would indicate the performance of the seal coat and not the asphaltic concrete, particularly in regard to flushing or raveling, and possibly shoving.

The test reports on samples taken during construction were scanned for two analyses that were near the average in gradation and asphalt content for the whole project. The points where these two samples were taken during construction were then designated as the points for the survey samples. The station location, granulometric analysis, asphalt content, density after compaction, and other general information were copied to a separate data sheet for each predetermined point. A serial number was assigned to each point consecutively in the field.

When each point was found, the wheel track depression was measured, the degree of flushing estimated on a scale of zero to three, and shoving, raveling, and cracking estimated as none, slight, or excessive. In the 1959 survey, one core was cut in the wheel track and one between the wheel tracks at each point. In the 1960 series, three cores were cut; one between the wheel tracks, one in the wheel track, and one in the outside edge at a point approximately 6 in. toward the wheel track from the edge of the traffic panel. In addition, an 8- by 12-in. cut sample was taken on the outside edge. Each sample was immediately identified with the point serial number and a sample number to correspond with duplicate information on the point data sheet.

On arrival at the laboratory, each core was measured for thickness, exclusive of any asphaltic binder, then cut to 2.5 in. The 2.5-in. sample included the top course of pavement plus any base course needed to make up the height. A series of tests were then made on each core. First, specific gravity and stability were measured. Then, after compaction with the kneading compactor, each core was retested for specific gravity and stability, followed by the determination of real specific gravity. Granulometric analysis and asphalt content were obtained from the cut sample. The remainder of the cut sample was heated and remixed. A molded cylinder was then made by use of the kneading compactor, and the specimen tested for specific gravity and stability. The cylinder was then inverted in the mold and recompacted, after which it was retested for specific gravity and stability.

In the tables and figures which follow, the cores are identified as BWT for between wheel track, WT for wheel track, and SH for the outside edge. Although the laboratory-molded specimens have the same dimensions as the cut core samples, they are identified as laboratory-molded specimens or cylinders and never as cores.

The assumption is made in the test procedure that granulometric analysis and asphalt content are constant transversely across the pavement at the test point, thus making the cut sample and all the cores at a given point comparable. Detailed test procedures are given in the Appendices.

RESULTS OF TESTS

The data obtained from the survey, and tests made on samples taken at the time of construction and at the time of survey provide comparative information showing the effect of age and traffic on some characteristics of asphaltic concrete. Because the surveys were made in the winter, the pavements laid the previous construction season vary in age from three to eight months. The same age differential exists in all the age groups with the effect decreasing to a minimum the eleventh year. An attempt to break down the projects into identical traffic and age groups would be futile, because any two projects laid the same date would not have the same traffic after any given period of time. Also, the difference in climatic conditions makes the effect of traffic and age on one project not comparable with another. In the moderate climate of the coastal area, the pavements seldom have freezing weather on the surface and only occasionally will they absorb enough heat to reach 100 deg. In the midvalleys the range is somewhat greater, whereas in the high plateau area east of the Cascades, the range is from some 40 degrees below zero to a temperature too high to hold one's hand on the pavement. Another condition that makes one project not comparable with another is the difference in aggregate type and gradation so that the same percentage of asphalt will not result in the same film thickness on any two projects.

To diminish, if not remove, the effect of uncomparable individual projects, the data were averaged for the different age groups from zero to 11 years. The data obtained at the time of construction is labeled the original or zero age. The projects that were laid the construction season previous to the survey are indicated as one year, and so on to 11 years. This procedure becomes valid only when the results of analysis portray the effect of age and traffic on pavements as a group, and when no attempt is made to predict the changes that will occur with age on any individual mixture of asphaltic concrete. The only procedure that would make the comparison of test results taken at different ages strictly valid would be to sample and test specific projects yearly. Such a research project is now in progress in which 28 points on six different sections of pavement are observed, sampled, and tested yearly.

The data obtained, pertinent to this report, on pavements one to 11 years of age include nine conditions for determining change from age and for comparison of tests on laboratory-molded specimens and actual pavement specimens. These are as follows:

1. Surface condition—degree of cracking, raveling, shoving, and flushing;
2. Wheel track depression and measured thickness;
3. Gradation and asphalt content—original and final;
4. Density, in-place—original and final in wheel track, final in shoulder and between wheel tracks;
5. Density, laboratory-compacted—final in wheel track, between wheel tracks, and shoulder;
6. Density, laboratory-molded specimen from cut sample—first compaction and second compaction.
7. Stability in-place—original in wheel track for some pavements laid in 1954, final for wheel track, between wheel tracks, and shoulder;
8. Stability laboratory-compacted—final in wheel track, between wheel track, and shoulder; and
9. Stability laboratory-molded specimen from cut sample—first compaction, and second compaction.

