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COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **72-8**

INVESTIGATION OF PAINTS AND GLASS BEADS USED IN TRAFFIC DELINEATION MARKINGS

PHASE 3

MISSOURI STATE HIGHWAY DEPARTMENT
FEDERAL HIGHWAY ADMINISTRATION

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16. Abstract

The white traffic delineation paints which were indicated as having the best wear resistance properties from Phase 1, cold applied paints, and Phase 2, hot applied paints, were used to test the porperties of various types and concentrations of reflective glass beads in Phase 3. The evaluation of longitudinal centerline stripes was based on daytime and nighttime observations as described in ASTM. The results reconfirm these paints as being longer wearing than the Missouri dispersion resin-varnish paint. A Type II "floating" bead was shown to rank high in performance. An alternate rating system for measuring the night visibility of each stripe was found to compare very well with the subjective rating given in the ASTM method.

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INVESTIGATION OF PAINTS AND GLASS BEADS USED IN TRAFFIC DELINEATION MARKINGS PHASE 3 EVALUATION OF GLASS BEADS WITH COLD AND HOT APPLIED TRAFFIC DELINEATION PAINTS UNDER ACTUAL CENTERLINE CONDITIONS

STUDY 69-6

Prepared by

MISSOURI STATE HIGHWAY DEPARTMENT

Division of Materials and Research

and

Division of Maintenance and Traffic

December 1972

in cooperation with

U. S. DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

SYNOPSIS

The white traffic delineation paints which were indicated as having the best wear resistance properties from Phase 1, cold applied paints, and Phase 2, hot applied paints, were used to test the properties of various types and concentrations of reflective glass beads in Phase 3. The evaluation of longitudinal centerline stripes was based on daytime and nighttime observations as described in ASTM. The results reconfirm these paints as being longer wearing than the Missouri dispersion resin-varnish paint. A Type II "floating" bead was shown to rank high in performance. An alternate rating system for measuring the night visibility of each stripe was found to compare very well with the subjective rating given in the ASTM method.

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INTRODUCTION

The necessity for maintaining adequate traffic delineation stripes is more apparent with the increased traffic densities on the Missouri state highway system. Longer lasting materials, especially those providing adequate night visibility, may substantially reduce the necessity for frequent restriping.

A joint research project, of which this study is the conclusion, was initiated between the Divisions of Materials and Research and Maintenance and Traffic within the Missouri State Highway Department in cooperation with the Federal Highway Administration. The scope of this investigation was to study (1) cold applied paints for durability due to wear, which was reported and published as Phase 1 in May 1970; (2) hot applied paints for durability due to wear, which was reported and published as Phase 2 in January 1972; and (3) the compatibility of these paints with various types and concentrations of reflective glass beads as reported in this Phase 3 Report.

This report covers a study of the useful life expectancy of the cold and hot applied white paints, when placed at 15 mils wet film thickness in a longitudinal centerline condition, with various types and concentrations of glass beads. Specific brands of paints were selected for use in this phase based on the results of the previous tests. The type of glass bead was the primary source from which information was desired, therefore, four types were included in this investigation.

Evaluation was based on the same criteria as that described in the Phase 1 and 2 Reports, where visual daytime ratings of general appearance and durability were observed for each individual test section. In addition, a night visibility rating was included to determine the relative effectiveness of the various bead types and bead concentrations to provide adequate nighttime delineation.

CONCLUSIONS

The tests performed under this phase of the field evaluation of the performance of various glass beads used with both the cold and hot applied paints indicate:

1. The overall performance of the Type II "floating bead" was better than the Type I gradation bead. It was significantly better than the Type I bead on concrete pavement regardless of traffic volume and as good or better than the Type I bead on high volume asphaltic concrete pavement. It was, however, significantly inferior to Type I bead on medium traffic volume asphaltic concrete pavements. This apparent anomaly warrants further study, especially considering that almost all of our secondary system is bituminous type construction.

2. The Type II "floating" bead, when applied at the rate of five pounds per gallon of paint, showed significantly better results than the four and three pound concentrations on the medium traffic volume concrete pavement but showed no significant difference on the high traffic volume asphaltic concrete pavement.

3. Bead Type III consisted of the same properties as the floating bead (Type II), however, the floating compound was not used. The Type II bead showed significantly better results than the Type III bead on both medium traffic volume pavements. The Type II bead showed significantly better results on the high traffic volume concrete pavement, however, showed no difference on the asphaltic concrete pavement. This indicates that the floatation compound does enhance the reflective properties of this particular gradation of glass bead.

4. Bead Type IV consisted of a different gradation than the Type I bead, however, all the other properties were similar. Bead Type IV ranked the lowest of all the beads tested on three of the four pavements used and not significantly better than the lowest in the fourth pavement.

5. When considering overall performance of the paint-bead system, night visibility was the controlling mode of failure.

6. The cold applied chlorinated rubber, Paint D, had wear characteristics very close to the Missouri dispersion resin-varnish paint.

7. The hot applied Paint G definitely indicated its superiority to provide good delineation in both day and night observations.

8. A less subjective point count method of rating the appearance of a stripe at night was included in this phase for exploratory information. This method gave results that compared well with the ASTM night visibility ratings which the observers made. This alternate method could be used by relatively inexperienced observers for purposes of determining when restriping is necessary.

IMPLEMENTATION

Based on the results of this study, the Missouri State Highway Department has initiated increased usage of the Type II floating bead for our pavement marking operation. The rate of application of the floating bead is 4 pounds per gallon. This rate is based on the comparison of the economic factors, along with the results of field testing.

The Type II floating bead, in conjunction with usage of the Type I bead in the state highway system, is being continued at the present time in order to provide additional verification of the floating bead performance. Included in this analysis is the field placement capabilities of the department's crews and striping equipment since the rate of usage is a critical factor in its economic advantage. In the future, it is anticipated that with the added information gained in the field operational review techniques, along with the results of this study, additional consideration will be given to complete usage of the Type II floating bead for the chlorinated rubber type paints utilized by the department.

SCOPE

The results of Phases 1 and 2 of this investigation indicated that specific brands or formulation of cold or hot applied paints had better wear characteristics than the other paints tested. The final phase of this investigation was programmed to test several glass bead types and concentrations with the paints found to be most satisfactory in the two previous phases. These tests were conducted on stripes in a normal longitudinal centerline condition in contrast to the other phases of this study.

The field observation sections were located on dual lanes of interstate or divided highways. The cold applied paint test sections were located in the Jefferson City area on Routes 50 and 54, a moderate traffic volume location, as shown in Figures 3 and 4, page 51. The high heat paint test sections were located in the St. Louis area on Interstate Routes 55 and 70, a very heavy traffic volume location, as shown in Figures 5 and 6, page 52.

The performance of the bead types was evaluated in each area for two types of pavement, portland cement concrete pavement (concrete pavement) and asphaltic concrete pavement. The concentration, in pounds per gallon, of the glass beads was studied using only one pavement type in each area, concrete for the cold applied paints and asphaltic concrete for the high heat paints.

Each test section was composed of two, 1200-foot dashed longitudinal centerlines with a 40-foot (15 feet of white and 24 feet of skip) repeating sequence. The two test stripes were located in the opposing travel ways of divided highways. This study consisted of a total of 34 test sections. All striping was done with Missouri State Highway Department equipment.

Observations were made at various time intervals by a panel of three men consisting of a:

Materials Research Engineer

Sign and Marking Engineer

Sign and Marking Inspector

ASTM D 713-69 was used as a guideline for rating appearance, durability, and night visibility. In addition, an alternate method of rating night visibility was included, whereby, the number of white dashes visible at night when illuminated by automobile headlights were counted.

