to the aggregate shape factor. But until a more-complete rational evaluation has been made, we would not suggest that the evaluation obtained with an arbitrary test procedure be ignored, especially if correlating field data are available.

Performance of Bituminous-Mix Designs

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This paper reports the observed behavior and performance of 14 sections, each 1,000 feet long, of bituminous concrete and various types of bituminous surface treatment overlay pavements on old portland-cement concrete.

Three types of coarse aggregate were used: crushed granite, crushed gravel (about 50 percent crushed particles), and uncrushed gravel. Approximately 550 samples were taken from the plant and roadway, during construction and after the pavement had been in service a year, with the location of every load placed in the road accurately identified in order to determine the uniformity of the proportioning and mixing operations.

One of the most-important factors in this test is the degree of compaction utilized in the design process and the correlation with that which can be obtained in the field. The compactive effort in the laboratory in the preparation of test specimens should be the same as, or bear a known relation to, the field compactive effort and the effect of traffic in relation to density after one year of service.

In connection with the overlay using asphaltic-pavement mixtures, two matters of general interest did not receive any special attention, namely, the treatment of cracks and the treatment of joints in the existing cement-concrete pavement before resurfacing.

The data should make it possible to develop satisfactory control for future asphalt-pavement construction for heavy-duty highways and aid in obtaining correlation between the results of mechanical tests on the materials and their road behavior.

● FOR several years the Research Branch of the Division of Materials has utilized the three factors, stability, density, and resistance to moisture, as measures of quality in evaluating and designing bituminous-concrete paving mixtures in the laboratory.

Density determinations are of first importance in the laboratory design and it is the practice in North Carolina, as in most other states, to endeavor to obtain a minimum void content of 15 to 20 percent through aggregate gradation—the denser the aggregate the greater the strength or stability to be expected. Asphalt is added to the extent necessary to leave approximately 5 percent of voids in the final mix when compressed as it is intended to be compacted on the road. Under no circumstances should this value be less than 3 percent, and it is desirable, in order to assure resistance to percolation of water and the effects of weather, that the value be not greater than 6 percent.

The density criteria are used in judging the quality of the road samples taken in conjunction with studies of old pavement. It has been found that most of the failures of bituminous pavements in North Carolina have been the result of the presence of an excess of asphalt as indicated by the absence of a safe amount of air voids.

One of the most-rapid and most-serious failures took place on US 301 north of Fayetteville. It has been necessary from time to time to reshape the surface by scraping off some of the surfacing which had been placed on about 19 miles of cement concrete pavement built in 1926. This is one of the most-heavily traveled routes through North Carolina. The daily traffic count for all vehicles is 4,500, of which 30 percent is heavy trucks. The bituminous resurfacing which failed by shoving and stripping after less than 17 months of service was not designed by the laboratory, and except for the excessive amount of moisture between the old concrete pavement and the new bituminous-concrete surfacing, which caused stripping of the aggregate, the cause of the failure was not readily apparent. It is thought that the type of aggregates used were such as to make the percentage of asphalt a critical value and that, because of insufficient control of the uniformity of the mixture produced by the plant, many areas of the pavement were in the unstable range of composition, although the average for the job did not appear to be so bad as to warrant the extensive failures which occurred.

At the request of the division engineer responsible for this road, the laboratory outlined an experiment in which three types of coarse aggregate were used: crushed granite, crushed gravel, (about 50 percent crushed particles) and uncrushed gravel. The uncrushed gravel was the same coarse aggregate used in the bituminous-concrete resurfacing where the rapid and serious failures took place on US 301. Mixtures were designed with all the care the laboratory could command. The laboratory personnel supplemented the inspectors assigned to the job, and every precaution was taken to secure a reasonably uniform product from the not-too-well-equipped plant that would conform to the laboratory designs. Numerous samples were taken from the plant and the roadway during construction and analyzed in the laboratory—with the location of every load placed in the road accurately identified.

DESIGN PROCEDURE

Among the chief factors considered in designing a high-type bituminous-concrete pavement is stability. Stability may be defined as resistance to deformation. The laboratory has found a close association between aggregate density and stability. Regardless of the type of aggregate, the grading that produces the highest aggregate density will produce a bituminous mixture having a higher stability than can be obtained with less-dense gradings of the same aggregate. The first problem, then, is to determine the aggregate blend which will produce maximum density (minimum void content).

A rather unusual procedure was used in designing the bituminous mixtures for the test sections. The optimum aggregate blend was determined with the vibratory compactor; the 6-inch Hubbard-Field stability test was used in preparing the test specimen; and the Marshall criteria were used as a basis of selecting the mix formula for each type of material.

At the time discussion first began concerning a test section, this laboratory was using the 6-inch Hubbard-Field stability test for all bituminous-concrete mixes. Due to the importance attached to this project, it was felt unwise to use the unconfined-compression test for designing the test mixtures, since the laboratory personnel were not familiar with the details of this test. Consequently, there was no choice other than the Hubbard-Field test. In selecting the formula the following items were taken into consideration: stability, density, percent of voids for total mix, and percent of voids filled with asphalt. All mixtures selected contained between 3 and 5 percent of voids in total mix and had from 70 to 78 percent of the voids in the aggregate filled with asphalt. Only grade AP-3 asphalt (85–100 penetration) was used in these mixes. Several other grades of asphalts were used as tack coats.

A number of conditions at the asphalt plant made reproduction of design mixes rather difficult. Since there was no elevator or bin for adding mineral filler to the mixtures, it was necessary to have an operator add the filler by hand. The filler (in 100-lb. bags) was added in these increments rather than attempting to break the bags further.

Screening efficiency at the plant was only about 80 percent, which made it necessary to make constant corrections for sand being in the stone bins and vice versa.

While the degree of accuracy obtained on this job is not as great as could have been obtained under ideal conditions, it was far greater than on the average North Carolina job. The attainment of the desired results will provide ample reward for the time and effort expended on scrupulous attention to the details of design and construction. It is believed that with

TABLE 1
JOB MIX FORMULAS

Passing	Retained	Vander (Un-crushed gravel) Percent	Lilesville (50% Crushed gravel) Percent	Grey-stone (Crushed Granite) Percent
Binder Course				
1 in.	¾ in.	0.82	1.24	0.00
¾ in.	½ in.	23.03	17.88	23.67
½ in.	⅜ in.	5.47	13.62	10.54
⅜ in.	No. 4	17.83	18.14	14.74
No. 4	No. 10	10.09	6.48	7.86
No. 10	No. 40	13.76	14.49	14.07
No. 40	No. 80	14.60	14.14	14.15
No. 80	No. 200	6.54	6.37	6.40
No. 200		3.26	3.24	3.23
Percent Bitumen		4.60	4.40	5.34
		100.00	100.00	100.C0
Wearing Surface				
¾ in.	½ in.	0.91	2.60	0.38
½ in.	⅜ in.	4.31	18.44	9.35
⅜ in.	No. 4	28.11	25.04	27.47
No. 4	No. 10	18.87	10.86	14.62
No. 10	No. 4C	14.88	14.04	15.44
No. 40	No. 80	15.60	13.32	15.37
No. 80	No. 200	7.29	6.24	7.10
No. 200		4.93	4.36	4.47
Percent Bitumen		5.10	5.10	5.80
		100.00	100.00	100.00

proper design and control many of our difficulties with bituminous mixes would be solved.

The job mix formulas for the different types of materials are shown in Table 1.