TABLE 1

SURFACE CONDITION (%)

Age (yr)	Flushing				Raveling			Cracking			Shoving
	3	2	1	0	Excessive	Slight	None	Excessive	Slight	None	
1	0.0	0.0	0.0	100.0	0.0	0 0	100.0	0 0	0 0	100.0	None
2	0.0	0.0	23 0	77 0	0 0	0 0	100 0	0.0	3 1	96.9	None
3	14 0	10 0	26 0	50 0	0 0	0.0	100 0	0 0	1.7	98 3	None
4	15 5	15 8	32 5	36.2	0 0	16 5	83 5	0 0	28.0	72 0	None
5	0.2	26 5	23 6	49 7	0.0	0 0	100 0	0 0	0 0	100 0	None
6	7.8	10.9	3 9	77 4	5 1	20 3	74 6	0 7	40 5	58 8	None
7	7 0	10 8	54 7	27 5	0 0	9 3	90 7	0 0	43 0	57 0	None
8	0.0	0.0	31 5	68 5	0.0	18 6	81 4	7 8	58 5	33.7	None
9	0.0	0 0	75.0	25 0	0 0	0 0	100.0	0.0	53 5	46.5	None
10	0 0	0 0	77 0	23 0	0.0	18 5	81 5	0 0	32 5	67 5	None
11	0.0	0 0	85 0	15 0	0.0	0 0	100.0	100.0	0.0	0 0	None
Total	6 9	8.1	34 0	51.0	0 9	8 7	90.4	1 7	26 0	72 3	None

Results of the survey concerning surface conditions are given in Table 1. The scale of flushing indicates a visual estimate of four conditions. A rough, dry surface was considered zero. A tight, smooth surface with no free asphalt was considered flushing 1. A slight existence of free asphalt was classed 2. Excess asphalt on the surface was designated as condition 3. The table gives the percentage of mileage classified in each category for each age and for the total of all the projects surveyed. The condition at the point of survey is assumed to represent the mileage for that particular project. The mileage for each condition was added and the percent of the total mileage of the same age was calculated. It should be re-emphasized that the data in Table 1 are group data and should be analyzed as such. For example, of the four-year-old group, 15.5 percent showed excessive flushing and 16.5 percent showed slight raveling. These two conditions are contradictory and would be impossible on the same pavements. The two percentages, however, represent entirely different projects in the four-year-age group. The purpose of this report is to indicate the existing conditions and point out relationships between the different conditions. No attempt is made to isolate the cause of the noted condition.

As indicated in Table 1, there was no visual evidence of shoving in any of the pavements surveyed. There was, however, considerable wheel track depression ranging from zero to 0.75 in. Even though there was no evidence of washboarding or other symptoms of horizontal movement on the surface, the existence of wheel track depressions may be evidence of such movement under the surface. If this were true, then the difference in thickness of between wheel track and shoulder cores and those cut in the wheel track should be comparable to the measured wheel track depression. Table 2 gives the averages of wheel track depressions for the different ages as actually measured and as calculated from thickness and density. The first column shows the averages of measured wheel track. The second column shows the difference between average thicknesses of shoulder and between wheel track cores and the wheel track cores. The third column shows the difference between thicknesses calculated from the average density of between wheel track and shoulder cores and in wheel track cores based on 3.5 in of pavement. The fourth column shows the increase in surface measurements of wheel track depressions measured in 1960 over those measured in 1959.

Comparison of the first three columns of Table 2 indicates that the measured wheel track is consistently greater than that calculated from either the pavement thicknesses or densities. Also, it is seen that the two calculated wheel track depressions are quite comparable, indicating that the decrease in thickness in the wheel track is due to the increased density caused by traffic. The considerably greater actual wheel track depressions indicate that, rather than horizontal instability, there was vertical movement resulting from increased compaction of the base or subbase.

Examination of column one and column four shows a consistency of increasing depression depth in the wheel track from zero to five years age, then decreasing with further traffic and age. A gradual decrease in consolidation of both the pavement and base in the wheel track after a few years, accompanied by a continued consolidation

TABLE 2

WHEEL TRACK DEPRESSION

Pavement Age	Wheel Track Depression (in.) Measured	Calculated from Measured Thickness	Calculated from Densities, 1960 Survey	Increase in Measured, 1959-1960
1	0.07	0.03	0.01	-
2	0.10	0.02	0.02	0.0
3	0.19	0.07	0.04	+0.01
4	0.13	0.03	0.02	+0.01
5	0.31	0.05	0.02	+0.06
6	0.21	0.02	0.04	-0.04
7	0.27	0.03	0.04	-0.02
8	0.20	0.03	0.03	-0.01
9	0.23	0.05	0.01	-0.04
10	0.21	0.03	0.05	-0.05
11	0.17	0.01	0.04	-0.03

between wheel tracks and in the shoulder would account for the measured decrease in wheel track depth after five years.

The gradation and asphalt content, both original and final for each age group, are found in Table 3. Because the original and final asphalt contents are not the same for any of the groups, the percentages in the aggregate portion are calculated to total 100 percent without asphalt. A comparison of the original and final quantity of each size for each age group should indicate the degree of degradation caused by traffic. Examination of Table 3 indicates that there is considerable variation in the change in individual quantities for the different age groups. The quantity passing the number 200 sieve is the quantity which shows an increase with traffic for each age group. Considering the total of 169 specimens of all ages, there is a tendency for the material larger than the number four screen to degrade into material smaller than the number four with the majority being pulverized into dust. This size degradation, however, would appear to be insignificant for asphaltic concrete as a whole.