MATERIALS

Materials used in this phase of our testing program were obtained from Missouri State Highway Department stock except for the special chlorinated rubber-alkyd formulation utilizing methylene chloride and the two special samples of glass beads, (Type III and IV). The Missouri dispersion resin-varnish and chlorinated rubber-alkyd paints were formulated from specifications similar to those shown in the Phase 1 Report, with only minor changes in the inspection and purchase procedures. The high heat paints were obtained by purchase order from the manufacturers of the paints which were shown to have the best wear characteristics determined from the results of Phase 2. Laboratory analyses of the paints are shown in Appendix A. Table 1, page 34 shows the standard laboratory test results. The method of analysis for each of the paints was primarily based on the methods set forth in "Physical and Chemical Examination of Paints, Varnishes, Lacquers and Colors" by Henry A. Gardner and G. G. Sward*. Many of these procedures are similar to ASTM methods except for quantities of material used. Table 2, page 35, shows special qualitative test results for the two major paints used in this phase which were obtained with the assistance of the University of Missouri at Rolla. Figures 1 and 2, pages 37 and 38 respectively, are the resulting infrared spectra for the vehicle and solvent portions of these two

*Distributed by Henry A. Gardner Laboratory, Inc., Bethseda, Maryland.

major paints. Spectrophotometer settings and constants, are shown in Table 2, for both spectra. Non-dispersive X-ray and ARL microprobe analyses were used to determine the major and minor components of the pigments.

Laboratory analyses of the glass beads are shown in Table 3, page 49. The method of analysis for each of the glass bead types followed directly from ASTM procedures.

The newly formulated chlorinated rubber-alkyd paint (Paint F), which incorporates the use of methylene chloride rather than methyl ethyl ketone as part of the vehicle, was included in this phase for exploratory study only.

The experimental test sections for the cold applied paints were located on Routes 50 and 54, Cole County.

A prebeaded, extremely fast drying, very high heat paint (Paint O) was also included in this phase as a possible substitute for a regular high heat paint in high traffic volume areas of our metropolitan centers. This paint dries in approximately three to five seconds as opposed to the regular fast dry three minute high heat paints. An experimental test section was established on Interstate Route 55, Jefferson County, and Route 70, St. Charles County.

The glass bead that was used almost exclusively by the Missouri State Highway Department at the beginning of this investigation was a free flowing gradation type bead as specified in Appendix B. This bead has been designated as Type I for this investigation. A bead which has been marketed in increasing quantities within the past few years and reportedly giving good service was included as bead Type II. This bead is more uniform in gradation and has a surface compound added to cause the bead to float in the wet paint film; thereby, utilizing the beads applied to their fullest extent. This bead is normally referred to as a "floating" bead.

In addition to these beads, it was desired to obtain exploratory data on the actual benefit derived by the added expense of having a floating compound required on the Type II bead. The possible increase in reflective properties could be a result of the more uniform gradation as compared to the Type I gradation. Thus, a special sample was purchased which had the same properties as the Type II bead, except that the floating treatment was omitted. This bead is referred to as the Type III bead for this investigation.

During preparation for this investigation, there was discussion regarding the most economic gradation which could be produced by the plants now operating. Requests for such a gradation were issued to the manufacturers and as a result bead Type IV was purchased and included in this investigation for exploratory data. It was specified that this bead meet all the requirements for the Type I bead with the exception of gradation as shown in Appendix B.

The Missouri dispersion resin-varnish paint placed at 15 mils wet film thickness with Missouri Type I glass beads applied at five pounds per gallon was used as control in this study.

FABRICATION OF TEST SECTIONS

The cold and hot applied paints were placed on asphaltic concrete and concrete pavements in moderate and very heavy traffic areas, respectively. The standard Missouri centerline 40-foot skip interval system was in existence at the time this Phase was programmed. This system allowed for 15 feet of white reflectorized four inch wide stripe with a skip of 25 feet which may be painted black. The stripes were placed adjacent to the old existing longitudinal stripes on clean pavement surfaces. Placing the new stripes on top of the old remaining stripes was avoided primarily because of the unknown influence of chipping due to bond failure of the old paint.

The test sections were identified by number and route only, thus avoiding knowledge by the observation team of the bead type, bead quantity, or the paint type. The only identification used was a number system placed on the extreme right edge of the pavement which denoted the test section number (1, 2, 3, . . etc.) and also served to identify the beginning of the observation section.

Each test section consisted of 1200 feet of centerline with the final 800 feet providing the observation section. The initial 400 feet were used to obtain normal operating speed of the equipment and to stabilize the paint and bead flow, as well as checking all systems on the equipment. Within the initial 400 feet, one non-beaded sample of the paint stripe was taken to measure the wet and dry film thickness of the paint.

All equipment was calibrated prior to placing the stripes. Paint thickness with relation to the speed of the vehicle and tank pressures were checked. Bead concentrations with various tank pressures or orifice settings were checked and recorded. Each time the bead concentrations were changed, a sufficient quantity of beads was released to prevent the possibility of variation due to increased or decreased tank pressures or orifice openings.

FIELD CONTROL TESTS

Weather Conditions:

The weather conditions during the application of the stripes were recorded and are shown in Table 4, page 53. The temperature and relative humidity variances for the Route 50 and 54 tests were not large considering the spread of time. Overall, the recordings show the maximum temperature difference to be 20°F and the maximum relative humidity differential to be 24 percent. For the Interstate Route 55 and 70 tests, the maximum temperature difference was 22°F; however, the relative humidity difference was 53 percent mainly because of the higher early morning values.

Wet Film Thickness:

Wet film thickness measurements were taken for each test section. One measurement at the beginning of the 800 foot observation section was taken by placing a metal plate (8 inches by 8 inches by 16 mils thick) directly in the path of the stripe to be painted. As the striper passed over this plate, the beads were deflected so that a proper paint film thickness measurement could be obtained. The wet film thickness measurements were taken immediately after being painted by the use of an Interchemical Wet Film Thickness Gage (ASTM D 1212-54). To obtain a correct wet film thickness measurement of the high heat paints, it was necessary to lightly coat the gage with xylol to provide the necessary pick-up of the paint on the eccentric ring of the gage. All measurements obtained are shown in Table 5, page 54.

Drying Time:

The apparatus used to evaluate the drying time required for each set of stripes is described in ASTM D 711-55. The results of the drying time measurements are shown in Table 6, page 55. A considerable variation in drying times of a paint existed between a few test sections. Whether or not this lack of uniformity could be attributed to the specific bead type or concentration can not be determined from these limited tests. However, as pointed out in the Phase 2 Report, the dry time measurement device presented some difficulty in obtaining proper measurements. Quite often it was noted that the stripes were dry to the touch but the dry time wheel would puncture the skin film and pick up the wet substrate, whereas, it was considered that an automobile tire may not. Because of the high volume of traffic in the test areas and in the interest of safety of the workmen, an automobile was not used to evaluate drying time.

Dry Film Thickness:

The non-beaded samples used to measure the wet film thickness of the stripes were allowed to air dry for approximately one week before making the dry film thickness measurements. The dry film thickness, as shown in Table 5, was determined by averaging seven thickness readings on each sample.

The dry film thickness is a more realistic measure of the actual amount of paint that is resisting abrasion and wear. Therefore, it is interesting to note the variability in the percentages of reduction from the wet film condition to the dry film condition as shown in Table 5. The cold applied Missouri chlorinated rubber-alkyd paint (Paint D) averaged 53.7 percent reduction and the high heat paint (Paint G) averaged 48.7 percent reduction.

EVALUATION TEST PROCEDURES

Evaluation of the paint stripes was based on the observation of three modes of failure and one weighted failure rating. As discussed in the Phase 1 Report, two of the modes of failure are general daytime appearance and durability. ASTM Method D 713-69 covers the basic mechanics of these observations and also describes the third mode of failure which is night visibility. Night visibility was used in this phase to test the reflective quality of the various glass beads. The weighted rating, as explained in ASTM Method D 713-69, is a weighted combination of the above mentioned modes of failure. The weighted rating is calculated as the sum of 30 percent of the appearance and durability ratings and 40 percent of the night visibility rating. The point of termination of the observations is when any one of the modes of failure drops to or below 3.0 on the 10 to 0 rating system as described in the ASTM Method D 713-69, or when the weighted rating drops to or below 4.0 on the same rating system.

