PAVEMENT DESIGN AND PERFORMANCE STUDIES

Final Report on Phase C

"Experimental Flexible Pavements"

by

K. H. McGhee
Highway Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway Research Council
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SUMMARY

A program of construction and the performance evaluation of three major Virginia experimental flexible pavements is reported. The objective of the program was to evaluate the performance of pavements incorporating new or timely design concepts and to assess the feasibility of these concepts for further use.

Among the major findings of the study are:

1. A resilient select borrow material used over a resilient subgrade does not enhance pavement performance. When used between a cement stabilized subgrade and a crushed stone base, the resilient select material may, in fact, impair performance. There is some evidence that resiliency is reduced after a substantial number of wheel loads, with an improvement in subsequent pavement performance.

2. Pavements having cement treated crushed stone under a thin (3 in.) bituminous structure have performed very poorly.

3. Transverse shrinkage cracks reflect from a cement treated stone subbase through 3 inches of bituminous concrete in as little as 18 months, and through 7 inches in less than 5 years.

4. Where cement stabilized stone subbases are used and when truck traffic is normally channeled into the outer lanes, advantage may be taken of the omission of the stabilization from stone subbases under inner or passing lanes.

5. Shrinkage cracking aside, 4 inches of cement treated aggregate base, 4 inches of bituminous concrete, and 6 inches of untreated crushed stone base (all underlying 7 inches of bituminous concrete) give approximately equal performance after 5 years under heavy traffic conditions. Higher deflections and greater cracking on the pavement incorporating the untreated stone suggest that the performance may not be equal after many load applications.

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INTRODUCTION

A program of construction and evaluation of experimental flexible pavements was undertaken in Virginia in 1958 with the completion of a 4.5 mile portion of U. S. Route 58 near South Boston in Halifax County.(1) Since that time, two major experimental pavements(2, 3) have been built in Charlotte and Prince Edward Counties.

All three projects lie within the residual micaceous silty soils of the south central piedmont region of Virginia. The resilient nature of these soils has contributed to poor pavement performance for many years, thus making the area a particularly good proving ground for trial pavement design features. Similarly, all three projects were constructed within major trucking corridors to ensure the occurrence of the many heavy wheel loads necessary to a performance determination. Finally, all three projects are in close enough proximity to assure similarity in climatic conditions. Considered together, the similarity in soils, traffic, and climatic conditions makes it possible to compare the various test sections within a given project and, at the same time, to compare the overall projects with each other. As will be pointed out later, there were differences in the basic design approach for the three projects. For example, one is underlain by a thick select material mat, another by a cement stabilized subgrade.

Evaluation studies have been conducted on either an annual or biannual schedule from 1958 to the present. These have consisted essentially of deflection tests, roughness tests (PSI determinations), and detailed inspections. Prior to 1962 these studies were financed from state research funds. In February 1962, financing was transferred to Highway Planning and Research funds through Federal Highway Administration approval of a broad pavement performance study proposed by F. P. Nichols,(4) former highway research engineer.

As indicated above, detailed reports of the construction phase and interim performance have been issued for each of the three experimental projects.(1, 2, 3) It is,therefore, the objective of the present report, for all three projects, to summarize the essential experimental features and to present performance histories leading to the conclusions which have been offered in this and in the earlier reports cited. In the interest of brevity, much of the detailed information is omitted from the present report and frequent references are made to the earlier reports.

EVALUATION PROCEDURES

In general, the steps in the evaluation of each of the experimental pavements were as follows:

1. Procurement of final plans and cross sections, materials descriptions, construction costs, and date of acceptance from the contractor.

2. Establishment of easily identified project limits by the use of roadside markers and written descriptions.

3. Initial and periodic, usually semiannual, collection of data reflecting:

   (a) traffic characteristics,

   (b) structural capability as indicated by deflection tests,

   (c) roughness, and

   (d) visual defects such as cracking, rutting, patching, and the presence of settlements.

4. Compilation of records of major maintenance operations (bituminous concrete overlays, for example), and their costs.

Before a meaningful display of information can be presented, it is necessary to outline some of the more subtle features of the performance evaluations. The following discussion has particular reference to item 3 above.

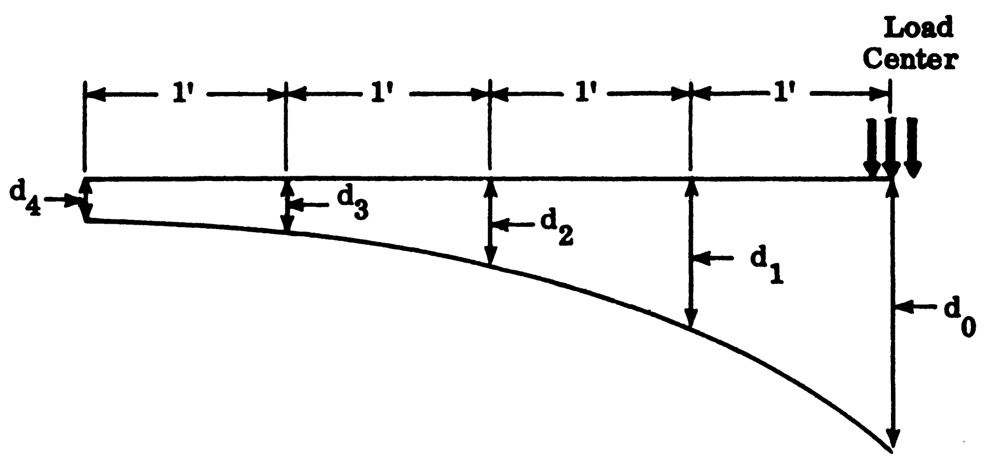
Traffic Characteristics

While Virginia's present design method utilizes the 18 kip equivalency concept defined by AASHO,[5] most of the pavements currently in the study were designed on the basis of traffic categories reflecting average daily trailer trucks and buses in both directions (T. T. & B.). Furthermore, T. T. & B. data are routinely collected by the Traffic and Safety Division while 18 kip equivalence determinations are obtained only through weight studies and are too expensive for other than special requirements. For these reasons, only T. T. & B. information is available for the study projects. Research Council efforts to develop a simple correlation between T. T. & B. counts and equivalent 18 kip axle loads have been unsuccessful.

Structural Capability

In this, as in the earlier reports[1, 2, 3], rebound deflections are used as an indication of the structural capabilities of the various flexible pavement systems. Tests conducted prior to 1966 were performed with Benkelman beams[1] and a truck loaded to 18,000 lb. on its rear axle. In 1966 a Dynaflect was purchased and its results correlated with those from Benkelman beam tests.[3] Since the regression equation (Benkelman beam deflection = 27.8 Dynaflect deflection) was found to have an excellent correlation coefficient, all tests subsequent to 1966 have been conducted with the much faster and less laborious Dynaflect method.