Of more significance is the drop in quantity of asphalt as indicated for each group in Table 3. The loss of asphalt is not a gradual process since the loss the first year is greater than that indicated in the second, fifth, eighth, and tenth year. Considering the total 169 specimens, 78 percent indicated a loss of asphalt from the time the mixture was placed on the road to the time it was resampled. No relationship can be found between asphalt content or void content at the time of construction and the loss of asphalt. Considering the oldest two groups of pavement, 10 and 11 years, and only those showing a drop in asphalt on retest, the 10-year-old group averaged one-half the asphalt loss and twice the void content as that of the 11-year-old group. This does not preclude a relationship between air or water permeability and asphalt loss because permeability depends on interlocking void space and not on void quantity.

A comparison of the densities in-place at the time of construction with the densities after traffic is shown in Figure 1. In this comparison, core specimens taken from the wheel track only were used in calculating the averages. All the densities are indicated as percent relative compaction which is calculated by dividing the specific gravity of the core as received by the specific gravity after laboratory compaction. Because the majority of cores taken at the time of construction was not laboratory compacted, the compacted value of the wheel track survey cores was used in calculating the original percent relative compaction. The assumption that the specific gravity of a laboratory-compacted core prior to traffic is the same as that after traffic is in error as will be indicated in later comparisons. However, the error applies to all the original specimens which makes them comparable as a group. The average value for percent relative

TABLE 3

GRANULOMETRIC ANALYSIS

Age (yr)	Percent Retained								
	¾-½	½-¼	¼-No. 4	No. 4-No. 10	No. 10-No 40	No. 40-No. 80	No. 80-No. 200	Pass. No. 200	A.C.
0	8.4	28.4	9 0	12.7	21 0	13 9	3 7	2 9	5.7
1	10.4	32.1	7.9	11 4	19 7	12 8	2.5	3.3	5.1
	+2.0	+3.7	-1.1	-1.3	-1.3	-1 1	-1 2	+0 4	-0.6
0	9 2	30 1	9.7	16.8	17 5	7 3	4.3	5 1	5 6
2	10.9	28.5	8.5	16.2	17 9	7 5	4.5	6.0	5.5
	+1 7	-1.7	-1 2	-0 6	+0.4	+0.2	+0.2	+0 9	-0.1
0	12.4	28 0	7 9	15.8	18.2	7 8	5.1	3 8	5 9
3	14 9	27 8	6.1	15 2	17.6	8.8	5.4	4.8	5 5
	+2.5	-0.8	-1 8	-0.6	-0 6	+1 0	+0 3	+1 0	-0 4
0	7 4	31 4	8 8	17 0	18 5	7.1	4.6	5 2	5 8
4	8 0	32 1	9 0	15 7	17 5	7.0	4 4	6.3	5 2
	+0 6	+0 7	+0 2	-1 3	-1 0	-0.1	-0 2	+1 1	-0 6
0	9 5	33 7	10.2	16 2	14 4	7.1	4 1	4 8	5 8
5	7 6	32.8	10.0	16.8	15.4	7 2	4.5	5 7	5 7
	-1 9	-0.9	-0.2	+0.6	+1 0	+0 1	+0.4	+0.9	-0 1
0	9 1	29.6	10.5	18.7	16 1	5.7	4.2	6 1	6.2
6	10.0	30.9	9.7	17.4	16.3	5.3	3.9	6.5	5 6
	+0.9	+1 3	-0 8	-1 3	+0 2	-0 4	-0.3	+0.4	-0.6
0	12 7	34 4	9.8	16.7	11.7	5.1	5.4	4 2	6.1
7	12 9	36.7	9 4	15 0	10 4	6.2	4.9	4.5	5.3
	+0.2	+2.3	-0.4	-1 7	-1 3	+1.1	-0.5	+0 3	-0.8
0	11 1	32 1	9.9	16.0	17.3	5 1	3.5	5 0	5.8
8	9 1	31.1	9.1	17.0	18.6	6.0	3.5	5.6	5.4
	-2.0	-1.0	-0.8	+1 0	+1 3	+0.9	0 0	+0.6	-0.4
0	16.4	28.8	9.7	15.7	17 1	4 8	3.3	4 2	6.1
9	16.3	29.6	8 7	14.8	16.0	5 5	3.4	5.7	5.5
	-0.1	+0.8	-0.1	-0 9	-1.1	+0.7	+0 1	+1 5	-0.6
0	11.4	27.8	11.0	18.5	16 8	4.9	3.5	5.1	5 4
10	12.3	28.6	10.4	18.2	15 9	4.6	3.4	5 6	5 2
	+0.9	+0.8	-0.6	-0 3	-0 9	-0 3	-0.1	+0.5	-0.2
0	12 2	27.8	11 7	20.0	15 7	3 8	2.7	6.1	4.8
11	13.1	26.2	12 2	20.3	15 2	4.0	2.6	6.4	4 2
	+0.9	-1 6	+0.5	+0.3	-0 5	+0.2	-0 1	+0.3	-0.6
0	11.8	30.3	10.0	16.7	16 2	6 1	3.9	5 0	5 9
Total	11.5	30.9	9 3	16 3	16.3	6 2	3.9	5 6	5 6
	-0.3	+0.6	-0.7	-0.4	+0.1	+0.1	0.0	+0.6	-0.4

compaction at the time of construction indicated in Figure 1 is lower than it would be if laboratory-compacted core values at the time of construction were available for all projects concerned.