The ASTM night visibility rating was applied to these centerline stripes by positioning an automobile on the shoulder of the highway with the left tires just touching the edge of the concrete pavement or just touching the white edge stripe on the asphaltic concrete pavements and the front bumper even with the leading end of a 15-foot white dash mark. The dash mark which was used as the beginning of the test section and also used as a reference for the automobile at night was established as stripe number 1.

In addition to the ASTM method of rating night visibility, an alternate procedure was established whereby the number of white dash marks were counted (point count method) for both the low and high beam condition. For each of the light settings, each observer counted the number of dash marks he could see by standing directly in front of the center of the front bumper of the automobile. Counting was terminated when, in the judgement of the observer, he could no longer see a distinct white reflection. This was observed to be a change from the white to a light gray shade which most of the time was quite obvious.

The point count readings that had been used by the department prior to this study were designed to provide data of an exploratory nature to establish a possible alternate to the ASTM method which would not require as much individual judgement as that required by the present method.

RESULTS AND DISCUSSION

Field observations were made at each test section at various time intervals until failure of the stripes was established according to the ASTM Method D 713-69. Table 7, page 57, presents the failure time in weeks for each test section that was included in this investigation. Each of the values shown was determined by interpolation between the average rating of three observers obtained for each observation. The modes of failure which had not reached terminal values were given values of weeks to failure by regression analysis and extrapolation.

Table 7, as a whole, indicates the night visibility rating to be the controlling source of failure of the three individual modes shown. The weighted rating, with the exception of Route 54 (part (b) of Table 7) only controlled in 4 out of 28 test sections and in those four cases were not appreciably different from the night visibility ratings. In the case of Route 50, the same ranking by rate of failure would be established, however, the significance between the various test sections may change. The relative difference in the age at failure between Test Sections 5 and 6 would be significant if considering the night visibility rating only. In the case of Route 54, the same ordering, with one minor exception, would be established regardless of which rating system was used even though the weighted ratings control.

In the following sections of the discussion of the work completed in this phase of the paint and bead study, much of the analysis will be made by using the individual rating values rather than the averages shown in Table 7. The reason for doing this is to provide three observations per variable rather than only one.

PART A - STUDY OF THE VARIATION BETWEEN PAINT TYPES

Cold-Applied:

Generally, this phase of study was designed to evaluate the effects of bead type and concentration as used with paints having the best wear resistance properties from Phases 1 and 2. In addition, one test section would be established on each pavement type consisting of the original Missouri dispersion resin-varnish paint which has been used as the basis of evaluation for the entire investigation. This paint was labelled as Paint B, the same as in the preceeding phase.

The cold applied Missouri chlorinated rubber-alkyd paint, as formulated by the specifications shown in the Phase 1 Report, was obtained and labelled the same as in Phase 2, as Paint D. In addition to this paint, a chlorinated rubber-alkyd paint (Paint F) which used methylene chloride rather than methyl ethyl ketone as the volatile portion of the paint was included. This formulation would allow for safe heating of the paint during striping. This paint was also tested in Phase 2 of this investigation and was designated in the Phase 2 Report as Paint F. This paint was reported as having about the same wear resistance characteristics as the non-heated chlorinated rubber paints.

To analyze the paint types, the data collected for the night visibility rating will be used exclusively. To enhance the single failure value per test section as shown in Table 7, a failure for use in Table 9, pages 59 and 60, was determined from the data for each individual observer, thus giving three values per variable rather than only one. The significance between observers had been tested previously and had shown no significant differences existing, however, this variable will be included in the analyses of variance in the discussion of bead types which follows in the next section. Definition of the analysis of variance terms to be used in these analyses, are shown in Table 8, page 58.

The Missouri Type I bead was used at five pounds per gallon application to establish a basis for evaluating these paints. The mean failure values shown in Table 10, page 61, for the cold applied paints definitely indicate that Paint F is poor in its ability to maintain a satisfactory night reflectivity. It is noted, however, that this paint did maintain a respectable daytime appearance and durability rating; therefore, the probable cause of failure was an excessive loss of glass beads or the inability of the beads to give reflection due to being embedded deeply in the paint film.

As an aid in studying the loss of glass beads, microphotographs of the paint stripes were taken each time the appearance and durability ratings were made. The microphotographs show that comparable to the weeks at which failure of Paint F was observed there was a very high percentage of the beads missing. The other paints (Paints B and D) retained many of the beads after the same comparable time interval.

The mean failure values shown in Table 10, cold applied paints, for the concrete test sections do not show any difference between Paint Types B and D. The values for the asphaltic concrete test sections show that the chlorinated rubber-alkyd (Paint D) did significantly outlast the dispersion resin-varnish (Paint B) by some 11 weeks. However, for Paint D, the difference shown between pavement type is 36 weeks more life on asphaltic concrete than on concrete pavements. These data indicate the possibility of selective striping by pavement types could be considered. As indicated by this analysis, concrete pavements having medium traffic volumes would receive stripes twice a year and the comparable asphaltic concrete pavements would only need one striping per year, using the chlorinated rubber-alkyd formulation.

Hot-Applied:

The best of the high heat paints tested in Phase 2 of this investigation and shown as Paint G was obtained and again labelled as Paint G for this phase. In addition, a very fast drying high heat paint that had a short life in the Phase 2 tests (as Paint O) was obtained and applied in one test section on each pavement to re-evaluate its ability to resist wear. Its attributes being the very ones that are so strongly desired for use in high traffic volume areas, a retest was considered essential. Also, another high heat paint (Paint K) which the Maintenance and Traffic Division requested be included was analyzed. This paint manufacturer did give the formulation for this particular paint.

The mean failure values shown in Table 10 for Routes I-55 and I-70 indicate Paint K had a very short life when considering night visibility. Paint O on the asphaltic concrete pavement also had a very poor life due to night visibility. Examination of the microphotographs revealed that these paints did have considerable bead loss at these early ages. However, Paint O on the concrete pavement did show significantly better wear characteristics than on the asphaltic concrete pavement.

Paint G which was the high heat paint that ranked consistently high as tested by wear resistance in Phase 2, definitely indicated its superiority over the other comparable paints tested in this phase when applied in the longitudinal centerline condition. Unlike the condition which existed with the chlorinated rubber, the high heat paints used in high traffic volume areas seem to fail at approximately 30 weeks regardless of pavement type. Apparently restriping will have to be a semi-annual occurrence or possibly more often in higher traffic volume areas, since the lives of these stripes were 29 and 28 weeks for the concrete and asphaltic concrete pavement, respectively.

PART B - STUDY OF THE VARIATION BETWEEN BEAD TYPE AND CONCENTRATION

The night visibility rating used to test the variation between bead concentrations is only as reliable as the ability of the striping machinery to accurately place the pounds per gallon concentrations necessary. New bead guns were ordered and installed on the cold application machine. They were the calibrated adjustable orifice type similar to those on the high heat striper. These guns allowed for more accurate and consistent bead concentration and flow. Prior to placing the stripes, all bead dispensers were calibrated for size of orifice opening and corresponding air pressures required in the bead tanks to place the 3, 4, and 5 pounds per gallon quantities as planned for this investigation.

During the planning of this investigation, each bead type was programmed to be placed on each of the four pavements to allow for analysis in much the same manner as the paint types shown in Part A of this discussion. Bead concentration was varied only on one of the pavements used for each of the cold and hot applied paints.

To analyze the bead types, the data collected for the night visibility rating will be used exclusively. This rating designates the apparent brightness of the stripes when examined by tungsten illumination from the side of the road. To enhance the single failure value per test section as shown in Table 7, a failure value for use in Table 11, pages 62 and 63, was determined from the data for each individual observer, thus giving three values per variable rather than only one. As added information, by having these values, the significance between observers can be computed. The method of analysis applied to this data was the analysis of variance with the results from each pavement considered separately.