CONSTRUCTION PROCEDURE

The experimental section of roadway begins at a point in US 301 1,000 feet south of the intersection of a county road and US 301 in Godwin and extends in a northerly direction along US 301 approximately 2.8 miles by and beyond Rhodes Pond, with the exception of a section on each end of the spillway bridge of about 350 feet. The test section is divided into two parts, Part 1 being the Godwin end beginning at roadway Station 0+00 and ending at Station 90+00 a point 350 feet south of Rhodes Pond spillway bridge and including Subsections 1 through 9. Part 2 consists of Subsections 10 through 14 and begins at a point approximately 350 feet north of the Rhodes Pond spillway bridge at roadway Station 0+00 and extends to Station 50+00.

This location was selected for a test section for several reasons. First, it is one of the heaviest-traveled through routes in North Carolina. Second, the surfacing, which had been considered to be a very-high type of bituminous concrete, after only 17 months had failed to such an extent that it was considered hazardous. Over most of this area this surfacing material was machined off and the old worn portland cement concrete pavement exposed to traffic again. This area included Subsections 1 through 12.

This section of US 301 is located in a comparatively flat section of Cumberland County which required no heavy grading, and therefore, the cut and fill sections are very light. In no case does the grade line exceed 1 percent. The soil throughout the whole sections consists of a sandy loam, and the drainage condition is from fair to good. Even though the terrain is comparatively flat, the roadway alignment is rather curved, as will be noted on accompanying straight-line diagrams describing each subsection in detail.

The original pavement consisted of plain portland-cement concrete, 16 feet wide with an 8-6-6-8-inch cross-section. The project was graded during 1926, and the pavement was completed during the earlier part of March 1927. After 12 years' service, three of the curves were relocated, and paved with uniform 7-inch portland-cement concrete 20 feet wide. At the same time, the remainder of the project was widened from the original 16 feet to 20 feet, with a 4-foot portland-cement-concrete widening strip of a uniform thickness of 8 inches. The original pavement was built with neither expansion nor contraction joints, but when the curves were reconstructed and the remainder of the project was widened, expansion joints were spaced 90 feet apart with two contraction joints spaced on 30-foot centers between expansion joints. The three sections which contain these expansion and contraction joints for the full width of the pavement are as follows: Part 1, from Station 15+90 to Station 37+95 and from Station 52+65 to Station 62+55; Part 11, from Station 0+00 to Station 25+60; the remainder of the test sections are the parts where only the old pavement was widened with the 4-foot widening strip, which contained the expansion and contraction joints previously described.

Prior to beginning construction of the experimental sections, a condition survey was made of the existing portland-cement-concrete pavement over the area that had been selected for the tests. This survey included the recording of observations made of the physical features of the pavement, such as type, design, apparent changes that had taken place since having been put into service, and maintenance repairs that had been made, such as removing and replacing of rocking slabs, surface patching, subsealing. These notes have been plotted and are included in the straight-line diagram of each subsection.

The F. D. Cline Construction Company of Fayetteville had the contract for mixing and placing the surfacing on the sections where hot plant mixes of bituminous concrete and hot sand-asphalt mixes were involved and the Third Division road-oil personnel and equipment did all the work required in connection with the construction of the sections specifying bituminous resurfacing.

The contractor's roadway equipment included two Barber-Green hot-mix spreaders; one 1,500-gal. Etnyre asphalt distributor, one 8-ton Buffalo-Springfield tandem roller, two asphalt hand rakes, one wooden lute, fifteen 6-ton hydraulic dump trucks, and one supply truck. The Barber-Green spreaders appeared to be probably 4 or 5 years old and had not been kept in good repair. Only the most-vital parts had received close attention, while such things as screws, which were used only when the finer adjustments became necessary, had been allowed to corrode or otherwise become frozen to the point that such adjustments were impossible. To put the spreaders in the mechanical condition with which a uniformly dense and even layer of the mix might be obtained would have required extensive replacement of parts and repairs. The Etnyre asphalt distributor was in good operating condition and manned with an experienced driver and operator. The design was such as to reduce the spreading of the material out of bounds to a minimum. The pressure pumps were in such condition as would maintain an operating pressure that would insure a uniform coating of tack coat material throughout the entire width to be treated. The Buffalo-Springfield tandem roller was in excellent mechanical condition and manned by an experienced and capable operator. It was a late model and when extra weight was desirable, two additional tons could be obtained by filling the interior of the wheels with water. This was done, bringing the operating weight up to 10 tons. Even with this additional weight it was considered advisable to supplement the rolling, which was done by borrowing an 8-ton tandem from the road-oil department of the highway commission. This roller was in good working condition and was operated by an experienced asphalt rollerman.

The contractor's forces consisted of: one superintendent, one paving foreman, two spreader operators, two asphalt rakers, two roller operators (one furnished by the highway commission's Third Division Road Oil Department), and four laborers. Neither of the two spreader operators had much experience with the Barber-Green spreader and, therefore, left much to be desired in the rate of feeding of the paving mix into the spreading unit, maintaining straight lines and straight construction joints, and the many smaller things that only an experienced operator will do in effecting satisfactory performance. The asphalt rakers were experienced and good workers, and the unskilled labor was adequate for the job at hand.

It was proposed in the beginning to place three types of resurfacing: hot-plant-mix bituminous concrete, bituminous-surface treatment, and a combination of both. During the course of construction of the bituminous concrete, such interest developed that the contractor requested and was granted permission to design and build a 1,000-foot section of sand-asphalt resurfacing, using his own kind, types, and blends of materials. Later it was decided to build another 1,000-foot section of sand-asphalt resurfacing differing from the first only in the design of the mix, which was done by the state highway-research laboratory and built by the highway commission's Third Division Road-Oil Department personnel and equipment.

Much thought was given to the choice of materials used in the construction of this test section, especially to the coarse aggregates. Crushed granite of comparable quality could be readily secured from both the Neverson and Greystone quarries, and quartzite gravel was available from the Vander, Lilesville, and Cheraw pits. All of the material from the Lilesville pits, both the Number 11 for the surface course and the Number 4 for the binder-course mix contained approximately 50 percent crushed particles and is referred to as crushed gravel. The material from the Cheraw and Vander pits contained no freshly crushed particles and is referred to as uncrushed gravel. All of the sand used in the several mix designs came from a local deposit on Route 210 about 5 miles northwest of Fayetteville, and the mineral filler was produced by the James River Hydrate Corporation, Buchanan, Virginia; Mexican Petroleum Corporation, Wilmington, North Carolina, furnished the asphalt, grades AP-5, AP-3 and RC-2 cutback. The emulsified asphalt, grade AE-3, was produced by the Emulsified Asphalt Refining Company of Wilmington.

The test section is divided into fourteen 1,000-feet subsections with each differing from the others either in type and kind of materials, mix design, or type of construction. Construction was started September 18, 1952, and was continuous daily, depending on receipt of material and weather conditions, which were very good. The last section was completed October 28, 1952.

Subsections 1, 2, and 3 begin at Station 0+00 and end at Station 30+00, Part 1. The original plans for this area called for a bituminous-concrete surface course of 150 lb. per sq. yd. laid directly on the existing portland-cement-concrete pavement, eliminating any binder or leveling course. Two grades of asphalt were used separately on these three sections as a tack coat between the surface course material and the existing pavement. Cutback asphalt, Grade RC-2, at the rate of 0.117 gal. per sq. yd. was applied to the western half, and hot bitumen, Grade AP-3, at the rate of 0.063 gal. per sq. yd. on the eastern half. Identical construction methods were employed throughout the surfacing operations, and one-way traffic was maintained on the east shoulder of the road while paving operations were in progress.