This method provides for deflection measurements directly at the point of load application and at distances of one, two, three, and four feet from that point. The plot of all five deflections defines the deflection basin as shown in Figure 1. Recent studies[6] have shown that the shape of the deflection basin may be of more importance than the maximum deflection. As a means of interpreting the shape of the basin a bending factor, or a "spreadability", has been defined and is also shown in Figure 1. This factor is the ratio of the average deflection to the maximum, expressed as a percentage. An increase in the factor indicates an ability of the pavement to spread the load over a wider area. Thus, a 65 bending factor indicates a much stiffer pavement than does a 45. The use of a bending factor in assessing flexible pavement performance has been discussed in an earlier report.[6]



$$\text{Spreadability} = \frac{d_0 + d_1 + d_2 + d_3 + d_4}{5\, d_0} \times 100$$

Figure 1. Dynaflect deflection basin.

Roughness

Road roughness tests utilizing a BPR type roughometer at 20 mph have been conducted on each project throughout the study period. These data will be discussed in connection with each project.

Visual Defects

Periodic inspections of the study pavements have resulted in the accumulation of considerable data reflecting various kinds of physical defects, the most common of which is cracking. Other defects noted are rutting, patching, and settlements.

Rutting of flexible pavements, once fairly common in Virginia, seems to have been nearly eliminated over the past few years with the advent of cement and lime stabilization and the resultant more stable subgrades. Rutting is, thus, seldom a factor in performance surveys but is noted as to extent and frequency as are patching and settlements.

To make cracking data more useable, a crack factor (CF) has been defined[6] for flexible pavements and it is determined for each of the study projects at the time of each inspection. To determine the factor, the project is separated into 1,000 ft. sections and each section is surveyed for cracking. Each incidence of cracking has been arbitrarily assigned a value of 15 units and 20 units for longitudinal cracking and pattern or alligator cracking, respectively. Transverse cracking of flexible pavements is so often related to cement stabilization that its presence is not considered detrimental. Thus, a section with five incidences of pattern cracking would have a crack factor of 100. Similarly, two incidences of longitudinal cracking and one of pattern cracking yield a factor of 50. An upper limit of 100 units per 1,000 ft. section is imposed on the data. After all sections within a project have been surveyed, the average crack factor is determined and designated as the factor for the project.

Clearly, the crack factor as used in this study is somewhat arbitrary and would not be adaptable to strict quantitative analysis. It is,however, the opinion of the researcher that the data are useful on a qualitative basis to determine whether or not a project is performing well. For example, other factors being equal, one can say that a crack factor of 5 for a ten-year old project clearly indicates better performance than say a crack factor of 50 for a five-year old project.

FIRST EXPERIMENTAL PROJECT

Route 58, Halifax County

The first of the experimental pavements to be constructed is located on U.S. Route 58 just west of U.S. Route 501 at South Boston in Halifax County. Approximately 4.5 miles long, the project lies entirely in the westbound lane (Figure A-1 of the Appendix). The road was opened to traffic in December 1958.

A major objective of the experiment was to compare the performance of pavements having similar total thicknesses but with various thicknesses of bituminous concrete.

Experimental Features

Soils

Progress Report No. One[1] summarizes the properties and location of the native soils within the right-of-way of the project. These were given as alluvial and residual soils having CBR values ranging from 5 to 30. In general the higher CBR values were found in the eastern portion of the project. Due to the extremely variable nature of these soils, the designers called for a 12 inch blanket of select borrow over the entire project. This blanket was constructed of a disintegrated granite containing a micaceous sand clay binder from a local borrow pit, and met the requirements for a minimum CBR value of 12. CBR values ranged from 13 to 66 with an average of 33.

Structural Variables

The CBR pavement design method in use in Virginia at the time the Route 58 project was constructed required a total pavement depth of 25 inches for the traffic and soil conditions given. Thus, in addition to the 12 inches of select material mentioned above, an additional 13 inches of crushed stone and bituminous concrete combined were provided. The typical pavement sections in Figures A-2 and A-2-b show the various combinations of stone and bituminous concrete used to make up the top 9 inches of the pavement structure. A minimum of 4 inches of crushed stone was provided, while the bituminous concrete depth was varied from 4 to 9 inches. The different sections identified in the Appendix as A, B, C, and D are located on the sketch shown in Figure A-1. Each design was repeated in order to reduce the effects on performance of variations in the subgrade support.

Detailed construction notes concerning materials sources, sequence of placement, special problems, etc., may be found in Progress Report No. One.[1]

Performance History

Early Performance

The early performance of all sections of this project was extremely poor. As pointed out by Hughes,[3] none of the four designs was able to survive the high deflections apparently resulting from the subgrade soils and the select borrow materials used, both of which were resilient. A seal treatment was required by the third year of the pavement's life, and by the fourth year (1963) the entire project had been overlaid with 160 psy of bituminous concrete surfacing.

Average Benkelman beam deflections (18,000 lb. axle load) are recorded on the appended case histories. Even the earlier (March 1959) deflections were moderately high and there was a marked increase during the first year the pavement was in use. At the same time Nichols[1] reported substantial rutting in all four design sections. By the summer of 1962, prior to the overlay, deflections had reached average values of 81, 42, 53, and 52 thousandths inch for designs A, B, C, and D, respectively. The high average deflections of design A were the result of very high values in one sub-section. Since this was supposedly the best design because of the thick bituminous concrete layer, the high deflections were taken as conclusive evidence that the select material blanket had not been effective in producing a uniform subgrade condition.

Present Serviceability Index (PSI) determinations have been conducted on the project periodically (see Appendix). There was a substantial decrease in PSI during the first year or two, primarily due to the rutting. The serviceability rating was restored somewhat by the 1963 resurfacing and has reduced only slightly since.

It is fairly apparent that the poor early performance of this project resulted from high deflections and the accompanying distortions (principally rutting). Nichols[7] contended that this behavior was primarily a result of the resilience of subgrade soils on the project, and implied that it could have been overcome with the use of subgrade stabilization (cement or lime). He presented data from other projects showing the dramatic reductions in both deflections and subgrade variability provided by stabilization.

Recent Performance

Performance since the 1963 overlay has been fair as evidenced by nine years of use under heavy truck traffic without an additional overlay. The project did exhibit a substantial amount of cracking by 1967, as evidenced by the crack factors ranging from 13 to 47 (Appendix).

Somewhat of a reduction in deflections following the overlay has probably been the major contributor to improved performance. (Note that the 1964 deflections were 53, 42, 51, and 44 thousandths inch for designs A, B, C, and D, respectively.) No significant rutting has been noted since the overlay and the PSI has remained fairly constant. The absence of further rutting suggests that additional densification may have occurred early in the life of the pavement and that it resulted in a relatively stable structure after the first several years. However, since adequate densities were reported by Nichols[1,7] it would appear that subgrade subsidence occurred when the resilient materials were structurally altered by repeated loadings through a mechanism akin to that reported by Larew and Leonards[8].