The values shown in Figure 1 include the test results of all the wheel track cores cut in the 1954, 1959 and 1960 surveys. Thus, many of the same projects are included in three different age groups. For example, a project constructed in 1953 is included in the one-, six-, and the seven-year groups.

Figure 1 shows the relative compaction as the average, the standard deviation, and the maximum high and low for the original and for each age group. The effect of traffic increases compaction a considerable amount for the first three years after construction, then slightly more for the remaining ages. In calculating the original compactions, the construction values of all the survey projects were averaged. The original average for each group may be either higher or lower than the total average indicated in Figure 1. Therefore, the increase in relative compaction may be for the four-year-age group than for the three-year-age group when the individual original averages are considered. Figure 1 is more a comparison of the percent relative compaction reached than it is a comparison of the amount of increase in compaction for the 11 age groups.

To compare the amounts of increase in compaction, the original relative compactions

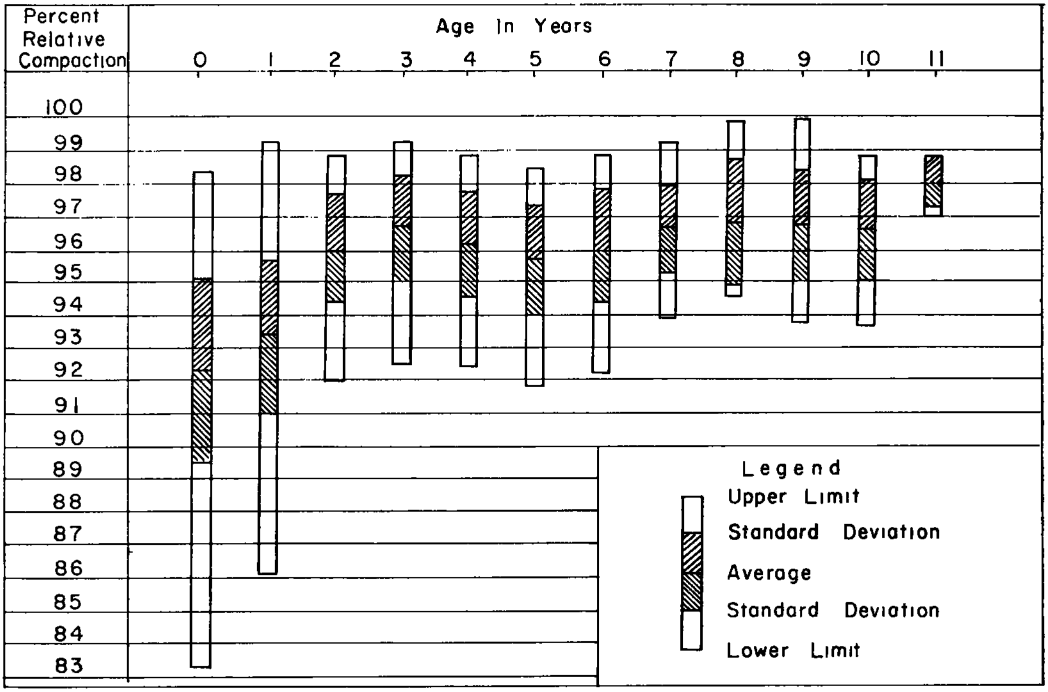

Figure 1. Percent relative compaction with age.