Each section has a special mix design as regards the type of coarse aggregate used. Other materials used in the three designs, such as fine aggregate, mineral filler, and the asphaltic cement, are similar throughout and have the same source.

Section 1 is paved with the crushed-stone mix design; Section 2 is of the crushed-gravel design; and Section 3 is of the uncrushed-gravel mix design.

The surface course material was transported from the mixing plant to the paving site in uniform loads of 6 tons each. The number and temperature of each load was taken and recorded, as was the beginning and ending roadway station of the area and the lane in which the material was spread. The material was spread in two 10-foot lanes, one at a time, by the use of a Barber-Green spreading machine. The speed of spreader was held to between 18 feet and 22 feet per minute and spreading was practically continuous. The bituminous concrete surface course material was delivered to the spreader at an average temperature of 297 F. with a maximum of 355 F. and a minimum of 255 F.

Rolling was begun as soon as the spreading operations were completed and while the paving mix was approximately 250 F. The first rolling or sealing was done with an 8-ton tandem roller and final compaction was obtained with a 10-ton tandem roller. The speed of the rollers was between ¾ and 1¼ mph. and rolling was continuous until the temperature of the new surfacing had cooled to 100 F. and lower. The sealing was kept close to the spreader, so as not to cause any displacement of the freshly placed surfacing material or otherwise damage the riding qualities of the pavement.

When the pavement had thoroughly cooled and had been turned over to traffic, samples for laboratory testing and density determination were lifted from representative points. Comparisons of the compaction developed by the construction methods described shows 95.5 percent of that developed in the laboratory during the design procedure, where the specimens were subjected to a static load of 350 psi. at 250 F. for 5 minutes after being subjected to 150 blows using standard Hubbard-Field tamps.

Tests performed on the finished surfacing using the road-roughness indicator showed a roughness of 84.48 inches per mile for Sections 1, 2, and 3.

Sections 4, 5, and 6 consisted of resurfacing composed of 150 lb. per sq. yd. of bituminous-concrete binder on the existing portland-cement-concrete pavement and 150 lb. per sq. yd. of bituminous concrete surface course. In these three cases, a tack coat of AP-3 asphalt was applied to the western half of the road, at a temperature of 415 F., at the rate of 0.063 gal. per sq. yd. On the eastern half-width the tack coat consisted of RC-2 and was applied at the rate of 0.120 gal. per sq. yd. The RC-2 tack coat material was applied two days before the laying of the binder course was begun to allow for sufficient curing.

The uncrushed-gravel mix was used on Section 4, crushed gravel on Section 5, and crushed-stone was used on Section 6. The binder mix was made of North Carolina Specification Grading No. 4 coarse aggregate, local sand, mineral filler and asphaltic cement, Grade AP-3, from the sources previously identified. The surface course mix was made of North Carolina Specification No. 11 coarse aggregate with sand, mineral filler, and asphaltic cement from the same sources.

The construction methods and procedure were practically the same for both the binder and the surface courses. In each case the hot-mix material was laid in 10-foot individual lanes, a lane at a time, which was half of the width of the finished pavement. Since each of the three sections called for a different mix design in both the binder and the surface courses and each design called for a different kind and type of coarse aggregate, spreading of both lanes was completed before beginning spreading on a new section with a different mix design.

Immediately before spreading the surface-course material a tack coat of Grade AP-3 asphaltic cement, which had a temperature range from 370 F. to 415 F., was applied to the binder course at an average rate of 0.063 gal. per sq. yd. One-way traffic was maintained on the east shoulder of the road while construction was in progress. The weather was comparatively dry and the native soil on the shoulder was soon pulverized, creating somewhat of a dust problem on the tack coat on the side next to traffic. To alleviate this unfavorable condition, this side was paved first and, in cases where it was considered necessary, hand brooms were used to brush off loose material.

The hot bituminous-concrete-mix materials were delivered to the spreader by trucks loaded uniformly with 6 tons each and at an average temperature of 290 F., maximum 390 F., minimum 255 F. The Barber-Green spreader was operated at a speed of between 18 feet and 22 feet per minute, which contributed to the uniformly smooth and dense distribution of the surfacing materials on these sections. During the spreading operation, a record was kept of the materials showing the temperature of each load, the beginning and ending roadway station of the area in which each load of material was placed, the load number, and which lane was being constructed at the time.

Rolling was done with two tandem rollers; one 8-ton and one 10-ton. The initial or sealing rolling was done with the 8-ton tandem and was kept up close to the spreading machine so as not to cause apparent displacement of the hot mix. The final compaction was attained with the 10-ton Buffaloe-Springfield, which followed closely the initial rolling. The speed of both rollers at all times did not exceed 1¼ mph. and rolling was continuous until the surfacing material had cooled to approximately 100 F.

Samples taken from the pavement on which laboratory tests were performed revealed that the compaction developed by the above described construction methods averaged 96.76 percent of that obtained in the laboratory.

Tests performed on the finished surfacing using the road roughness indicator showed a roughness of 75.76 inches per mile for Sections 4, 5, and 6.

Pavements showing road roughness of 65 inches per mile are considered excellent; 75 inches per mile, very good; 90 inches per mile, average; and 150 inches or more per mile, unsatisfactory.

Sections 7, 8, and 10 differ radically from the other test sections in design. On each of these sections a standard-specification bituminous-surface-treatment mat course was substituted for the usual binder course, and after a 12-day curing period this mat course was surfaced with a designed hot plant mix of bituminous-concrete surface-course material or of hot-plant-mix sand-asphalt surface-course material as prescribed for the subject section.

Section 7 was built with a mat course which consisted of 65 lb. per sq. yd. of Neverson No. 10 crushed stone and 0.613 gal. per sq. yd. of emulsified asphalt grade AE-3. The surface course was 104.8 lb. per sq. yd. of the bituminous-concrete crushed-stone mix as placed on Sections 1 and 6.

Section 8 was built with a mat course which consisted of 64 lb. per sq. yd. of Cumberland No. 10 uncrushed gravel and 0.645 gal. per sq. yd. of emulsified asphalt, grade AE-3. On this mat course was placed 102.6 lb. per sq. yd. of bituminous concrete of the uncrushed gravel surface course mix design as used on Sections 3 and 4.

The mat course on Section 10 was built in two sections. The first 500 feet was built of 64 lb. per sq. yd. of Cheraw uncrushed gravel and 0.589 gal. per sq. yd. of emulsified asphalt Grade AE-3. On the second 500 feet, 65 lb. per sq. yd. of Neverson No. 10 crushed stone was placed as a mat course with 0.633 gal. per sq. yd. of AE-3 emulsified asphalt. On these mat courses was placed 164.7 lb. per sq. yd. of sand-asphalt surface-course-mix material. The asphaltic cement used in this surface course was AP-5.

The surface courses on these three sections were built similarly to the other sections on which hot mixes were specified, with the exception that there was no tack coat between the mat and surface courses.

Samples of the surface courses were taken from each section and laboratory tests showed the compaction developed during construction to be 99.15 percent of that developed in the laboratory.

Section 9 was not originally planned, but during the progress of construction interest in the project developed to the point that the contractor asked for and was granted permission to design the mix for and resurface a section. This section has no binder or leveling course and consists of 170.1 lb. per sq. yd. of sand-asphalt surface course placed in one course on the existing worn portland-cement-concrete pavement.