Very recent studies of the project show that designs A and C are performing similarly and have similar deflections. Hughes[3] makes the point that for similar deflections the thicker bituminous concrete layer will be distressed first. The analogy with beam bending is clear in this case; i.e., for similar deflections the thicker beam (rigid layer) will experience a higher stress level in the extreme fiber.

The project has now carried approximately two million tractor-trailers and buses (one direction) with the one resurfacing. However, while recent performance has been acceptable, the early failure would cause the overall performance to be classified as poor to fair.

Conclusions

Due to the extreme variations in subgrade support it has been impossible to derive the originally expected information from the study of this project. While no useful comparison of bituminous concrete thicknesses was possible, the following conclusions appear to be supported:

1. Thick blankets of local select material are not necessarily effective in reducing the variation in subgrade support.

2. Poor support conditioning (particularly resiliency) should be counteracted in the layer in which it exists.[3] The strengthening of overlying layers is relatively ineffective in correcting this condition.

3. There is evidence that resiliency can be reduced by sufficient exposure to repeated loadings (traffic) and that pavements can perform satisfactorily after this "adjustment" period. This method of overcoming resiliency would be undesirable because of the early maintenance requirements.

SECOND EXPERIMENTAL PROJECT

Route 360, Charlotte and Prince Edward Counties

The second experimental project was constructed on U. S. Route 360 between Keysville and Meherrin, and was completed in November 1962. The project is 5.8 miles long and lies partially in the eastbound and partially in the westbound lanes (Figure A-3).

The purpose[3] of the project was to compare:

"1. Six inches of cement treated crushed stone subbase and six inches of non-cement treated crushed stone subbase; and

2. Seven inches of asphaltic concrete and a combination of three inches of bituminous concrete and four inches of cement treated crushed stone."

The project was also seen as an opportunity to assess the influence of different bituminous concrete thicknesses on the progression of reflection cracks from a cement treated subbase to the surface.

Experimental Features

Soils

Soils encountered on the project were typical piedmont micaceous silts and silty clays. Nichols[2] reported soil classification A-7-5 to be the most prevalent, followed by A-7-6 and A-5. These native soils ranged in CBR value from 5 to 28 with an average for the project of 20. Due to the resilience of these soils and to the experience gained on the first experimental project and other projects, the top 6 inches of the subgrade soils were stabilized with 10% cement by volume. At the same time, in keeping with the then accepted practice, a blanket of select borrow (minimum CBR 20) was provided over the entire project. Tests on this material showed an average CBR value of 33.

Structural Variables

The CBR design method called for a total pavement depth of 23 inches. This was made up of a constant 6 inches of cement treated subgrade, 6 to $6\frac{1}{2}$ inches of select borrow, and the bituminous concrete and crushed stone combinations shown in the Appendix (Figures A-4-a and A-4-b). In this upper portion of the pavement structure, the principal variables were the thickness of bituminous concrete, the thickness of crushed stone, and cement treated versus non-treated crushed stone. The minimum thickness of stone (4 in.) and maximum thickness of bituminous concrete (7 in.) are found in design A. Design C has the minimum thickness of bituminous concrete (3 in.) and the maximum of crushed stone (8 in.), the top half of which is cement stabilized. Designs B and D are identical in cross section except that the crushed stone in B is cement stabilized. Again, as in the previous experimental project, the designs were repeated in an effort to minimize the influence of local variations in soil conditions.

Details of the construction procedures, special problems encountered, and the materials sources may be found in the Progress Report No. Three[2].

Performance History

Early Performance

The early performance of this project was good in that there were no dramatic early failures as in the first experimental project. Doubtlessly this was due largely to the provision of a cement stabilized subgrade, which was reflected in the earlier (1962) Benkelman beam deflections of 35, 18, 29 and 48 thousandths of an inch for designs A, B, C, and D, respectively. These values are much lower than those found on the Route 58 project and are in the expected order if pavement rigidity is the criterion. Note (in Appendix) that the lowest deflections are in the designs having a cement stabilized stone layer and that where no stone stabilization was provided the lowest deflection is found in the section (A) having the thickest bituminous concrete layer. This observation led the early researchers[2] to classify the designs according to strength in the order B, C, A, and D. Ironically, early serviceability determinations (see the Appendix), based entirely on roughness, showed Design D to have the highest initial serviceability. There was speculation that this high PSI would not be retained.

Subsurface deflections on each layer of each design were reported in Progress Report No. Three[2]. These showed that most of the elastic deformation (40 to 67%) could be attributed to the select material from the local borrow pit. The untreated crushed stone also contributed significantly to the deflections, while those attributable to the cement stabilized subgrade were not measurable. Based on these data, Nichols[2] concluded that the use of the select material blanket should have been avoided.

Recent Performance

In more recent studies of the project it has been possible to differentiate between the performances of the designs as related to the pavement structure. By 1967 moderate longitudinal cracking had developed in designs A and B while designs C and D showed severe longitudinal and pattern cracking. Transverse shrinkage cracks as a result of the use of the cement treated stone appeared in designs B and C shortly after construction but had no appreciable affect on the PSI rating for several years. The absence of these cracks in designs A and D has contributed to the higher PSI ratings retained by these sections.

Based on field inspections of the project, the four designs are presently classified according to appearance as A best, followed in order by B, C, and D. From a structural standpoint, based on deflections and bending factors, the ranking from best to worst is B, C, A, and D. The apparent inconsistency between the two rankings results from the transverse shrinkage cracks, which give a bad impression of designs B and C. Design C, which the measurements indicate is structurally similar to design A, has cracked badly and will doubtlessly require major maintenance at about the same time as design D. Hughes[3] theorized that the distress in design C was a result of the thin bituminous concrete (3 in.), found to be excessively brittle, and overlying cement treated stone, which has numerous shrinkage cracks.

It is concluded from the above that thin bituminous concrete overlays should not be provided over a cement treated stone base. While the pavement may exhibit good rigidity, the bituminous concrete is unable to withstand the massive shrinkage cracking of the base.

The project has sustained approximately 1.8 million tractor-trailers and buses (one direction). Since it is now 9 years old without major maintenance the project as a whole must be considered a qualified success. Designs A and B probably can be used for several more years without an overlay, while patching is currently prevalent on designs C and D. Design A, with its economic advantage over B, seems to have been the overall best design.

Conclusions

The conclusions resulting from this project are to some extent clouded by the select material blanket overlying the cement stabilized subgrade. This procedure is now acknowledged in Virginia as undesirable. However, if the assumption is made that all sections are similarly affected by this resilient select material the following statements appear warranted:

1. Cement stabilization of resilient subgrade soils is beneficial in reducing elastic deflections and in providing the accompanying improved performance.