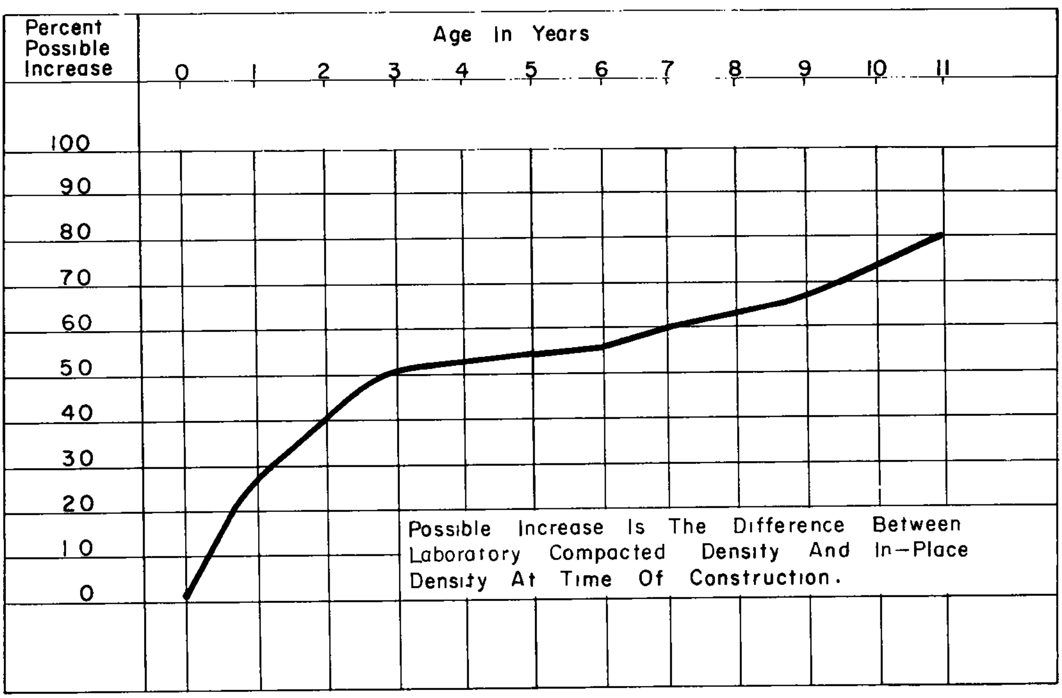

Figure 2. Percent of possible increase in compaction with age.

for all age groups were made comparable by considering the increase as a percent of possible increase. Thus, in Figure 2, the original compaction for each age group is considered zero percent. The difference between the original percent compaction for each age group and the percent compaction obtained after traffic was calculated as percent of the possible increase. It is seen from Figure 2 that approximately 50 percent of the possible increase is obtained in the first three years, and that in the next eight years an additional 30 percent is obtained.

Figures 1 and 2 further indicate that traffic, even after 11 years, does not compact the pavement to the extent that it can be compacted in the laboratory. Because desirable compaction during construction should approach that which traffic will accomplish, so that there will be a minimum of particle movement under traffic, requirement for relative compactions should be based on a laboratory compaction equal to the maximum traffic compaction. It is seen that laboratory compactive effort is higher than it should be.

Table 4 presents a comparison of specific gravities in-place and laboratory-compacted for shoulder, between wheel tracks, and wheel track core samples. Because core specimens were not taken from the shoulder in the 1954 and the 1959 survey, the data presented in Table 4 were obtained from the 1960 survey. The averages for wheel track densities, therefore, will not conform to those presented in Figure 1. Also, the specific gravities of laboratory-molded specimens, made from the cut samples, are shown after both the first and second laboratory compaction. As would be expected, there is an increase in density-in-place values from the shoulder to between wheel tracks and from between wheel tracks to wheel tracks. These are the values used in calculating the wheel track depressions given in Table 2.

The laboratory-compacted cores (Cols. 4, 5, 6, Table 4) show the same pattern of increase in density from shoulder to between wheel tracks to wheel tracks as do the densities-in-place. Although the increase in density with location on the roadway is not so great in the compacted-core data as it is in the in-place data, the definite increase indicates that some change took place with traffic which permits greater laboratory compaction. Further evidence of the effect of traffic on possible compaction is indicated in the last two columns of Table 4. These data were obtained from laboratory-molded specimens the same dimensions as the cut cores and using the mixtures obtained in the cut shoulder samples. After the first compaction, the specimen was tested for specific gravity, then inverted and placed in the mold for recompaction. In each single laboratory compaction, the temperature, number of loads, or tamps, and pressure per tamp were constant. The density obtained from the first compaction of laboratory-molded specimens is consistently lower than the density obtained from compacted wheel track cores. These differences would indicate that the action of traffic on pavement reorients the particles to permit greater laboratory compaction on the core samples, and also, that turning the specimen over permits even greater reorientation and laboratory compaction. Table 5 indicates that this reorientation of particles occurs in the placing and rolling during construction as well as by traffic. Results of tests on 104 cores cut during construction immediately after rolling, along with results of tests on molded specimens of bituminous mixture samples taken prior to rolling at the same points are given in Table 5.

Tables 4 and 5 present data which indicates the difficulty in determining a base density from which to calculate a required relative compaction to be used during construction. The degree to which a pavement can be compacted, as measured by laboratory tests, changes while compaction is being accomplished. It is possible for a contractor, required to obtain further compaction on a project, to operate rolling equipment on the pavement and obtain higher density but still have the same percent relative compaction that was originally considered insufficient. Also, the data indicate that laboratory compaction and ultimate traffic compaction do not result in quite the same densities.

Table 6 presents the average results of Hveem stability tests on all the cores and laboratory-molded specimens obtained in the 1960 survey. Previous laboratory work has indicated a definite relationship between density and stability. This relationship

TABLE 4

SPECIFIC GRAVITIES

Age (yr)	In-Place			Laboratory Compacted			Laboratory-Molded	
	Sh	BWT	WT	Sh	BWT	WT	1st Comp	2nd Comp
1	2 202	2 215	2 225	2.353	2 356	2 362	2.295	2 371
2	2 216	2 248	2 259	2 364	2.370	2 371	2 340	2.409
3	2 307	2 328	2 345	2 413	2 417	2 420	2 373	2 432
4	2 250	2 266	2 278	2 362	2 372	2 374	2 342	2.402
5	2.190	2 255	2 280	2 335	2 365	2 370	2.320	2 370
6	2 260	2.275	2 302	2 391	2.403	2 404	2 344	2 413
7	2 320	2 341	2 370	2 437	2 444	2.450	2 406	2 456
8	2 267	2 293	2 297	2 370	2 375	2 379	2 360	2 402
9	2 227	2 247	2 260	2 307	2 305	2 322	2 265	2 325
10	2 281	2 305	2 318	2 401	2 417	2 431	2 363	2 416
11	2 282	2.320	2 335	2.365	2.377	2 382	2 320	2 372
Total	2 273	2 286	2 319	2 396	2 400	2 406	2 357	2 415