Prior to placing the surface course material, a tack coat of 0.10 gal. per sq. yd. of AP-5 asphaltic cement at a temperature of 400 F. was applied to existing pavement. The construction methods exercised in placing and compacting this surfacing were similar to those used on other hot-mix-paved sections, with apparently the same results obtained elsewhere. Records on each load of the surfacing material were kept, showing the temperature and the area on which each load was placed. About two weeks later the road-oil department applied a seal coat of 0.506 gal. per sq. yd. of AE-3 emulsified asphalt and 43.2 lb. per sq. yd. of Greystone No. 11 crushed stone.

Tests performed on the finished surfacing using the road-roughness indicator showed a roughness of 86.0 inches per mile for Sections 7 through 10.

As formerly described, the pavement surfacing and mix designs for Subsections 1 through 10 are hot-plant-mixed bituminous materials. While these mixes were being planned, it was decided to make a further study of bituminous resurfacing as embodied in bituminous-surface-treatment type of surfacing. Therefore, Subsections 11 through 14 are composed entirely of this type of construction and differ from each other only in design and type of materials used.

Subsections 11 and 12 are areas where a badly deformed surfacing composed of bituminous-concrete binder and surface courses had been removed from the original 20-foot portland-cement-concrete pavement. Subsections 13 and 14 are areas where the deformed bituminous-concrete surfacing had been reheated and somewhat smoothed by a blading process but had not been removed entirely as had been in Sections 11 and 12.

The materials selected for study were crushed stone from the Neverson and Greystone quarries and gravels from the Vander and Cheraw pits. Emulsified Asphalt Refining Company of Wilmington, N. C., furnished the AE-3 emulsified asphalt used in the surfacing. The construction methods employed were similar throughout these four sections.

On Subsection 11 the mat course was made of 65 lb. per sq. yd. of Neverson No. 10 crushed stone and 0.77 gal. per sq. yd. of emulsified asphalt, and the surface course consisted of 46 lb. per sq. yd. of Greystone No. 11 stone applied in two courses and 0.441 gal. per sq. yd. of emulsified asphalt, applied in three shots. Immediately after the last application of the asphalt, a choke course of local coarse sand and gravel was spread over the new treatment at approximately 10 lb. per sq. yd. and turned over to traffic for use. The mat course was placed eleven days before the seal course was spread.

Subsection 12 is built of gravel throughout. The mat course is made of 64.8 lb. per sq. yd. of Cheraw No. 10 gravel with 0.682 gal. per sq. yd. of AE-3 emulsified asphalt. The seal course on the first 500 feet of this section is made of 43.2 lb. of Vander No. 4 gravel and 0.458 gal. per sq. yd. of AE-3 emulsified asphalt. The seal course on the remaining 500 feet of this section consists of 43 lb. of Vander No. 11 gravel and 0.454 gal. per sq. yd. of AE-3 emulsified asphalt.

Subsection 13 is divided into two parts. The first 500 feet is surfaced similar to the last 500 feet of Subsection 12, but the mat course on the last 500 feet of Subsection 13 is made of 64 lb. of Neverson No. 10 stone and 0.792 gal. per sq. yd. of AE-3 emulsified asphalt. The seal course on this last 500 feet consists of 43.6 lb. Greystone No. 11 stone and 0.549 gal. per sq. yd. of AE-3 emulsified asphalt.

The surfacing on Subsection 14 consists of the seal course applied on the existing bituminous surfacing without a mat course. The first 500 feet was treated with 43.8 lb. of Greystone No. 11 crushed stone and 0.478 gal. of emulsified asphalt and the last 500 feet was treated with 43 lb. of Vander No. 11 gravel and 0.438 gal. per sq. yd. of emulsified asphalt grade AE-3.

PAVEMENT-CONDITION SURVEY AFTER A YEAR OF SERVICE

Test Sections 1, 2, 3, and 5 show little to no evidence of internal movement, shoving, or rutting. The riding quality remains good, as will be observed from the road-roughness report. In Sections 1, 2, and 3, many of the construction, contraction, and expansion joints, as well as the cracks which had developed in the old portland-cement concrete, have made an appearance in the surfacing. None of these cracks show any tendency toward raveling or spalling at the edges.

Sections 4 and 6 show little to no evidence of internal movement or displacement in the east or northbound traffic lane, but each shows definite indications of lateral movement or rutting in certain areas in the west or southbound traffic lane. In Section 4 this area lies between Stations 30+90 and 33+40, along the path of the outside wheels, and is also located on the outside of a 6-deg. superelevated curve. The area along the path of the inner wheels, opposite the distorted area, shows no appreciable displacement or internal movement. Pavement Samples 4–17, 4–18, 4–19, and 4–20 were taken from the displaced area and tests show an average deviation of 0.55 percent in an excess of asphaltic cement from the mix design for the surface course, and a comparable excess in asphaltic cement in the binder course of 0.64 percent.

Much of the west lane of Section 6 shows displacement in the area of the normal path of inside vehicle wheels which appear in the form of lateral movement or rutting. There is little evidence of forward movement and apparently no great change in the riding quality. This area, which is apparently more plastic, is between Station 54+00 and Station 59+00 and also lies on the inside or low side of a 6-deg. superelevated curve. Very little to no movement is noted in the opposite lane.

In an effort to uncover pertinent information on these distressed areas a comparison was made between the composition of the mixes used and their respective designs. These comparisons are shown in the comparative composition of mixes which follows on the next page. In Section 4 there seems to be no more than normal deviation in the mineral aggregates in both the binder and surface course mixes from their respective designs, but we do note the possibility due to the type of aggregate involved (uncrushed gravel), that there might be an excess of asphaltic cement present. The binder analyses show a bitumen content of 5.24 percent where the design calls for 4.60 percent, or an excess of 0.64 percent, and the surface-course analyses show an asphalt content of 5.65 percent when the design specifies 5.10 percent, or an excess of 0.55 percent.

In Section 6 the comparison shows less deviation between the mix composition and the design than in Section 4, but in both the binder and the surface courses, the bitumen content is higher than that which the designs call for. The surface-course design was the same in Sections 1 and 6, and the only difference in design in these two sections is that Number 6 has a binder course whereas Section 1 has no binder. It was thought that a comparison of Section 1 similar to that made to the surface course of Section 6 might be revealing, since the surface course of Section 1 shows no marked degree of internal movement. An examination of the data in Table 2 shows that the aggregate blends of the mixes used in both Sections 1 and 6 are almost identical, but there appears to be a difference in the bitumen content; Section 1 shows 5.61 percent and Section 6 shows 6.13 percent, or a difference of 0.52 percent more in the unstable section. Roadway Samples 6–19, 6–20, 6–21, 6–22, 6–23, 6–24, and 6–25 represent the unstable area in Section 6.

A check of the construction methods and

TABLE 2

	Mineral Aggregate +10 Sieve	Mineral Aggregate −10 Sieve	Mineral Filler	Bitumen Content
	Section No. 4 Binder			
	%	%	%	%
Mix Design	57.24	34.94	3.26	4.60
Test Results	56.84	33.90	4.14	5.24
	Section No. 4 Surface Course			
Mix Design	52.20	37.77	4.93	5.10
Test Results	45.52	43.32	5.53	5.65
	Section No. 6 Binder			
Mix Design	56.81	34.62	2.23	5.34
Test Results	52.41	36.70	4.15	5.69
	Section No. 6 Surface Course			
Mix Design	51.82	37.81	4.47	5.80
Test Results	46.52	41.55	5.79	6.13
	Section No. 1 Surface Course			
Mix Design	51.82	37.81	4.47	5.80
Test Results	47.27	41.62	5.87	5.61

designs as related to the type and kind of tack coat material used and the rate of application shows that cutback asphalt grade RC-2 at the rate of 0.117 gal. per sq. yd. was applied to the old portland-cement concrete on the west lane of Sections 1, 2, and 3, and on the east lane in a similar manner of Sections 4, 5, and 6. In the opposite lanes in each section the tack coat consisted of hot bitumen grade AP-3 at the rate of 0.063 gal. per sq. yd., thereby subjecting each type of material and rate of application to as near the same type of service as possible. Sections 4, 5, and 6 have a binder course to which a tack coat of hot bitumen grade AP-3 was applied at a rate between 0.053 and 0.064 gal. per sq. yd. before spreading the surface-course material.