2. Transverse shrinkage cracks from a cement treated stone subbase reflect through the surface in a very short time. They are not particularly injurious to performance unless the bituminous overlay is quite thin (design C).

3. A cement treated stone subbase, covered with a sufficient thickness of bituminous concrete (design B), performs far better than a similar design without the cement treatment (design D).

4. Cement treatment of stone is not, however, necessarily an acceptable substitute for bituminous concrete (designs A and C). A seven-inch thickness of bituminous concrete performs far better than a three-inch thickness over four inches of cement treated stone.

THIRD EXPERIMENTAL PROJECT

Route 7360, Charlotte County

The third experimental project was opened to traffic in December 1965. The project is on all new locations and forms the U. S. Route 360 Bypass of Keysville, Virginia. Figure A-5 shows the plan view and locations of the four experimental sections. Replicate sections are parallel in both the westbound and eastbound lanes.

The comparisons to be made from the designs (Figure A-6-a, A-6-b) were given by Hughes[3] as:

1. "Base — compares 4 inches of cement treated aggregate base (Design B) with 4 inches of asphaltic concrete base (Design C). (The additional $1\frac{1}{2}$ inches of asphaltic concrete base plus the $1\frac{1}{2}$ inch surface are assumed to be equivalent to the 3 inch surface of Design B.)

2. Subbase — compares 4 inches of lean mix asphaltic concrete (Design D) with 4 inches of cement treated aggregate base (Design C).

3. Subbase — compares 4 inches of lean mix asphaltic concrete (Design D) with 6 inches of untreated aggregate base (Design A).

4. Subbase — compares 4 inches of cement treated aggregate (Design C) with 6 inches of untreated aggregate base (Design A).

5. Compares EBPL to EBTL of S. Section of Design B and Design C to determine effect of omitting cement from lightly traveled passing lane."

Experimental Features

Soils

The soils native to the project are micaceous silts and silty clays of the A-4 to A-7-5 classifications. CBR values were found to range from 3.1 to 11.5. As might be expected, the soils are very similar to those in the second experimental project, which lies just to the east. As on the previous project, the top six inches of the subgrade soil were stabilized with 10% cement by volume. Unlike the earlier project, no select materials blanket was provided.

Structural Variables

In this project, for the first time in the experimental studies, advantage was taken of the much lower truck traffic in the passing lanes. Since the additional strength was deemed unnecessary, the cement stabilization was omitted from the crushed stone used in the westernmost eastbound sections of designs B and C. The feeling was that the somewhat objectionable transverse shrinkage cracks could be avoided with no loss in performance.

Among the structural features indicated earlier are three designs (A, B, and C) having thick bituminous concrete surface and base courses. Seven inches of bituminous concrete in these designs were considered equivalent to three inches of bituminous concrete and 4 inches of cement treated stone. Similarly, in the subbase 4 inches of bituminous concrete, 4 inches of cement treated stone, and 6 inches of untreated crushed stone all were considered equivalent.

Thus, also for the first time in the experimental projects, some consideration was given to the thickness index concept developed at the AASHO road test and reported for Virginia materials by Vaswani.[9] Note that total pavement thickness is 17 inches for designs B, C, and D while design A, with only a crushed stone subbase, is 19 inches thick. Thickness indices[9] are 11.5, 10.8, 13.4 and 13.4 for designs A, B, C and D, respectively.

Hughes[3] has reported the construction details for this project.

Performance History

Visual Features

The first visually apparent features noted on this project were transverse shrinkage cracks found in design B. These were reported by Hughes[3] when the project was about two years old and had sustained about 0.4 million tractor-trailers and buses (one direction). The report indicated that these cracks had reflected through 3 inches of bituminous concrete within the first $1\frac{1}{2}$ years. At the same time one transverse crack was reported in design C ($7\frac{1}{2}$ inches of bituminous overlying cement treated stone).

Recent studies show more fully developed crack patterns after 5 years under traffic (about 1.0 million T. T. & B. in one direction). The average spacing of transverse reflection cracks is approximately 25 and 75 feet for designs B and C, respectively. As expected, no cracks are present in the westerly sections of designs B and C, where the cement was omitted from the stone subbase. It is clear that given enough time the cracks will reflect through even $7\frac{1}{2}$ inches of bituminous concrete.

In the thin overlay sections (design B) the reflective cracking seems to have proceeded beyond a mere visual nuisance. Several sections have developed longitudinal cracks which, combined with the transverse cracks, have created slablike portions of pavement. Slab action is apparent to the extent of horizontal shifting, faulting, and pumping. The sections seriously affected are fairly limited in extent and may not lead to a significant reduction in the service life of this design since the rate of progression seems relatively slow. Hughes[3] reported some construction difficulties in a nearby area where an unstable subgrade was undercut and backfilled.

Possibly the most significant finding from the transverse cracking studies is the confirmation of the earlier Route 360 project findings; i.e., that cement treated stone subbases should not be used very close to the surface of bituminous pavements.

Other features noted after 5 years under traffic are moderate longitudinal and pattern cracking and several isolated instances of rutting.

The cracking is indicated in the crack factors shown in the Appendix, where design B is seen to have one of the highest factors, no doubt because of the above mentioned distress related to the stabilized stone. Design A has recently developed the highest degree of cracking, probably because of its higher deflections.

Rutting has been found in short segments of design C. This does not appear to be a serious condition and, judging from the surface appearance, is almost certainly related to increased densification of the bituminous concrete.

Serviceability Index

As reported earlier[3] no serviceability index data were available on this project until 1967. Data collected from 1967 to the present are shown on the appended project history sheets. There has been no pronounced loss of PSI, because of the excellent general condition of the project. There is a tendency for design B to show slightly more loss than the other designs. This again is related to the reflection cracking and resultant increased roughness.

Deflections

Deflections throughout the project have generally been excellent as shown by the latest Benkelman beam values of 34, 14, 15, and 19 in the order of the designs. These are no doubt lower than those on the adjoining experimental project because of the omission of the select material blanket and the resultant more rigid pavement. Note the bending factors of from 59 to 79 as compared to 44 to 66 on the second project.

Design A, with the highest deflections, shows some longitudinal cracking at present. Even these deflections (34/1000 average) probably are not high enough to cause much of a performance problem. All other designs have an additional stabilized layer and considerably lower deflections. Design B has low deflections, but, again, has not performed well because of the slab effect. Designs C and D also have very low deflections and both have performed well. The former has widely spaced transverse cracking, mentioned previously, while the latter is practically unblemished.