The data shown in Table 11, is the raw data and the resulting analysis of variance table for each pavement respectively. In two out of the four analyses shown, the difference between observers was of questionable significance. The main source variable, bead type and concentration, is shown in all cases to be highly significant at the 0.001 level. The data in Table 12, page 64, show the ranked mean failure values for the complete analyses shown in Table 11, for each of the pavements respectively.

Bead Type:

This investigation consisted of four types of glass beads as mentioned previously. The Type I bead is the Missouri specification free flowing drop-on bead, the Type II bead is the Missouri specification "floating" bead, the Type III bead is a modification of the Type II bead, and the Type IV bead is a modification of the Type I bead.

The performance of these four beads with the cold applied paints on Routes 50 and 54 are shown in Table 12. Bead Types III and IV are not significantly different on either pavement. This is shown in Table 12 by use of the vertical lines to the right of the mean failure values. The values bounded within each vertical line indicate that between any combination of these variables no claim can be made as to any significance in their behavior. Bead Type II shows significantly better results than either Type III or IV on both pavements. Bead Type II shows significantly better results than bead Type I on concrete, however, bead Type I was significantly better on medium volume asphaltic concrete pavement.

The performance of these four beads with the hot applied paints, shown in Table 12 for Routes I-55 and I-70, respectively, show that for concrete pavement all types are significantly different from each other, Type II giving the best performance. However, on high volume asphaltic concrete pavement Types I, II, and III show no significant difference and Type IV shows signficantly poorer performance than any other type.

These results indicate that the Type II bead, when applied in concentrations equal to the other types of beads, consistently ranks high in performance. The Type II bead shows the best performance on the concrete pavements and is significantly better than the next best bead. On the asphaltic concrete pavements the Type I bead is significantly better than the Type II bead when used with the cold applied paints. However, considering the failure values shown, the Type II bead shows the most consistent rate of failure.

Bead Concentration:

The striping program of the Missouri State Highway Department at the beginning of this investigation called for the Type I specification glass bead to be applied at the rate of 5 to 6 pounds per gallon of paint. During review of the literature, the newer Type II "floating" bead was noted as requiring lesser concentrations than the Type I bead. Therefore, for purposes of determining which concentration would give sufficient service life and to provide a basis for economic consideration, three rates of application were chosen. The rates of 3, 4, and 5 pounds per gallon were designed into the investigation for both the cold and hot applied paints. However, only one of each pavement type was chosen to make this study, the concrete pavement for the cold applied and the asphaltic concrete pavement for the hot applied paints.

The differences between the concentrations of the Type I bead with the cold applied paints, as shown in part (a) of Table 12, were not significant. The maximum difference in mean failure was less than two weeks. The Type II bead at a 5 pound concentration has a significantly longer life than the 4 pound concentration and both of these concentrations are significantly better than the 3 pound concentration.

The differences between the concentrations of the Type I bead with the hot applied paints, as shown in part (d) of Table 12, show the 5 pound concentration to be significantly better than the 4 or 3 pound concentration with no significant difference between the latter two. The Type II bead, however, shows no significant difference between concentrations.

The results show the Type I bead at 5 pounds per gallon and the Type II bead at either 5 or 4 pounds per gallon to be consistently high in the ranking shown in Table 12. The one exception is the Type I bead at 5 pounds per gallon on Route 50. The most consistent results were obtained with the Type II bead at 4 pounds. However, the Type I bead at 5 pounds per gallon used with the cold applied paint on medium traffic volume asphaltic concrete pavement did show a significant increase in service life. The Type II bead at 4 pounds per gallon concentration was not placed on low traffic volume asphaltic concrete pavement in this test, and results which could be obtained with this combination are unknown.

PART C - STUDY OF AN ALTERNATE METHOD FOR ESTABLISHING NIGHT VISIBILITY RATING

The method of rating traffic delineation stripes by night visibility as stated in ASTM Method D 713-69, may be done with the human eye and judgement or by photographic methods with the rating being based on a factor of 10 for the highest reading and 0 for complete failure. It was difficult for the rating team to mentally adjust from observation to observation on this type of subjective rating. Therefore, another system of night visibility rating, which had been used previously in an exploratory test, was also included.

The alternate (point count) method of rating the stripes for night visibility was also included in this phase to provide for comparison of the two methods. To make this rating, the automobile was placed in exactly the same manner as described in the Evaluation Test Procedures section of this report. However, the observers positioned themselves immediately in front of the automobile standing between the headlights, rather than being seated in the front seat of the automobile. The first observation was with the low beam light and the second observation was with the high beam light. The observer, with each light setting, made a point count of how many 15-foot dashes could be clearly and distinctly seen, including the one which was used to place the automobile in position. The decision of when to stop counting was a judgement each observer had to make. It was accepted that this point would be when the stripe no longer gave a clear distinct white appearance, fading to a dull gray appearance.

The observers engaged in this study consistently felt more comfortable with this rating system than that of the subjective 10 to 0 ASTM rating. For all test sections in this phase of this investigation, both ratings were made. From the number of observations made and the large number of test sections included in this phase, a large quantity of data were made available for analysis. Figure 7, pages 65 and 66, shows the results of regression analyses made from the high beam point count ratings for each pavement type for the cold and hot applied paints versus the ASTM night visibility ratings.

The very good similarity between all of these regression analyses suggested a complete regression analysis be made utilizing all 307 pairs of data. The resultant equation is shown in Figure 8, page 67. As this equation was shown to have a standard error of estimate of only 0.59 and a coefficient of variation of only 12.5 percent, this alternate method does appear to have greater promise than initially anticipated. From this analysis of the high beam point count ratings there does appear to be a less subjective method available whereby night visibility observations may be made by less experienced people who are not familiar with the ASTM method.

The low beam point count ratings were taken with each observation. It became apparent near the latter stages of the investigation, however, that a leveling off of the ratings occurred around the third and fourth dash marks, while the high beam point count ratings continued to deteriorate. Due to this inconsistency, the low beam point count ratings were omitted and considered inadequate for use as a night visibility rating method.

APPENDIX A

Chemical Analysis
of Traffic Delineation Paints

Table 1

Properties of Paints

Paint Type	B	D	F	G	K	O [a]
Lab. Number	71-10030	71-10032	71-10033	71-10031	71-10029	70-12899
Percent Pigment	51.2	49.2	44.6	52.4	41.2	57.4
Percent Vehicle	48.8	50.8	55.4	47.6	58.8	42.6
Percent Non-Volatile in Vehicle	37.7	42.0	29.1	34.9	33.3	61.5
Weight Per Gallon, Lbs. at 25°C	10.86	12.08	14.90	14.49	14.95	12.33
Viscosity at 77°F, Krebs Units	63	70	70	107	99	NA
Drying Time, Min., ASTM D711-67	23	3½	1	4	3	NA
Minimum Grind, Hegman Gage	5½	3½	3	4½	3½	NA
Skinning Test, 72 Hours	Passed	Passed	Passed	Passed	Passed	NA
Settling Test, ASTM D1309.56	2	8	8	6	7	0

(a) Properties of this paint were obtained from previous Phase 2 analyses.

Table 2

Infrared Spectra, X-ray Spectra and ARL Microprobe Analyses of Paints G and K

Paint Type G: Lab. No.: 71-10031

Vehicle: Oil Modified Phthalic Alkyd
Medium-Long Oil

Solvents: Trichloroethylene

Pigments:

Major Components: Ca, Ti, Si.

Minor Components: Zn, Al, Cr, Fe.

Most Probable Chemical Compounds:

Calcium Carbonate
Titanium Dioxide
Calcium Sulfate
Silica
Zinc Oxide

Paint Type K: Lab. No.: 71-10029

Vehicle: Oil Modified Phthalic Alkyd
Short-Medium Oil

Solvents: Trichloroethylene
Commercial Mineral Spirits

Pigments:

Major Components: Ca, Ti.