TABLE 5

SPECIFIC GRAVITIES

Job No.	No. of Samples	Cores		Remolded Specimens	
		In-Place	Compacted	1st Compaction	2nd Compaction
1	20	2.22	2.32	2.28	2.35
2	16	2.32	2.45	2.41	2.47
3	4	2.34	2.49	2.48	2.53
4	9	2.26	2.41	2.37	2.43
5	15	2.15	2.29	2.25	2.31
6	6	2.32	2.43	2.43	2.50
7	6	2.14	2.29	2.25	2.32
8	4	2.31	2.52	2.49	2.55
9	10	2.25	2.47	2.46	2.52
10	14	2.21	2.33	2.29	2.53

TABLE 6

STABILITY VALUES

Age (yr)	Group	In-Place			Laboratory Compacted			Laboratory Molded	
		Sh	BWT	WT	Sh	BWT	WT	1st Comp.	2nd Comp
1	A	21 0	20 6	21 8	51 1	51 3	51 5	32 2	49.0
2	A	19 2	20 6	21.4	47 9	49 2	51 0	37 1	48 2
	B	21 3	23 6	23.3	22 0	18 0	31 0	15 6	10.5
3	A	24 6	26 6	21.2	49 0	45 7	47 1	34 2	43 4
	B	22 2	22 3	20 5	27 6	34 1	27 4	18 4	8 5
4	A	22 5	24 5	23 5	45 0	45 0	44 5	33 3	41.0
	B	18 0	17 3	16 3	38 3	40.3	39 0	25 6	12 0
5	A	19 5	22 5	23 0	50 5	52 0	48 0	32 0	46 5
6	A	22 6	21 8	22 0	46 9	39.8	37 9	32 3	45 6
	B	20 1	19 7	20 8	34 4	35 0	33 8	27 2	6 3
7	A	24 1	23.2	24 2	47 0	48 4	43.4	34 7	46.0
	B	19 3	20.4	20.4	22 3	17 7	19 8	15 0	5 5
8	A	22 5	25 8	23.0	48 8	52 8	54 5	39 2	49 2
	B	22 5	26.8	23.5	17 5	24 0	33 5	12 6	0 0
9	A	23 6	29 0	32.3	37 3	49 0	50 0	32 0	36 0
	B	28 0	34.0	32 0	18 0	56 0	25 0	16 0	14 0
10	A	25 7	30.7	28 0	51 0	44 0	41 7	38 0	49 5
	B	15 7	14 5	19 2	4 0	10 7	6 5	11 5	2.7
11	A	22 6	25 6	24 6	44 3	49 0	47 6	38 6	49.0
	B	22 0	26 0	17 0	25 0	39 0	31 0	31 0	22 0

is shown for one mixture in Figure 3 from which it is seen that stability increases to a maximum with increased density, then decreases with further increase in density. Considering the laboratory-molded specimens, it would appear valid to assume that if the stability for the second compaction is less than that for the first compaction, the specimen density is past the peak of its stability-density curve. The data in Table 6 are presented as averages of two groups for each age. In group A the stability for the second compaction is greater than that for the first compaction, and in group B the stability for the second compaction is less than that for the first. The counteracting effect of the two conditions of pavement which would tend to even out averages of the stability-density relationships are thus reduced.

Examination of Table 6 indicates there is some increase in stability of the in-place condition with increase in age from one to 11 years for both groups. In group B it would appear that the relative compaction for the in-place cores for all ages is approaching the peak of the density-stability curve and that further compaction would begin to decrease the stability. In group A, however, compaction would increase to very near 100 percent relative before stability begins to decrease. There are some individual cases scattered through all age groups, total approximately 12 percent of the total, in which the wheel track stability in-place is less than the shoulder and between wheel track stability. These are all in the group B class and the compacted core stabilities and the laboratory-molded specimen stabilities are either zero or approach zero. It would appear that these pavements have reached their maximum stability and that further compaction will decrease stability. Because there was no evidence of instability in the 1960 survey, it is believed that the low stability values in-place are not significant provided the stability-density relationships indicate that the peak of the stability-density curve for the mixture in question has not been reached. The individual specimens that do appear to be on the right slope of the curve in Figure 3 may be susceptible to shoving if further compaction is achieved. However, examination of Figure 1 would indicate that further compaction is doubtful.