General Appraisal

Based on the factors discussed above and recognizing that the pavement has served only about half its design (before resurfacing) life of 8 to 10 years, the researchers have classified the performance of the four designs as:

Design A — good
B — poor
C — good
D — excellent

Note that design D, showing excellent performance, is essentially a full depth asphalt pavement on an improved subgrade. It was considerably more expensive than the other designs (see data sheets) and recent prices indicate that the cost spread at present would be even wider. For this reason, the design probably would not be feasible in the same area today.

Designs A and C were less costly than design B and have performed better. If the present performance continues, and in view of the transverse cracking in design C, design A may prove to have been the best investment of the four designs for the particular condition encountered.

Conclusions

The following conclusions appear to be warranted from the third experimental project:

1. Transverse shrinkage cracks reflect from a cement treated stone subbase through 3 inches of bituminous concrete in as little as 18 months, and through 7 inches of bituminous concrete in less than 5 years.

2. Cement treatment of stone subbases can be omitted in passing lanes with no detriment to performance. (This may not be true with traffic volumes near capacity because of the change in distribution of truck useage as that point is approached.)

3. Improved performance results when a resilient select material blanket is omitted from between a stabilized subgrade and a crushed stone subbase.

4. It has been reaffirmed that cement treated stone subbases should not be used in close proximity (3 inches, for example) to a bituminous pavement surface under heavy traffic conditions.

5. Shrinkage cracking aside, 4 inches of cement treated aggregate base, 4 inches of bituminous concrete, and 6 inches of untreated crushed stone base (all underlying 7 inches of bituminous concrete) give approximately equal performance after 5 years under heavy traffic conditions.

ACKNOWLEDGEMENTS

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C. S. Hughes and Dr. N. K. Vaswani are acknowledged for their conduct of portions of the study and for their technical assistance in other portions. The interest and cooperation shown by R. W. Gunn and G. V. Leake in the collection and analysis of data are sincerely appreciated.

The work was conducted under the general direction of Jack H. Dillard and the late Dr. Tilton E. Shelburne, state highway research engineers. The study was financed from HPR funds in cooperation with the U. S. Federal Highway Administration.

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APPENDIX

APPENDIX

PROJECT CASE HISTORIES

The case histories tabulated on the following pages have been described in sections of this report. The major components of pavement cross sections have been sketched with the materials indicated according to the following key:

Surface and binder courses, all types; also penetration tops.

Black base courses, H-3 (1) or special sand asphalts.

Compacted aggregate bases or subbases (commercial sources).

Select material, Type I, commercially crushed.

Select materials, all other types.

In place soil, cement or lime added.

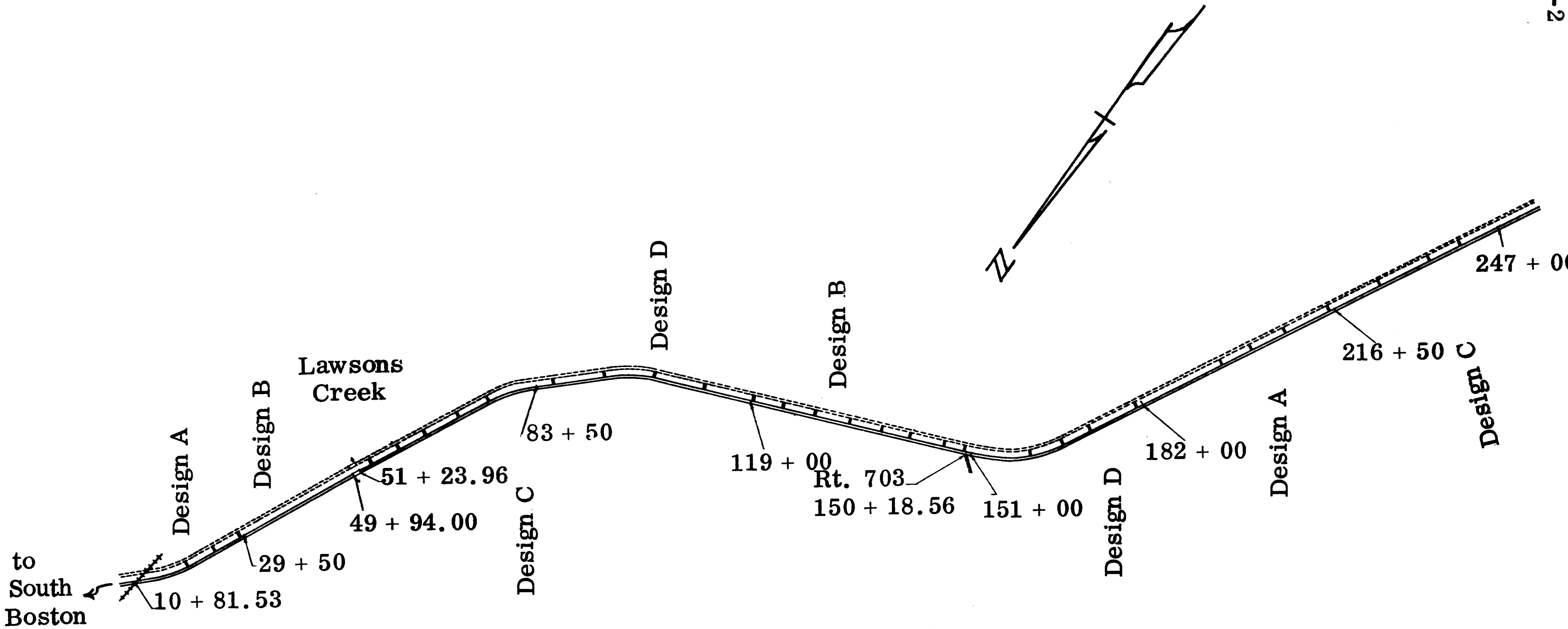
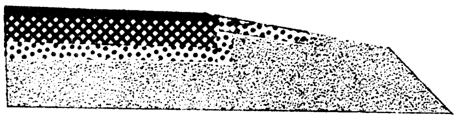


Figure A-1. Plan of project 0058-041-012-033 showing locations of pavement design variables.

oject No. 0058-041-012-033 (Design A)
om: 0.192 mi. W. of Int. Rte. 501
 : 4.570 mi. E. of Turbeville P.O.
st: $67,478 per mi.

Completed: 1-15-59
County: Halifax
Length: 4.452 mi.