Minor Components: Si, Al, Cr.

Most Probable Chemical Compounds:
Calcium Sulfate
Titanium Dioxide

PROCEDURES USED FOR DETERMINATION OF GENERIC COMPOSITIONS OF VEHICLES, SOLVENTS, AND PIGMENTS.

Vehicles:

In the cases where the pigments had settled, a sample of the vehicles and solvent was applied to a KBr plate and dried in a 120°C oven for 5-10 minutes. Paints in which the pigments had not settled were diluted with a mixture of equal parts of xylenes, methyl ethyl ketone, and methylene chloride. The diluted mixture was centrifuged to settle the solids. The solvent was evaporated on a KBr plate to leave a film of the vehicle itself. Infrared spectra were obtained using a Beckman IR-12 spectrophotometer.

Solvents:

The solvents were removed from the paint by simple distillation. Where possible, individual solvents were separated before infrared analysis; otherwise, a composite spectrum was obtained. Infrared spectra of all solvents were obtained using KBr liquid cells on a Beckman IR-12. This technique proved more meaningful than NMR or chromatographic techniques.

Pigments:

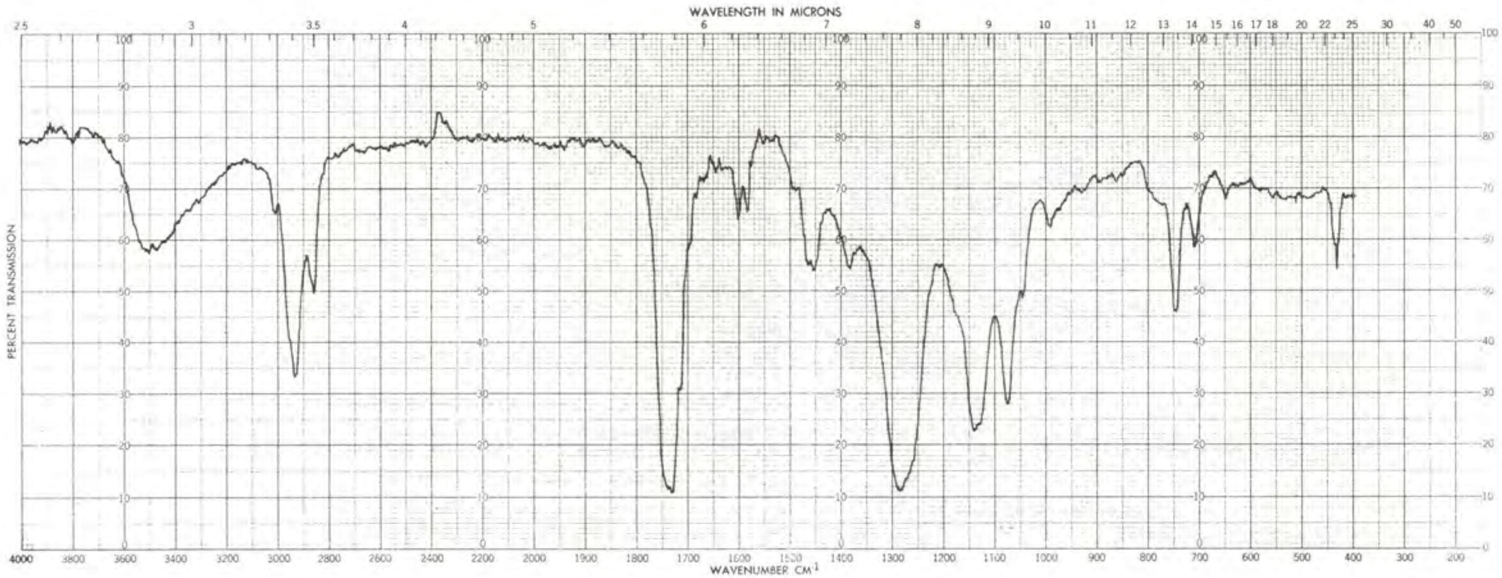
A sample of each paint was diluted with a mixture of equal parts of xylene, methyl ethyl ketone, and methylene chloride. The diluted mixture was centrifuged and the solvent decanted. More of the mixed solvent was added to the solids, the mixture thoroughly stirred, centrifuged, and decanted as before. The washing procedure was repeated twice more. The solids were dried in a 120°C oven for 10 minutes and analyzed by an Ortec non-dispersive X-ray spectrometer and by an ARL microprobe.

Spectrophotometer Settings and Constants:

SB = 98 SB/DB Energy Ratio = 1
DB = 98 Resolution = Maximum

Speed = 200
Gain = 350
Period = 2
Ordinate Seale = 0 - 100

FIGURE 1



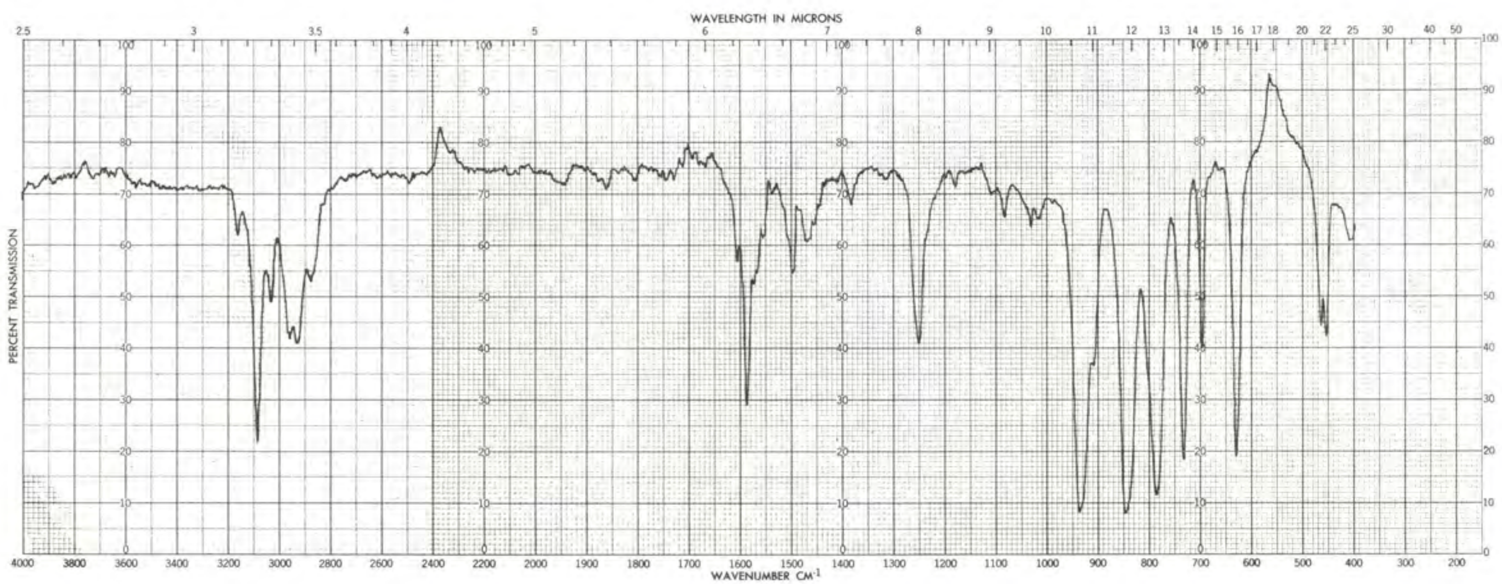
PAINT TYPE - G

(VEHICLE)

COLOR - WHITE
LAB NO 71-10031

GENERIC COMPOSITION:

OIL MODIFIED
PHTHALIC ALKYD,
SHORT-MED. OIL



PAINT TYPE - G

(SOLVENTS)