The range of individual wheel track stabilities in-place, including the 1954 survey, is from 7 to 38. The average stabilities for group A and for group B for all ages as indicated in Table 6, are presented in Figure 4. This average presentation is quite

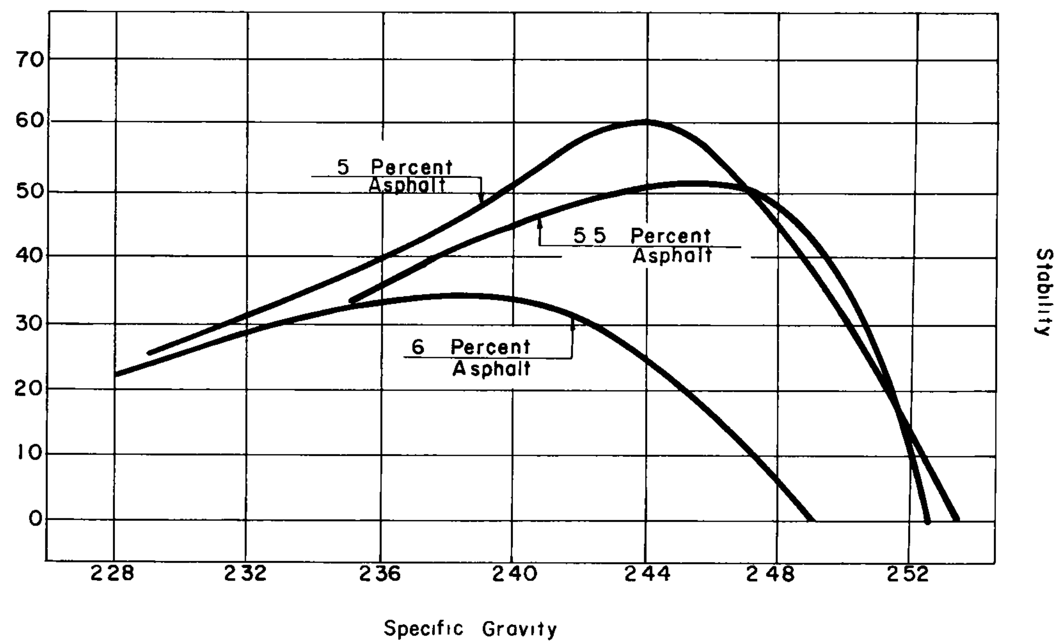

Figure 3. Characteristic stability-density relationship using one aggregate and one gradation.

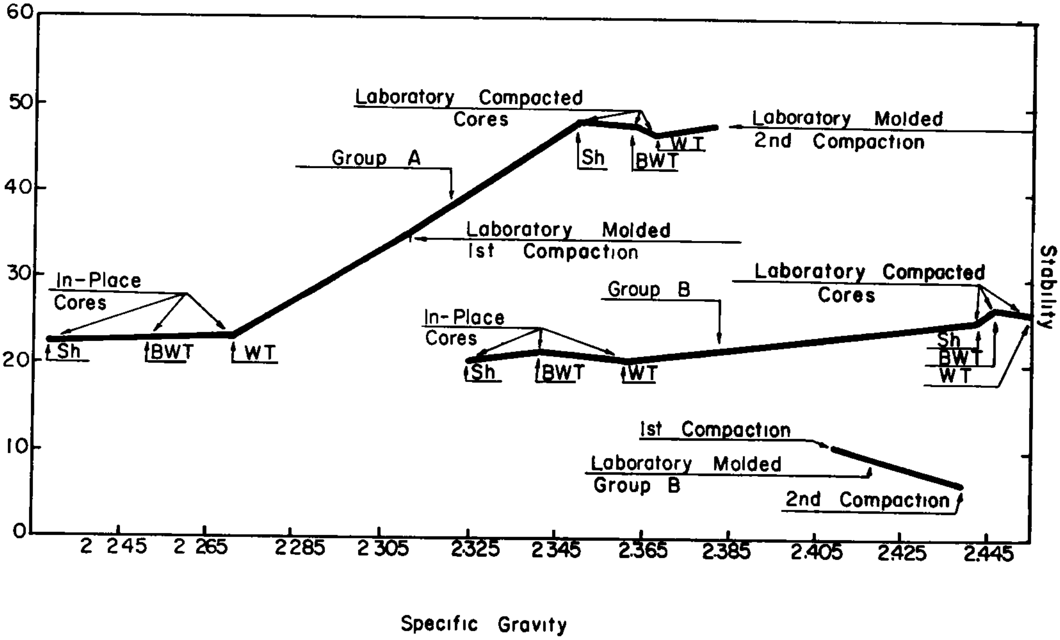

Figure 4. Field condition—laboratory treated.

typical of comparable figures for each age group even though the in-place stabilities are greater for the eleventh year than they are for the first year.

The lowest stability obtained in the 1954 survey was 9 which increased to 17 in the 1960 survey. The average in-place stability in 1954 was 21.4 which increased to 24.8 in 1960.