Surface: 1½" I-3
Base : 7½" H-3(1)
Subbase: 4" Cr. Aggregate
Subbase: 12" S. B. CBR 12

affic: 875-1085 Tractor-trailers & Buses (per day)

flection Data

	Benkelman Beam	BF
2/59	47	
/29/59	57	
21/60	81	
3/61	82	
29/62	81	
?/64	53	
9/65	52	
19/67	39	50
8/68	34	53
14/69	35	53
18/71	37	55

PSI

3/2/59	4.98
5/24/61	4.16
12/26/63	4.20
7/20/65	4.43
8/29/67	4.49
10/16/69	4.25

Crack Factor

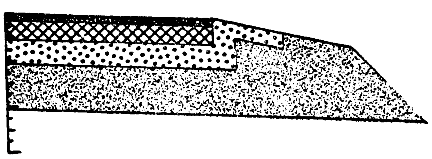
8/29/67	38
8/7/68	85
10/16/69	100
5/26/71	100

marks:

mmer 1963 seal over traffic lane
30/63 160#/sq. yd. I-3 Poor performance.

oject No. 0058-041-012-033 (Design B)
om: 0.192 mi. W. of Int. Rte. 501
 : 4.570 mi. E. of Turbeville P.O.
st: $62,304 per mi.

Completed: 1/15/59
County: Halifax
Length: 4.452 mi.



Surface: 1½" I-3
Base : 5½" H-3(1)
Subbase: 6" Cr. Aggr.
Subbase: 12" S. B. CBR 12

affic: 875-1085 Tractor-trailers & Buses (per day)

flection Data

	Benkelman Beam	BF
2/59	33	
/26/59	34	
21/60	47	
3/61	43	
29/62	43	
?/64	42	
9/65	36	
19/67	33	46
8/68	27	50
14/69	28	50
18/71	31	51

PSI

3/2/59	5.05
5/24/61	4.23
12/26/63	4.26
7/20/65	4.34
8/29/67	4.70
10/16/69	4.49

Crack Factor

8/29/67	13
8/7/68	65
10/16/69	74
5/26/71	82

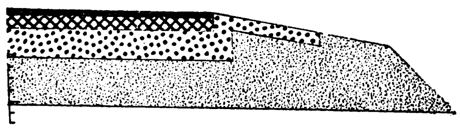
marks:

mmer 1963 seal over traffic lane
30/63 160#/sq. yd. I-3 resurface. Poor performance.

Figure A-2-a

Project No. 0058-041-012-033(Design C)
From: 0.192 mi. W. of Int. Rte. 501
To : 4.570 mi. E. of Turbeville P.O.
Cost: $57,077 per mi.

Completed: 1/15/59
County: Halifax
Length: 4.452 mi.



Surface: 1½" I-3
Base : 3½" H-3(1)
Subbase: 8" Cr. Aggr.
Subbase: 12" S. B. CBR 12

Traffic: 875-1085 Tractor-trailers & Buses (per day)

Deflection Data

	Benkelman Beam	BF
3/2/59	45	
10/26/59	44	
4/21/60	57	
3/3/61	55	
3/29/62	53	
4/?/64	51	
4/9/65	43	
4/19/67	42	49
5/8/68	35	53
5/14/69	37	53
5/18/71	41	55

PSI

3/2/59	5.08
5/24/61	4.17
12/26/63	4.23
8/29/67	4.42
10/16/69	4.20

Crack Factor

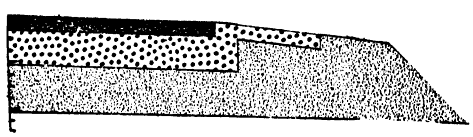
8/29/67	47
8/7/68	87
10/16/69	99
5/26/71	100

Remarks:

1960 150#/sq. yd. I-3 on portion design C, extensive work on subgrade and base. 1963 seal over traffic lane, 8/30/63 160#/sq. yd. I-3 resurface. Poor performance.

Project No. 0058-041-012-033 (Design D)
From: 0.192 mi. W. of Int. Rte. 501
To : 4.570 mi. E. of Turbeville P.O.
Cost: $55,018 per mi.

Completed: 1/15/59
County: Halifax
Length: 4.452 mi.



Surface: 1½" I-3
Binder : 2½" H-2
Base : 9" Cr. Aggr.
Subbase: 12" S. B. CBR 12

Traffic: 875-1085 Tractor-trailers & Buses (per day)

Deflection Data

	Benkelman Beam	BF
3/2/59	38	
10/26/59	34	
4/21/60	51	
3/3/61	52	
3/29/62	52	
4/?/64	44	
4/9/65	39	
4/19/67	37	45
5/8/68	33	50
5/14/69	34	49
5/18/71	37	50

PSI

3/2/59	5.10
5/24/61	4.59
12/26/63	4.23
8/20/67	4.60
10/16/69	4.33

Crack Factor

8/29/67	28
8/7/68	86
10/16/69	90
5/26/71	95

Remarks:

1963 seal over traffic lane
8/30/63 160#/sq. yd. I-3 resurfacing. Poor performance.

Figure A-2-b

2083

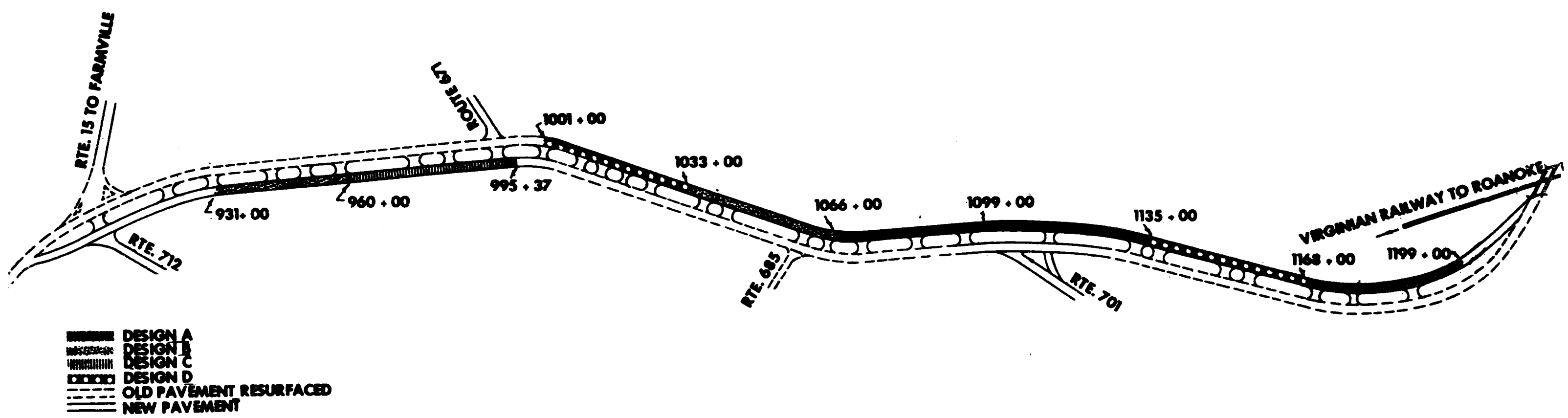
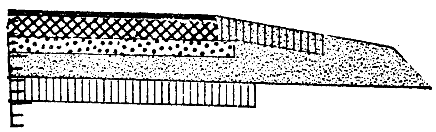


Figure A-3. Plan of experimental project on Route 360.