COLOR - WHITE
LAB NO 71-10031

GENERIC COMPOSITION:

TRICHLOROETHYLENE
COMM. MINERAL SPIRITS

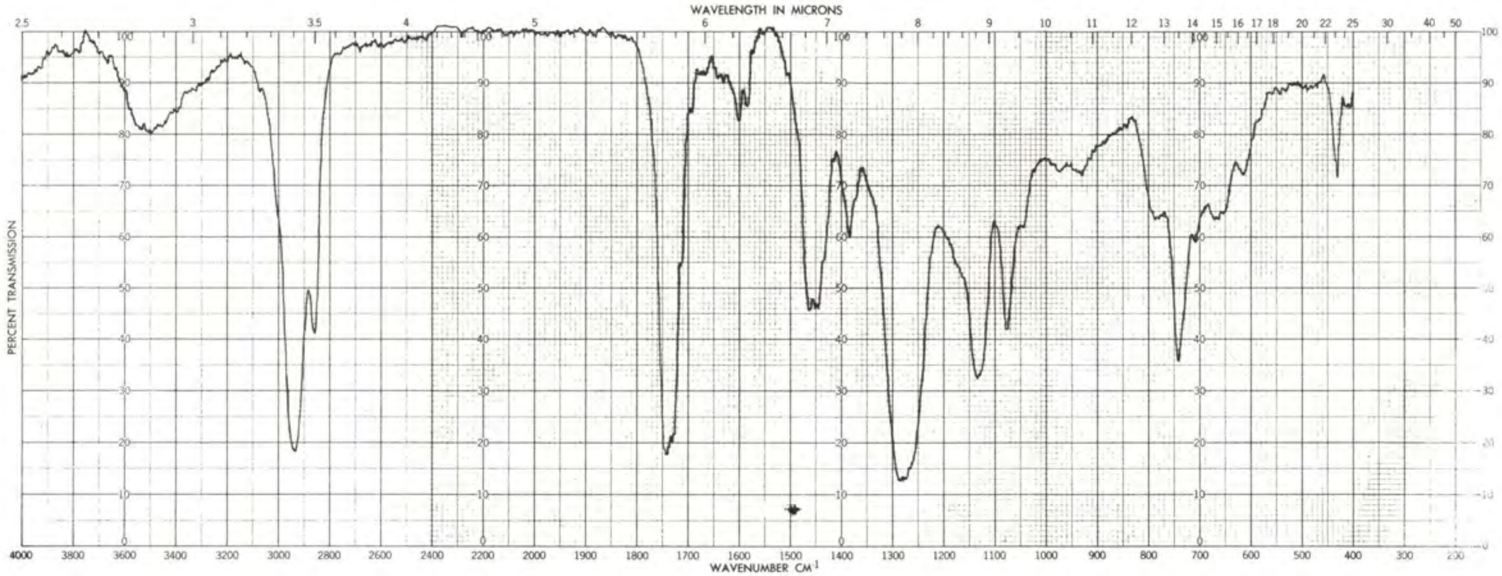


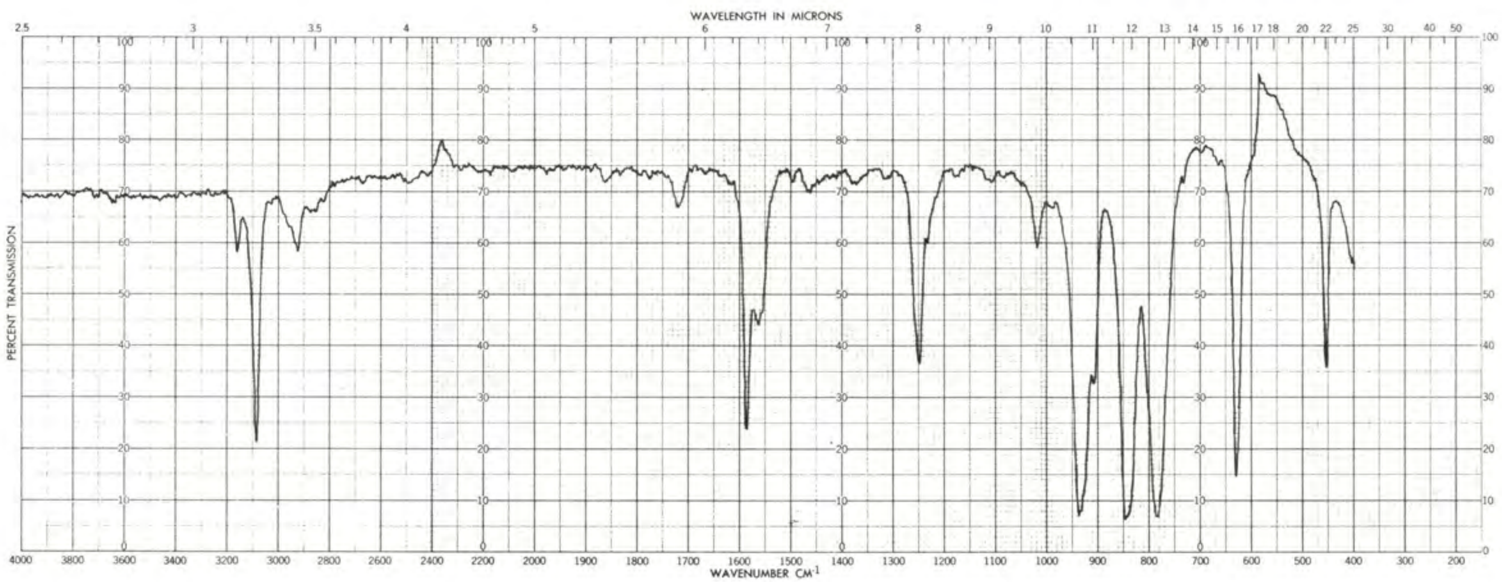
FIGURE 2

PAINT TYPE - K

(VEHICLE)

COLOR - WHITE
LAB NO 71-10029

GENERIC COMPOSITION:
OIL MODIFIED PHTHALIC ALKYD, MED.-LONG OIL



PAINT TYPE - K

(SOLVENTS)

COLOR - WHITE
LAB NO 71-10029

GENERIC COMPOSITION:
TRICHLOROETHYLENE

APPENDIX B

Specifications and Properties

of

Glass Beads

TYPE I GLASS BEADS

SPECIFICATION FOR FREE FLOW REFLECTORIZING SPHERES

For Application on Traffic Marking Paint

GENERAL

1. These specifications cover free flow reflectorizing spheres for drop-on application on traffic paint for the production of a reflective surface to improve the night visibility of the paint film.

2. The spheres shall be manufactured from glass of a composition that is highly resistant to traffic wear and to the effects of weathering.

3. All spheres furnished shall be shipped in clean containers or bags, each of which shall contain a nominal maximum weight of fifty (50) pounds of spheres. All such containers or bags shall be of such type that spheres will not be lost due to package failure during normal handling and storage conditions. Each container shall be marked with the name and type of contents, manufacturer of beads, net weight, and lot designation, if any. All containers or bags shall be of such type that they will repel rather than absorb moisture.

MATERIAL

1. The beads shall be spherical in shape, containing not more than thirty (30) per cent irregularly shaped particles when tested in accordance with ASTM Method D 1155-53.

2. The glass shall have a refractive index of not less than 1.50.

   Method of Test for Refractive Index:

   This method determines the refractive index of the beads by comparing them with oils of known refractive index. A set of oils in the proper range, graduated in steps of 0.01, is used for this comparison.