When the samples for this report were being lifted from the pavement, a careful visual examination was made of each individual sample and of the underlying concrete. All samples were easily separated from the old concrete—offering little resistance to displacement. On the average, an estimated 70 percent of the tack coat material left the surface of the old concrete and went with the bottom surface of the sample. The portion of the surface of the old pavement which was stripped of tack-coat material was moist throughout. This condition existed in each area sampled. In no case was there more than an estimated 40-percent bond existing between the bituminous surfacing and the old pavement. In practically every case where a portion of the bottom of the sample was left on the surface of the portland-cement concrete in sampling operations, the separation occurred directly between the surface of the particles involved and the coating of asphaltic cement. In all cases there was obviously present a noticeable amount of moisture in the old pavement which had penetrated upward an estimated 35 percent of the thickness of the surfacing. These conditions existed in all sections and to an equal extent in both lanes, irrespective of types of materials and quantities of tack coat applied.

Sections 7, 8, and 10 are the ones built of a combination surface treatment mat course on the old portland-cement-concrete pavement and sealed with 100 lb. of hot plant-mixed surface-course material. These sections differ from each other only in the kind of coarse aggregate used in the composition of the mixture. Section 7 is of crushed granite, Section 8 is of uncrushed quartzite gravel of comparable particle size, and the mat course of the first 500 feet of Section 10 is of crushed granite. Both areas or all of Section 10 are surfaced with 167 lb. per sq. yd. of hot plant-mixed sand-asphalt mix.

An examination of samples taken recently from these sections and the areas underneath the samples shows the presence of a considerable amount of moisture on the old portland-cement concrete surface throughout the entire thickness of the mat course and an estimated 30 percent of surface-course thickness. This moisture had penetrated the film of asphaltic cement on the particles in the mat course and those of the lower part of the surface course material. Much separation of asphalt from the particles occurred when disturbed by the process of sampling.

Few of the cracks and expansion joints in the old pavement have shown in the surfacing of these three sections, with no noticeable difference among the three. Slight forward movement of displacement has appeared in small areas of Section 8 and the first 500 feet of Section 10. Otherwise the riding quality and general physical condition are good.

Test Sections 11 through 14 are generally in fair condition. There has been some maintenance work performed due to loss of aggregate and areas where bleeding has occurred due to loss of aggregate. During the time these sections were being constructed, the weather was not favorable for this type of work; however, it is expected that valuable information will be obtained from their service behavior.

SUMMARY

It is believed that this project will have a definite effect on future specifications for high-type bituminous concrete. These sections are considered to be the most-carefully designed and most-closely controlled bituminous pavement in North Carolina. The project was constructed for a twofold purpose. First, the aggregates used are considered to be typical of North Carolina commercial aggregates. The three principal types of coarse aggregate (crushed stone, crushed gravel, and uncrushed gravel) are represented on this job. Therefore, the project is considered a test of average commercial aggregates under severe service conditions. Second, it is hoped that the importance of design and field control will be recognized through this work.

Several types of asphalt were used in various quantities as tack coats. This will afford an opportunity to study the value of a tack coat when portland-cement concrete is resurfaced with a bituminous overlay. This type of construction has been a constant source of trouble during the past few years. When samples were removed after a year of service, little or no difference was noted between the various types of tack coats. Bond between the old cement concrete and the bituminous resurfacing varied from 0 to 40 percent throughout. Owing to the comparatively short period which has elapsed since the construction of the project described in this report, there are no conclusions which can be reached with assurance at the present time.

The bituminous-concrete sections after a year of service are showing no signs of failure due to the design mixes. It has been necessary to patch two places approximately 8 inches wide and 10 feet long. Inspection of the straight-line diagrams (Figures A and B in the appendix) reveals that the concrete pavement at those two points had severe cracks which extended the full width of the pavement. Consequently, it may be assumed that the failures are due to the condition of the underlying portland-cement-concrete base rather than to the bituminous mixture. If all material had been removed from construction joints and cracks prior to the placing of the bituminous overlay, even this type of failure would probably have not occurred.

It is felt that these test sections will point out the importance of good design and control and the rewards will be more than ample for the painstaking care exercised in planning and constructing this project.

One of the most-important factors in this test is the degree of compaction utilized in the design process and the correlation with that which can be obtained in the field. That is, the compactive effort in the laboratory in the preparation of test specimens, for the determination of the optimum bitumen content, which should be the same as, or bear a known relation to, the field compactive effort and the effect of traffic in relation to density after a year of service.

As indicated by Table E, an average of 98.1 percent of the laboratory density has been obtained after a year of service.

APPENDIX

Table A shows a comparison between the laboratory design mix, samples taken immediately after construction, and samples taken one year after construction. One shortcoming of this table is that only two (in some cases, three) samples are represented by series number one. Series 2 represents an average of 28 samples. This item should be kept in mind when comparing these results.

Table B contains progressive roughness measurements made since completion of the test sections. Normally, this type of measurement is reported in inches per mile. In this case, however, the measurements are recorded as inches per section, i.e., inches per 1,000 feet.* The following information is given as an aid in evaluating these results.

Excellent	Below 75 in. per 1,000 miles (14 in. per 100 ft.)
Good	75–100, (14–19 inches)
Fair	100–125 (19–24 inches)
Unsatisfactory	Over 125 (24+ Inches)

Table C is concerned with a statistical analysis of the bitumen content in each section determined on samples from the plant and from

* To convert recorded measurements to inches per mile, multiply by 5.28.

TABLE A

Passing	Retained	Lab. Design	Series No. 1*	Series No. 2†
	Test Section No. 1 Wearing Surface			
¾"	½"	0.38	0.00	0.54
½"	⅜"	9.35	5.36	7.09
⅜"	#4	27.47	19.18	24.24
#4	#10	14.62	13.56	14.77
#10	#40	15.44	24.46	20.74
#40	#80	15.37	15.85	12.93
#80	#200	7.10	10.25	8.66
#200		4.47	5.67	5.65
Bitumen		5.80	5.67	5.38
		100.00	100.00	100.00
Sp. Gr. of sample		2.35	2.25	2.30
Sp. Gr. of Aggregate		2.63	2.63	2.63
Solid Volume Density		2.41	2.41	2.40
% Solids Total Mix		97.51	93.36	95.83
% Voids Total Mix		2.49	6.64	4.17
% by Volume of A.C.		13.36	12.51	12.18
% Solids Agg. Only		84.15	80.85	83.65
% Voids Agg. Only		15.85	19.15	16.35
% Voids filled with Asp.		84.29	65.33	74.50
	Test Section No. 2 Wearing Surface			
¾"	½"	2.60	0.00	1.23
½"	⅜"	18.44	11.48	10.47
⅜"	#4	25.04	21.58	22.35
#4	#10	10.86	13.19	13.35
#10	#40	14.64	21.86	21.20
#40	#80	13.32	13.12	12.34
#80	#200	6.24	8.71	8.31
#200		4.36	5.21	5.73
Bitumen		5.10	4.85	5.02
		100.00	100.00	100.00
Sp. Gr. of Sample		2.36	2.28	2.28
Sp. Gr. of Aggregate		2.64	2.64	2.64
Solid Volume Density		2.44	2.45	2.44
% Solids Total Mix		96.72	93.06	93.44
% Voids Total Mix		3.28	6.94	6.56
% by Volume of A.C.		11.80	10.84	11.22
% Solids Agg. Only		84.92	82.22	82.22
% Voids Agg. Only		15.08	17.78	17.78
% Voids Filled with Asp.		78.25	60.97	63.10
	Test Section No. 3 Wearing Surface‡			
¾"	½"	0.91	0.00	2.20
½"	⅜"	4.31	8.23	6.90
⅜"	#4	28.11	31.27	25.88
#4	#10	18.87	21.33	19.84
#10	#40	14.88	14.96	17.35
#40	#80	15.60	9.05	10.88
#80	#200	7.29	5.87	7.09
#200		4.93	4.24	4.70
Bitumen		5.10	5.05	5.16
		100.00	100.00	100.00
Sp. Gr. of Sample		2.36	2.30	2.33
Sp. Gr. of Aggregate		2.63	2.63	2.63
Solid Volume Density		2.43	2.44	2.43
% Solids Total Mix		97.12	94.26	95.89
% Voids Total Mix		2.88	5.74	4.11
% by Volume of A.C.		11.80	11.39	11.78
% Solids Agg. only		85.32	82.87	84.11
% Voids Agg. only		14.68	17.13	15.89
% Voids filled with Asp.		80.38	66.49	74.13