2084

Project No. 0360-073-008 (Design A)
-019-002
From: 1.768 mi. W. Charlotte-Prince Edward CL
To : 0.014 mi. W. of W. End future Virginian RR overpass
Cost: $65,842 per mi.

Completed: 11/14/62
County: Charlotte and Prince Edward
Length: 5.821 mi.



Surface: 1½" I-3
Base : 5½" H-3(1)
Subbase: 4" Cr. Aggr.
Subbase: 6" S. M. CBR 20
Subbase: 6" Soil Cement

Traffic: 1015-1220 Tractor-trailers & Buses (per day)

Deflection Data

	Benkelman Beam	BF
4/10/62	75	
4/16/62	45	
12/5/62	24	
3/19/63	34	
4/17/64	39	
4/6/66	34	
4/12/67	33	51
5/7/68	36	50
4/21/69	42	59
5/18/71	44	50

PSI

11/8/62	4.52
1/24/64	4.28
7/8/65	4.34
7/12/67	4.24
8/8/68	4.19
8/13/69	4.34

Crack Factor

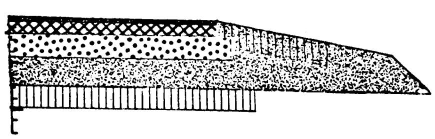
7/12/67	35
8/8/68	60
8/13/69	49
5/26/71	89

Remarks:

Isolated patching; minor alligator cracking; longitudinal crkg.; transverse cracks, minor rutting; best performance of four designs.

Project No. 0360-073-008 (Design B)
-019-002
From: 1.768 mi. W. Charlotte-Prince Edward CL
To : 0.014 mi. W. End future Virginian RR overpass
Cost: $69,221 per mi.

Completed: 11/14/62
County: Charlotte & Prince Edward
Length: 5.821 mi.



Surface: 1½" I-3
Base : 3" H-3(1)
Subbase: 6" Cement tr. cr. aggr.
Subbase: 6" S. M. CBR 20
Subbase: 6" Soil Cement

Traffic: 1015-1220 Tractor-trailers & Buses (per day)

Deflection Data

	Benkelman Beam	BF
4/10/62	18	
3/19/63	19	
4/17/64	19	
4/5/65	19	
4/6/66	22	54
4/12/67	24	57
5/7/68	24	58
4/21/69	28	60
5/18/71	26	66

PSI

11/8/62	4.40
1/21/64	4.23
7/8/65	4.21
7/12/67	3.93
8/8/68	3.85
8/13/69	3.85

Crack Factor

7/12/67	28
8/8/68	34
8/13/69	56
5/26/71	77

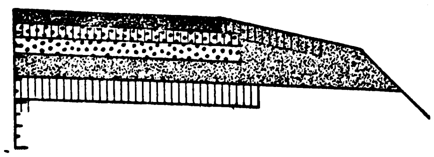
Remarks:

Transverse cracks, alligator & long. cracks; riding surface good; 2nd best performance--would be best except for deterioration in riding qualities due to transverse cracks.

Figure A-4-a

:oject No. 0360-073-008 (Design C)
-019-002
:om: 1.768 mi. W. Charlotte-Prince Edward CL
) : 0.014 mi. W. of W. end future Virginian RR overpass
)st: $64,838 per mi.

Completed: 11/14/62
County: Charlotte & Prince Edward
Length: 5.821 mi.



Surface: 1½" I-3
Binder : 1½" H-2
Base " 4" cement tr. cr. aggr.
Subbase: 4" Cr. aggr.
Subbase: 6" S. M. CBR 20
Subbase: 6" soil cement

:affic: 1015-1220 Tractor-trailers & Buses (per day)

:flection Data

	Benkelman Beam	BF
'10/62	29	
'19/63	31	
'17/64	31	
'5/65	32	
'6/66	35	
'12/67	33	48
'7/68	33	49
'21/69	42	49
'18/71	39	54

PSI

11/8/62	4.43
1/12/64	4.17
7/8/65	3.85
7/12/67	3.60
8/8/68	3.58
8/13/64	3.41

Crack Factor

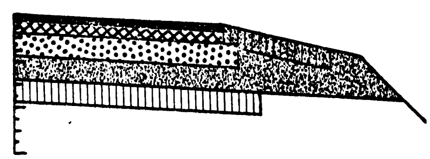
7/12/67	92
8/8/68	99
8/13/69	100
5/26/71	100

:marks:

:me patches; transverse cracks; severe alligator cracks; poor riding surface; <u>poor</u> performance.

:oject No. 0360-073-008 (Design D)
-019-002
:om: 1.768 mi. W. Charlotte-Prince Edward CL
) : 0.014 mi. W. of W. end future Virginian RR overpass
)st: $61,248 per mile

Completed: 11/14/62
County: Charlotte & Prince Edward
Length: 5.821 mi.



Surface: 1½" I-3
Base : 3" H-3(1)
Subbase: 6" Cr. Aggr.
Subbase: 6½" S. M. CBR 20
Subbase: 6" Soil cement

:affic: 1015-1220 Tractor-trailers & Buses (per day)

:flection Data

	Benkelman Beam	BF
'16/62	48	
'19/63	44	
'19/64	41	
'5/65	44	
'6/66	40	
'12/67	38	43
'7/68	40	43
'21/69	48	41
'18/71	45	44

PSI

11/8/62	4.59
1/12/64	4.31
7/8/65	4.34
7/12/67	4.26
8/8/68	3.85
8/13/69	3.93

Crack Factor

7/12/67	92
8/8/68	95
8/13/69	84
5/26/71	100

:marks:

:vere cracking throughout; patched; minor rutting; terminal condition. Poor performance.