   Place a few beads in the cavity of a hanging drop microscope slide, having a cavity 1.7 millimeters deep. Select an oil of approximately the expected refractive index and add an amount sufficient to immerse the beads in the cavity. Place the slide on the stage of a microscope having a magnification of approximately 150 power and illuminate from beneath with a white light source. A band of light, known as the Becke line, is visible surrounding each bead. This Becke line moves toward the medium of higher refractive index if the focus is raised, and toward the medium of lower index if the focus is lowered. By making slides using oils of varying refractive indices, and gradually narrowing the ranges, above or below the one originally used as becomes necessary, a point will be reached where the beads become invisible or have only a thin faint yellow Becke line surrounding them. When this occurs, the beads have the same refractive index as the oil, and this is the value to be reported for the beads.

3. Reflectance: Brightness, expressed as candle power per foot candle per square foot, not less than 3.25. (Entrance angle 0° and observation angle 0.2°).

   Method of Testing for Reflectance:

   Optical testing shall consist of measuring the brightness by the following procedure: a 5 inch diameter test panel shall be prepared by applying the beads to a wet paint film of Sherwin Williams Super Kem-Tone Ceiling Flat White Paint. The paint film shall have a minimum thickness of 6 mils and beads applied at a minimum rate of 6 pounds per gallon. The excess beads that do not adhere to the paint film shall be removed after the paint film has dried by lightly tapping the panel when in a vertical position. The panel to be tested shall be located at a distance of 100 feet from a single uniformly bright light source having an effective diameter of 2 inches; the light source shall be operated at approximately normal efficiency. The return light from the reflector shall be measured by means of a photoelectric photometer having a minimum sensitivity of 1 x 10-7 footcandle per millimeter scale division. The photometer shall have a receiver aperture 0.5 inch in diameter, shielded to eliminate stray light. The distance from light source center to aperture center shall be 4.2 inches for 0.2° observation angle.

4. Water Resistance: The spheres, when subjected to the following test, shall show no readily discernible dulling, and the amount of 0.1 Normal Hydrochloric Acid needed to titrate the filtrate shall not exceed 4.5 milliliters.

   Method of determining water resistance:

   Ten (10) ± 0.5 grams of glass spheres placed in a Whatman single thickness cellulose extraction thimble, 33 by 80 millimeters, are refluxed for one (1) hour in a Soxhlet extractor having an 85 milliliter siphon capacity using 150 milliliters of distilled water. All connections shall be ground glass. At the end of the refluxing period, allow the filtrate to cool to room temperature and titrate with 0.1 Normal Hydrochloric Acid, using phenolphthalein indicator. The beads shall be dried at 110°C and examined for dulling under 60 power magnification.

5. Resistance to Calcium Chloride: The spheres shall show no readily discernible dulling when subjected to the following test.

   Method of determining Calcium Chloride resistance:

   Immerse approximately ten (10) grams of the spheres in a 1.0 Normal Calcium Chloride solution for three (3) hours. Rinse well, by decantation, with distilled water. Spread beads on a clean filter paper and allow to dry. Examine the spheres for dulling under 60 power magnification.

6. Resistance to Sodium Sulfide: The spheres shall show no readily discernible darkening or dulling when subjected to the following test.

   Method of Determining Sodium Sulfide Resistance:

   Immerse approximately ten (10) grams of the spheres in a fifty (50) per cent solution of Sodium Sulfide for one (1) hour. Rinse well, by decantation, with distilled water. Spread beads on a clean filter paper and allow to dry. Examine the spheres for darkening or dulling under 60 power magnification.

7. Free Flowing Properties: The beads shall be sufficiently free of clusters and hard lumps to flow uniformly through dispensing equipment under any weather conditions suitable for striping. In addition they shall pass the following laboratory test.

   Method of Determining Free Flowing Properties:

   Weigh 100 grams of dry beads in a Corning number 3140 glass crystallizing dish, 100 mm diameter and 50 mm depth. Place the dish in a Corning number 3080 desiccator, 250 mm inside diameter by 330 mm overall height and 130 mm chamber depth, which shall be filled with water to a point 1 inch below the top of a size 5 Coors number 60003 desiccator plate. The specimen shall remain in the desiccator with the cover in place at 25 $\pm$5°C for four hours. When the sample is removed from the desiccator, the beads are transferred to a metal pan and inspected for lumps and clusters. The beads shall be essentially free of lumps and clusters and shall flow without stoppage through a Corning number 6120 glass funnel, top diameter 5 inch, stem length 4 inches.

8. Silica Content: The beads shall be made of glass containing not less than 58.0 per cent silica (SiO_2) when tested in accordance with ASTM Method C 169-69, Procedure for Referee Analysis.

9. Gradation: The spheres shall meet the following gradation requirements when tested in accordance with ASTM Method D 1214-58.

U. S. Standard Sieve No.	Per Cent Passing
20	100
30	75-90
50	15-30
100	0-5
200	0-1

10. Each bidder shall furnish a typical, chemical analysis of the spheres to be furnished. This analysis shall show each chemical component present in the amount of one (1) per cent or more, calculated as the oxide.

TYPE II GLASS BEADS

SPECIFICATION FOR FLOATING REFLECTORIZING SPHERES

For Application on Traffic Marking Paint

GENERAL

1. These specifications cover free flow floating reflectorizing spheres for drop-on application on traffic paint for the production of a reflective surface to improve the night visibility of the paint film.

2. The spheres shall be manufactured from glass of a composition that is highly resistant to traffic wear and to the effects of weathering.

3. All spheres furnished shall be shipped in clean containers or bags, each of which shall contain a nominal maximum weight of fifty (50) pounds of spheres. All such containers or bags shall be of such type that spheres will not be lost due to package failure during normal handling and storage conditions. Each container shall be marked with the name and type of contents, manufacturer of beads, net weight, and lot designation, if any. All containers or bags shall be of such type that they will repel rather than absorb moisture.

MATERIAL

1. The beads shall be spherical in shape, containing not more than thirty (30) per cent irregularly shaped particles when tested in accordance with ASTM Method D 1155-53.

2. The glass shall have a refractive index of not less than 1.50.

   Method of Test for Refractive Index:

   This method determines the refractive index of the beads by comparing them with oils of known refractive index. A set of oils in the proper range, graduated in steps of 0.01, is used for this comparison.

   Place a few beads in the cavity of a hanging drop microscope slide, having a cavity 1.7 millimeters deep. Select an oil of approximately the expected refractive index and add an amount sufficient to immerse the beads in the cavity. Place the slide on the stage of a microscope having a magnification of approximately 150 power and illuminate from

from beneath with a white light source. A band of light, known as the Becke line, is visible surrounding each bead. This Becke line moves toward the medium of higher refractive index if the focus is raised, and toward the medium of lower index if the focus is lowered. By making slides using oils of varying refractive indices, and gradually narrowing the ranges, above or below the one originally used as becomes necessary, a point will be reached where the beads become invisible or have only a thin faint yellow Becke line surrounding them. When this occurs, the beads have the same refractive index as the oil, and this is the value to be reported for the beads.

3. Reflectance: Brightness, expressed as candle power per foot candle per square foot, not less than 3.25. (Entrance angle 0° and observation angle 0.2°).

Method of Testing for Reflectance:

Optical testing shall consist of measuring the brightness by the following procedure: a 5 inch diameter test panel shall be prepared by applying the beads to a wet paint film of Sherwin Williams Super Kem-Tone Ceiling Flat White Paint. The paint film shall have a minimum thickness of 6 mils and beads applied at a minimum rate of 6 pounds per gallon. The excess beads that do not adhere to the paint film shall be removed after the paint film has dried by lightly tapping the panel when in a vertical position. The panel to be tested shall be located at a distance of 100 feet from a single uniformly bright light source having an effective diameter of 2 inches; the light source shall be operated at approximately normal efficiency. The return light from the reflector shall be measured by means of photo-electric photometer having a minimum sensitivity of 1 x 10-7 footcandle per millimeter scale division. The photometer shall have a received aperture 0.5 inch in diameter, shielded to eliminate stray light. The distance from light source center to aperture center shall be 4.2 inches for 0.2° observation angle.