CONCLUSIONS

From the analysis of the surface conditions obtained from the survey, and tests on samples taken, it is concluded that:

1. Cracking and raveling are as prevalent as flushing in the pavements surveyed, neither of which conditions are excessive.
2. There is no evidence to indicate that wheel track depressions are caused by instability or horizontal shoving of the pavement but rather by a combined compaction of pavement and base.
3. There is a significant loss of asphalt content occurring in many mixtures after they have been placed on the roadway. Both the physical changes taking place and the conditions prevailing which permit such changes remain a matter of conjecture.
4. The rapid increase in density caused by traffic the first three years after construction indicates a need for higher compaction during construction. Traffic compaction continues after construction for at least 11 years, the last eight of which cause only slight particle reorientation. A requirement of 95 percent relative compaction would place the pavement in a condition only slightly susceptible to further traffic compaction.
5. Laboratory compaction on field cut cores is slightly greater than is achieved by 11 years of traffic. The density obtained from laboratory-compacted cores changes in a degree depending on the amount of traffic prior to cutting the cores. The greater the prior rolling or traffic, the greater will be the laboratory compacted value.
6. Low in-place stability values are not indicative of pavement instability, particularly when the mix design is such that further consolidation by traffic increases the measured stability value.

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Appendix A

Equipment and Procedure for Measuring Wheel Track Depressions

The equipment consisted of a 5.5-ft length of 2- by 2-in. aluminum H-beam. One-half inch holes were bored in the flanges close to the web, 2.75 ft from the ends. The holes were bored exactly opposite each other. A ½-in. rod approximately 3.5 in. in length was ground and polished to fit the ½-in. holes with slight clearance. The beam was placed on a level surface with the rod through the holes so that the end of the rod rested on the level surface. The rod was marked at a point even with the top surface of the top flange. An inch of the rod was then calibrated with markings at 1/16-in. intervals from the zero marking toward the upper end.

In making depression measurements, the beam was placed across the wheel track then moved slowly across the roadway until the deepest depression was found which was read on the calibrated rod and recorded.

Procedure for Determining Specific Gravity of Cores and Laboratory-Molded Specimens

Bulk specific gravity determinations were made on core specimens for each condition of compaction. The sample to be measured was weighed in water then wiped surface dry and weighed in air. The sample was then oven dried at 230 F for 15 hours and reweighed. Specific gravity was calculated by dividing the oven-dried weight by the difference between the wet weight in air and the weight in water.

Equipment and Procedure for Determining "Effective" Apparent Specific Gravity for Use in Determining Void Content

The apparatus for this determination consists of a 1-qt fruit jar with a conical cover in which are two vents, one at the peak of the cone and the other part way down the side of the cone. A short metal tube, of approximately 1/16-in. diameter, is threaded into the second vent. The volume of the pycnometer was determined by weight using a solvent of known specific gravity.

In determining the specific gravity of the asphaltic mixture, 500 grams of warm oven-dried sample were placed in the jar and solvent added to near the top. The contents were stirred until the asphaltic mixture had completely disintegrated, and all air bubbles had been removed. The cover was then fastened tight and solvent entered through the tube vent until the top vent overflowed. The jar and contents were placed in a water bath and held for two hours at the temperature used in calibrating the volume. Further solvent was added, if needed, to overflow the pycnometer which was then taken out of the bath, wiped dry, and weighed. The weight of mixture used divided by the volume of the jar minus the volume of solvent resulted in an effective specific gravity value. This value is slightly less than that obtained from the combined specific gravity of asphalt and apparent specific gravity of the aggregate and is slightly higher than the combined specific gravity of the asphalt and the bulk specific gravity of the aggregate.

Equipment and Procedure for Laboratory Compaction and Laboratory-Molded Specimens

The automatic kneading compactor used and the procedure followed is in conformance with ASTM: D 1561-58T. A temperature of 230 F was used for both the consolidation of core samples and the formation of laboratory-molded specimens.

Equipment and Method for Determining Stability

Stabilities of cores and laboratory-molded specimens were determined in accordance with the apparatus and procedure described in ASTM: D1560-58T with the exception that cohesion was not determined.

Appendix B

SEQUENCE OF SAMPLE TREATMENT

Cores

On arrival at the laboratory the core samples were measured for thickness and cut to 2.5 in., then weighed in water, cloth dried and weighed in air. The cores were then placed in tared molds and dried for 15 hr at 230 F and reweighed. This weight is the dry weight used in calculating specific gravity. The molds and cores were brought to 140 F in an oven and the cores transferred to the stability apparatus. After stability measurements were taken the cores were replaced in the molds, heated to 230 F and compacted with the kneading compactor using 160 blows at 450 psi. After compaction, the cores were removed from the molds, weighed in water and in air cloth dried. The dry weight previously used for calculating specific gravity in-place was used for calculating the compacted specific gravity. The cores were then replaced in their molds, heated at 140 F for two hours and retested for stability. The "effective" apparent specific gravity was determined on the cores after the second stability measurements were made.

Cut Samples and Laboratory-Molded Specimens

On arrival at the laboratory the cut samples were divided in half. Granulometric analysis and asphalt content were determined on the top lift of one-half by the rotarex method.

The top lifts of the second half were heated to 140 F for 15 hours, mixed and molded into 2.5-in. specimens with the kneading compactor using 20 blows at 225 psi, then 160 blows at 450 psi and finished with 1,000-lb static load. After removal from the molds the specimens were measured for specific gravity and stability using the same technique as was used for the core samples. The specimens were then inverted in their molds, recompacted using 160 blows at 450 psi and remeasured for specific gravity and stability. These specimens were not measured for "effective" apparent specific gravity.