TABLE A—*Continued*

Passing	Retained	Lab. Design	Series No. 1*	Series No. 2†
	Test Section No. 4 Binder‡			
¾"	½"	23.85	16.04	19.87
½"	⅜"	5.47	11.12	9.46
⅜"	#4	17.83	17.94	17.33
#4	#10	10.09	11.45	11.62
#10	#40	13.76	16.75	16.11
#40	#80	14.60	11.60	10.24
#80	#200	6.54	7.07	6.72
#200		3.26	3.08	3.86
Bitumen		4.60	4.95	4.79
		100.00	100.00	100.00
Sp. Gr. of Sample		2.37	2.34	2.31
Sp. Gr. of Aggregate		2.63	2.63	2.63
Solid Volume Density		2.48	2.44	2.44
% Solids Total Mix		95.56	95.90	94.67
% Voids Total Mix		4.44	4.10	5.33
% by Volume of A.C.		10.69	11.36	10.85
% Solids Aggregate Only		84.87	84.54	83.82
% Voids Aggregate only		15.13	15.46	16.18
% Voids Filled with Asp.		70.65	73.48	67.06
	Test Section No. 4 Wearing Surface‡			
¾"	½"	0.91	0.82	0.00
½"	⅜"	4.31	8.76	7.18
⅜"	#4	28.11	25.52	26.11
#4	#10	18.87	17.43	19.15
#10	#40	14.88	19.63	19.03
#40	#80	15.60	11.37	11.53
#80	#200	7.29	6.82	6.70
#200		4.93	4.42	5.32
Bitumen		5.10	5.23	4.98
		100.00	100.00	100.00
Sp. Gr. of Sample		2.36	2.34	2.32
Sp. Gr. of Aggregate		2.64	2.64	2.64
Solid Volume Density		2.44	2.44	2.45
% Solids Total Mix		96.72	95.90	94.69
% Voids Total Mix		3.28	4.10	5.31
% by Volume of A.C.		11.80	12.00	11.32
% Solids Aggregate only		84.92	83.90	83.37
% Voids Aggregate only		15.08	16.10	16.63
% Voids Filled with Asp.		78.25	74.53	68.07
	Test Section No. 5 Binder‡			
¾"	½"	19.12	18.40	16.03
½"	⅜"	13.62	16.05	13.11
⅜"	#4	18.14	20.15	19.15
#4	#10	6.48	8.26	10.00
#10	#40	14.49	14.17	16.74
#40	#80	14.14	10.02	9.83
#80	#200	6.37	5.70	6.83
#200		3.24	2.93	3.53
Bitumen		4.40	4.32	4.78
		100.00	100.00	100.00
Sp. Gr. of Sample		2.40	2.34	2.34
Sp. Gr. of Aggregate		2.64	2.64	2.64
Solid Volume Density		2.47	2.47	2.45
% Solids Total Mix		97.17	94.74	95.51
% Voids Total Mix		2.83	5.26	4.49
% by Volume of A.C.		10.35	9.91	10.97
% Solids Agg. only		86.82	84.83	84.54
% Voids Agg. only		13.18	15.17	15.46
% Voids filled with Asp.		78.53	65.33	70.96

TABLE A—*Continued*

Passing	Retained	Lab. Design	Series No. 1*	Series No. 2†
TEST SECTION NO. 5 Wearing Surface‡				
¾"	½"	2.60	1.45	1.79
½"	⅜"	18.44	13.40	11.25
⅜"	#4	25.04	23.66	21.56
#4	#10	10.86	12.88	12.61
#10	#40	14.04	18.82	22.27
#40	#80	13.32	12.25	12.90
#80	#200	6.24	6.71	7.58
#200		4.36	5.60	5.20
Bitumen		5.10	5.23	4.84
		100.00	100.00	100.00
Sp. Gr. of Sample		2.36	2.34	2.34
Sp. Gr. of Aggregate		2.66	2.66	2.66
Solid Volume Density		2.46	2.45	2.47
% Solids Total Mix		95.93	95.51	94.74
% Voids Total Mix		4.07	4.49	5.26
% by Volume of A.C.		11.80	12.00	11.10
% Solids Aggregate Only		84.13	83.51	83.64
% Voids Aggregate		15.87	16.49	16.36
% Voids Filled with Asp.		74.35	72.77	67.85
TEST SECTION NO. 6 Binder‡				
¾"	½"	23.67	19.86	15.26
½"	⅜"	10.54	9.71	16.51
⅜"	#4	14.74	10.39	13.17
#4	#10	7.86	8.54	7.79
#10	#40	14.07	20.03	17.78
#40	#80	14.15	13.66	11.87
#80	#200	6.40	8.73	8.16
#200		3.23	4.53	3.86
Bitumen		5.34	4.55	5.60
		100.00	100.00	100.00
Sp. Gr. of sample		2.37	2.33	2.34
Sp. Gr. of Aggregate		2.63	2.63	2.63
Solid Volume Density		2.43	2.45	2.42
% Solids Total Mix		97.53	95.10	96.69
% Voids Total Mix		2.47	4.90	3.31
% by Volume of A.C.		12.41	10.39	12.84
% Solids Aggregate Only		85.12	84.71	83.85
% Voids Aggregate Only		14.88	15.29	16.15
% Voids filled with Asp.		83.40	67.95	79.50
TEST SECTION NO. 6 Wearing Surface‡				
¾"	½"	0.38	0.00	1.13
½"	⅜"	9.35	9.82	8.30
⅜"	#4	27.47	26.66	24.00
#4	#10	14.62	16.17	14.57
#10	#40	15.44	17.79	21.29
#40	#80	15.37	11.71	11.87
#80	#200	7.10	7.18	7.55
#200		4.47	5.27	5.32
Bitumen		5.80	5.40	5.97
		100.00	100.00	100.00
Sp. Gr. of Sample		2.35	2.33	2.33
Sp. Gr. of Aggregate		2.63	2.63	2.63
Solid Volume Density		2.41	2.42	2.40
% Solids Total Mix		97.51	96.28	97.08
% Voids Total Mix		2.49	3.72	2.92
% by Volume of A.C.		13.36	12.33	13.64
% Solids Aggregate Only		84.15	83.95	83.44
% Voids Aggregate Only		15.85	16.05	16.56
% Voids filled with Asp.		84.29	76.82	82.37

* Series No. 1 taken immediately after construction. (Represents average of three samples.)
† Series No. 2 taken one year after construction. (Represents average of 28 samples.)
‡ Series No. 1 taken immediately after construction. (Represents average of two samples.)