Figure A-4-b

2086

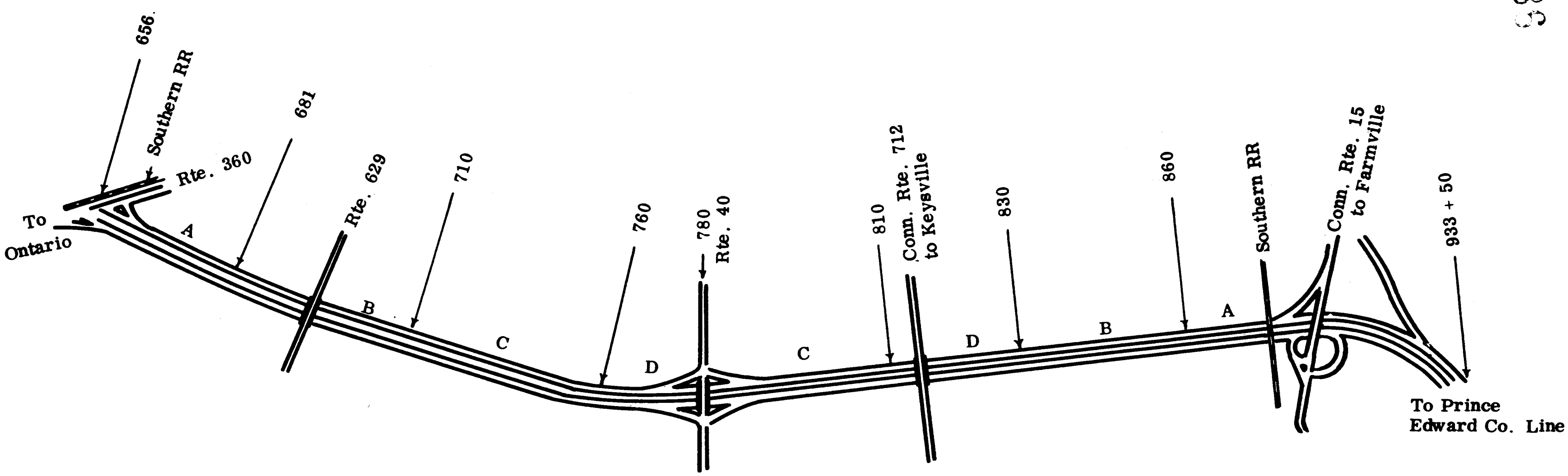
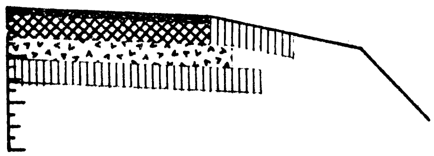


Figure A-5. Plan view of experimental project Route 7360.

roject No. 7360-019-102,C501 (Design A)
rom: 2.014 mi. S. Int. Rte. 40
o : 1.263 mi. W. Prince Edward CL
ost: $70,752 per mi.

Completed: 12/31/65
County: Charlotte
Length: 4.486 mi.
Thickness Index 11.5



Surface: 1½" I-3
Base : 5½" H-3(1)
Subbase: 6" S. M. Gr. 1
Subbase: 6" Soil Cement

raffic: 835-970 Tractor-trailers & Buses (per day)

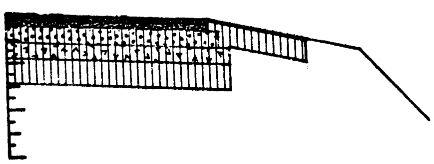
eflection Data	Benkelman Beam	BF	PSI		Crack Factor	
/5/66	25					
/11/67	29	54	7/12/67	4.28	7/12/67	2
/7/68	27	62	8/8/68	4.14	9/17/69	15
/21/69	38	57	8/17/69	4.26	5/26/71	52
/20/71	34	59				

emarks:

ery minor cracking, performance good.

roject No. 7360-019-102,C501 (Design B)
rom: 2.014 mi. S. of Int. Rte. 40
o : 1.263 mi. W. Prince Edward CL
ost: $73,075 per mi.

Completed: 12/31/65
County: Charlotte
Length: 4.486 mi.
Thickness Index 10.8
7.8



Surface: 1" I-3
Binder : 2" H-2
Base : 4" cement treated cr. aggr.
Subbase: 4" cement tr. cr. aggr.
Subbase: 6" soil cement

raffic: 835-970 Tractor-trailers & Buses (per day)

eflection Data	Benkelman Beam	BF	PSI		Crack Factor	
/5/66	10					
/11/67	12	70	7/12/67	4.31	7/12/67	2
/6/68	12	77	8/8/68	4.14	9/17/69	37
/21/69	13	74	8/17/69	4.17	5/26/71	43
/20/71	14	78				
assing Lane, no cement in 4" Cr. Aggr.						
/6/66	25					
/11/67	25	50				
/6/68	22	49				
/21/69	30	47				

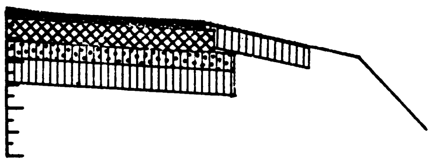
emarks:

ransverse cracks (traffic lane only) some are pumping. Cement in both lanes on exp. sections E. of Rte. 40 ransverse cracking across both lanes. One mile east of Rte. 40 on EBL--appears to be slab action including bvious pumping. Performance poor.

Figure A-6-a

Project No. 7360-019-102,C501 (Design C)
From: 2.014 mi. S. of Int. Rte. 40
To : 1.263 mi. W. Prince Edward CL
Cost: $72,230 per mi.

Completed: 12/31/65
County: Charlotte
Length: 4.486 mi.
Thickness Index 13.4
10.8



Surface: 1½" I-3
Base : 5½" H-3(1)
Subbase: 4" cement tr. cr. aggr.
Subbase: 6" soil cement

Traffic: 835-970 Tractor-trailers & Buses (per day)

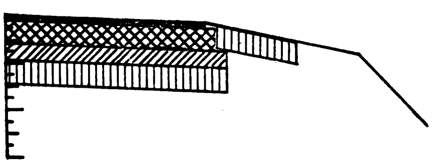
Deflection Data	Benkelman Beam	BF	PSI		Crack Factor	
4/5/66	12					
4/11/67	14	70	7/12/67	4.43	7/12/67	0
5/6/68	12	79	8/8/68	4.34	9/17/69	16
4/21/69	17	77	8/17/69	4.31	5/26/71	22
5/20/71	15	79				
Passing Lane, no cement in 4" cr. aggr.						
4/6/66	16					
4/11/67	19	63				
5/6/68	19	66				
4/21/69	29	65				

Remarks:

Compare with Design B. Transverse cracking--occurred after cracks in B section. Non-visible in passing lane even in section E of Rte. 40, which has cement. Rutting evident in several short segments. Performance good.

Project No. 7360-019-102,C501 (Design D)
From: 2.014 mi. S. Int. Rte. 40
To : 1.263 mi. W. Prince Edward CL
Cost: $77,141 per mi.

Completed: 12/31/65
County: Charlotte
Length: 4.486 mi.
Thickness Index 13.4



Surface: 1½" I-3
Base : 5½" H-3(1)
Subbase: 4" B-4 (lean mix)
Subbase: 6" soil cement

Traffic: 835-970 Tractor-trailers & Buses (per day)

Deflection Data	Benkelman Beam	BF	PSI		Crack Factor	
4/5/66	14					
4/11/67	16	69	7/12/67	4.28	7/12/67	0
5/6/68	16	76	8/8/68	4.26	9/17/69	11
4/21/69	18	75	8/17/69	4.12	5/26/71	21
5/20/71	19	75				

Remarks:

Excellent performance.

Figure A-6-b