TABLE B
PROGRESSIVE ROUGHNESS
B. S. 3-6-30-155
Test Sections

Section and Date	Inches of Roughness E. Lane	Inches of Roughness W. Lane	Section and Date	Inches of Roughness E. Lane	Inches of Roughness W. Lane
Section No. 1			Section No. 6		
10-6-52	18	18	10-6-52	15	15
12-4-52	17	16	12-4-52	14	15
2-27-53	18	17	2-27-53	15	16
4-20-53	18	16	4-20-53	15	16
9-4-53	20	18	9-4-53	19	23
11-30-53	17	19	11-30-53	20	22
Section No. 2			Section No. 7		
10-6-52	16	17	10-6-52	18	16
12-4-52	16	15	12-4-52	17	15
2-27-53	17	15	2-27-53	17	15
4-20-53	15	15	4-20-53	16	15
9-4-53	19	16	9-4-53	16	18
11-30-53	18	16	11-30-53	16	16
Section No. 3			Section No. 8		
10-6-52	15	16	10-6-52	18	16
12-4-52	15	16	12-4-52	16	15
2-27-53	14	16	2-27-53	17	16
4-20-53	14	16	4-20-53	15	15
9-4-53	19	21	9-4-53	17	16
11-30-53	17	19	11-30-53	17	16
Section No. 4			Section No. 9		
10-6-52	14	15	10-6-52	17	17
12-4-52	13	14	12-4-52	20	20
2-27-53	14	14	2-27-53	20	20
4-20-53	13	13	4-20-53	20	20
9-4-53	17	22	9-4-53	20	20
11-30-53	18	20	11-30-53	20	22
Section No. 5			Section No. 10		
10-6-52	13	14			
12-4-52	13	14			
2-27-53	13	13			
4-20-53	12	14			
9-4-53	14	15			
11-30-53	14	15			

TABLE C

PERCENTAGE OF BITUMEN CONTENTS IN SAMPLES TAKEN FROM U. S. #301 N. OF FAYETTEVILLE

Description	Test Sec. Nos.	No. of Samples	Max.	Min.	Range	Average	±[a]	Std. Deviation	Coeff. of Variation %	Formula
Plant Samples										
Bit. Conc. Wearing Surface	1	32	5.85	5.05	0.80	5.50	.05	.141	2.56	5.80
Bit. Conc. Wearing Surface	2	19	5.40	4.10	1.30	4.73	.18	.360	7.61	5.10
Bit. Conc. Wearing Surface	3	13	5.30	4.60	0.70	4.97	.17	.265	5.33	5.10
Bit. Conc. Wearing Surface	4	20	5.45	4.10	1.35	4.84	.17	.345	7.13	5.10
Bit. Conc. Binder	4	15	4.95	3.95	1.00	4.40	.14	.245	5.57	4.60
Bit. Conc. Binder	5	23	4.55	3.90	0.65	4.20	.12	.264	6.28	4.40
Bit. Conc. Wearing Surface	5	26	4.50	3.80	0.70	4.15	.07	.173	4.17	5.10
Bit. Conc. Binder	6	30	5.90	4.75	1.15	5.29	.10	.265	5.00	5.34
Bit. Conc. Wearing Surface	6–7	40	5.75	4.40	1.35	5.33	.10	.300	5.63	5.80
Bit. Conc. Wearing Surface	8	27	5.10	4.20	0.90	4.66	.11	.283	6.07	5.10
Sand Asphalt Wearing Surface	9 (c)	28	6.75	5.45	1.30	6.21	.14	.346	5.57	6.25
Sand Asphalt Wearing Surface	10 (L)	33	8.55	7.40	1.15	7.96	.06	.173	2.17	7.50
Road Samples										
Bit. Conc. Wearing Surface	1	28	6.55	4.29	2.26	5.38	.19	.448	8.32	5.80
Bit. Conc. Wearing Surface	2	28	5.97	4.22	1.75	5.03	.15	.374	7.43	5.10
Bit. Conc. Wearing Surface	3	28	5.87	4.63	1.24	5.16	.11	.282	5.47	5.10
Bit. Conc. Wearing Surface	4	30	5.80	4.02	1.78	4.99	.17	.448	8.98	5.10
Bit. Conc. Binder	4	30	5.95	4.13	1.82	4.80	.19	.500	10.42	4.60
Bit. Conc. Binder	5	27	5.52	4.21	1.31	4.78	.13	.316	6.61	4.40
Bit. Conc. Wearing Surface	5	27	5.44	4.14	1.30	4.85	.13	.331	6.82	5.10
Bit. Conc. Wearing Surface	6	27	6.62	5.42	1.20	5.97	.08	.200	3.35	5.80
Bit. Conc. Binder	6	27	6.20	4.59	1.61	5.60	.17	.424	7.57	5.34
Bit. Conc. Wearing Surface	7	18	6.21	5.52	0.69	5.90	.17	.332	5.63	5.80

c = Contractor; L = Laboratory; [a] = the ± entry indicates 95% confidence limits.

TABLE D

SPECIFIC GRAVITY OF ROAD SAMPLES AFTER ONE YEAR OF SERVICE

Description	Test Sec. No.	No. of Sample	Max.	Min.	Range	Average	Std. Dev.	Coeff. of Variation %	Design Sp. Gr.
Bit. Conc. Wearing Surface	1	28	2.40	2.26	0.14	2.30	.03	1.3	2.35
Bit. Conc. Wearing Surface	2	28	2.38	2.16	0.22	2.28	.06	2.6	2.36
Bit. Conc. Wearing Surface	3	28	2.37	2.28	0.09	2.32	.03	1.3	2.36
Bit. Conc. Binder	4	30	2.35	2.25	0.10	2.31	.03	1.3	2.37
Bit. Conc. Wearing Surface	4	30	2.36	2.28	0.08	2.32	.02	0.8	2.36
Bit. Conc. Wearing Surface	5	27	2.38	2.26	0.12	2.34	.03	1.3	2.36
Bit. Conc. Binder	5	27	2.38	2.26	0.12	2.34	.03	1.3	2.40
Bit. Conc. Wearing Surface	6	27	2.36	2.29	0.07	2.33	.02	0.8	2.35
Bit. Conc. Binder	6	27	2.36	2.29	0.07	2.33	.02	0.8	2.37

TABLE E

Section No.	Design Sp. Gr.	Roadway Sp. Gr.	Percentage
1. W.S.	2.35	2.30	97.9
2. W.S.	2.36	2.28	96.6
3. W.S.	2.36	2.32	98.3
4. W.S.	2.36	2.32	98.3
4. Binder	2.37	2.31	97.5
5. W.S.	2.36	2.34	99.1
5. Binder	2.40	2.34	97.5
6. W.S.	2.35	2.33	99.1
6. Binder	2.37	2.33	98.3
Average			98.1% of lab. density

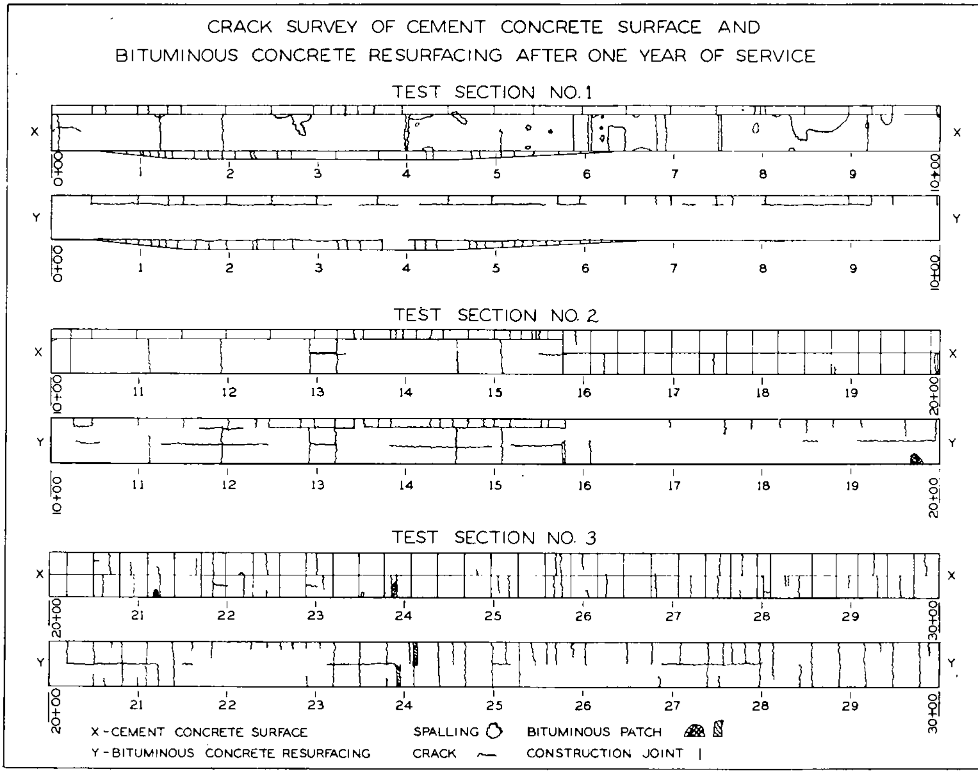

Figure A

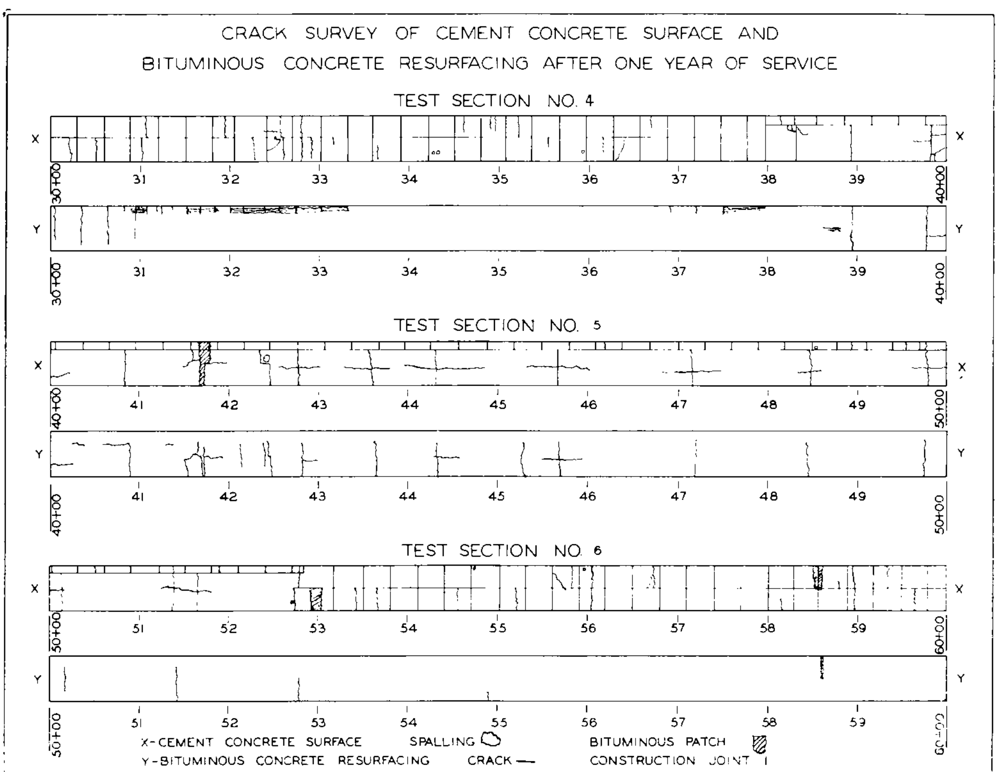

Figure B

the roadway after one year's service. It shows the maximum, minimum, and average contents. Also shown is the standard deviation and the coefficient of variation. The deviation is used to measure the dispersion of figures about the mean. The coefficient of variation of a set of numbers is the ratio of their standard deviation to their average expressed as a percentage.

Table D is a statistical analysis of the specific gravity of each section immediately after construction. Here again the maximum, minimum, average, standard deviation and coefficient of variation are shown.

Table E shows the percent density for each section after a year of service.

Figures A and B represent crack surveys made of the portland-cement-concrete pavement prior to placing the bituminous overlay and of the bituminous pavement after a year of service. X-X represents the cement-concrete surface and Y-Y represents the bituminous resurfacing.

Correlation between Stability and Certain Physical Properties of Bituminous Materials

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Data from several hundred closed-system triaxial-compression tests on thin specimens of bituminous mixtures are analyzed by graphical methods to obtain the significant physical properties. These properties are then treated by statistical methods and correlation charts constructed for several pairs of variables measured in the stress diagrams. Two of the most-significant variables, Hveem stability and critical shear resistance on the surface of failure, are subjected to a formal statistical analysis in which quantitative indexes of variation and correlation are calculated.

● THE final aim in this investigation was to find the relation between the most-significant physical properties of bituminous road mixes, as measured in the closed-system triaxial test with the Hveem stabilometer, and their performance characteristics when placed on the road. It consists chiefly of correlations between the Hveem stability index and various magnitudes representing physical properties of the mix derived by graphical analysis, employing Mohr circle and stress-triangle diagrams (*1*), from data on 685 Hveem specimens of bituminous materials composed of a wide variety of minus-½-inch aggregate gradings and RC-2 bitumen contents. The specimens were approximately 4 inches in diameter and 2 inches thick. Standard routine procedures described in Texas Highway Department Testing Procedures 35, 40, and 46 (see Appendix A) were used for fabricting the specimens and determining Hveem stability and voids in the compacted aggregate. Standard procedures were also followed in taking the data (*2*) and in construction of graphs and charts and calculation of the statistical indexes (*3*). The data for the correlations were separated into two groups differing in surface texture of aggregate used (crushed limestone and crushed flint) because the variables to be correlated were of different orders of magnitude.

CALCULATION OF VARIABLES

Before discussion of the correlations it is necessary to make some brief explanation concerning the derivation of the correlated variables from curved Mohr envelopes obtained in all tests on limestone-aggregate specimens. Some of the underlying theory, with supporting experimental evidence, will also be presented.

The cause of curvature in the Mohr envelope is a highly controversial subject. It is no doubt due, directly or indirectly, to many contributing factors related to the preparation and dimensions of the specimen: size, grading, and surface texture of the aggregate; experimental procedures, etc., and many of the apparent inconsistencies in reported results from different laboratories are believed to stem from such differences in test conditions. Literally interpreted, the curved envelope simply denotes that shear resistance on the surface of failure