4. Water Resistance: The spheres, when subjected to the following test, shall show no readily discernible dulling, and the amount of 0.1 Normal Hydrochloric Acid needed to titrate the filtrate shall not exceed 4.5 milliliters.

Method of determining water resistance:

Ten (10) ±0.5 grams of glass spheres placed in a Whatman single thickness cellulose extraction thimble, 33 by 80 millimeters, are refluxed for one (1) hour in a Soxhlet extractor having an 85 milliliter siphon capacity using 150 milliliters of distilled water. All connections shall be ground glass. At the end of the refluxing period, allow the filtrate to cool to room temperature and titrate with 0.1 Normal Hydrochloric Acid, using phenolphthalein indicator. The beads shall be dried at 110°C and examined for dulling under 60 power magnification.

5. Resistance to Calcium Chloride: The spheres shall show no readily discernible dulling when subjected to the following test.

Method of determining Calcium Chloride resistance:

Immerse approximately ten (10) grams of the spheres in a 1.0 Normal Calcium Chloride solution for three (3) hours. Rinse well, by decantation, with distilled water. Spread beads on a clean filter paper and allow to dry. Examine the spheres for dulling under 60 power magnification.

6. Resistance to Sodium Sulfide: The spheres shall show no readily discernible darkening or dulling when subjected to the following test.

Method of determining Sodium Sulfide Resistance:

Immerse approximately ten (10) grams of the spheres in a fifty (50) per cent solution of Sodium Sulfide for one (1) hour. Rinse well, by decantation, with distilled water. Spread beads on a clean filter paper and allow to dry. Examine the spheres for darkening or dulling under 60 power magnification.

7. Free Flowing Properties: The beads shall be sufficiently free of clusters and hard lumps to flow uniformly through dispensing equipment under any weather conditions suitable for striping. In addition they shall pass the following laboratory test.

Method of Determining Free Flowing Properties:

Weigh 100 grams of dry beads in a Corning number 3140 glass crystallizing dish, 100 mm diameter and 50 mm depth. Place the dish in a Corning number 3080 disiccator, 250 mm inside diameter by 330 mm overall height and 130 mm chamber depth, which shall be filled with water to a point 1 inch below the top of a size 5 Coors number 60003 desiccator plate. The specimen shall remain in the desiccator with the cover in place at 25 $\pm 5^{\circ}C$ for four hours. When the sample is removed from the desiccator, the beads are transferred to a metal pan and inspected for lumps and clusters. The beads shall be essentially free of lumps and clusters and shall flow without stoppage through a Corning number 6120 glass funnel, top diameter 5 inch, stem length 4 inches.

8. Silica Content: The beads shall be made of glass containing not less than 58.0 per cent silica (SiO_2) when tested in accordance with ASTM Method C 169-69, Procedure for Referee Analysis.

9. Gradation: The spheres shall meet the following gradation requirements when tested in accordance with ASTM D 1214-58.

U. S. Standard Sieve No.	Per Cent Passing
40	90-100
80	0-10

10. Floatation: 90% of the glass spheres shall float on xylol when tested as follows:

    A single layer of spheres shall be spread on a clean, inverted pint tin can lid. Xylol shall be slowly introduced with a syringe or dropper at the edge of the lid until it overflows. The percentage of spheres floating on the xylol surface shall be estimated visually.

11. Each bidder shall furnish a typical, chemical analysis of the spheres to be furnished. This analysis shall show each chemical component present in the amount of one (1) per cent or more, calculated as the oxide.

TYPE III GLASS BEADS

SPECIFICATION FOR REFLECTORIZING SPHERES

For Application on Traffic Marking Paint

This specification is similar to the Type II specification with the exception that all reference, to "floating" was omitted and that paragraph 10 be omitted in its entirety.

This glass bead was designated as a drop-on bead having the same gradation requirements as the Type II bead without the floating properties.

TYPE IV GLASS BEADS

SPECIFICATION FOR REFLECTORIZING SPHERES

For Application on Traffic Marking Paint

This specification utilized all paragraphs shown for the Type I bead with the exception of a substitution for the gradation requirements in paragraph 9 as follows:

U. S. Standard Sieve No.	Percent Passing
20	100
30	95-100
40	70-95
80	0-20
100	0-5
200	0-1

Table 3

Properties of Glass Beads

Bead Type	I	I	II	III	IV
Lab. Number	70-15832	71-37	71-2249	71-9855	71-9854
Lot Number	108	117	38	-	-
Percent Irregularly Shaped Particles	28.5	27.6	15.4	6.7	9.5
Free Flowing Test	S (b)	S	S	S	S
Refractive Index at 25°C	1.51	1.51	1.51	1.52	1.52
Brightness (a)	4.23	4.16	4.91	4.99	5.44
Percent Silica (SiO_2)	71.5	71.8	71.2	72.6	72.4
Chemical Stability					
Resistance to CaCl	S	S	S	S	S
Resistance to Na_2S	S	S	S	S	S
Water Resistance	S	S	S	S	S
Gradations: (Average of several samples as indicated)					
No. of Samples	7	3	8	7	7
% Passing Sieve					
No. 20	100	100	-	-	100
No. 30	87.8	86.6	100	100	99.1
No. 40	-	-	97.6	99.1	89.1
No. 50	22.1	18.2	-	-	-
No. 80	-	-	4.0	9.1	8.4
No. 100	0.8	0.7	-	-	1.9
No. 200	0.3	0.3	-	-	0.3

(a) Candle Power/Ft. Candle/Sq. Ft.
(b) S indicates Satisfactory

APPENDIX C

Test Section Design and Field Data

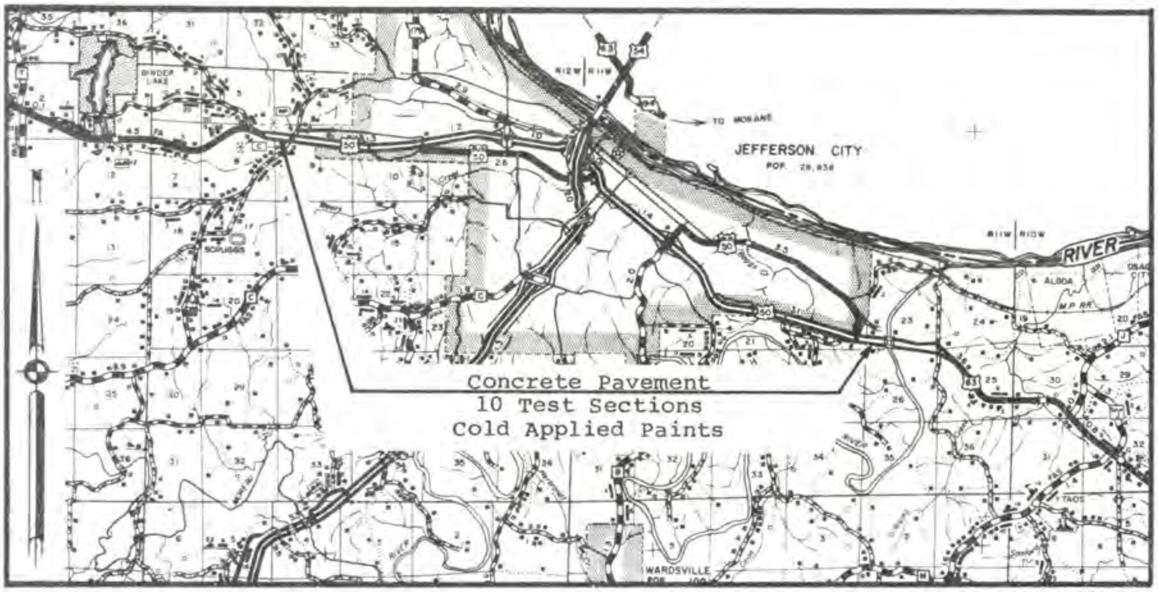


Figure 3 - Location of Test Sections for Cold Applied Paints
on Concrete Pavement, Cole County, Route 50

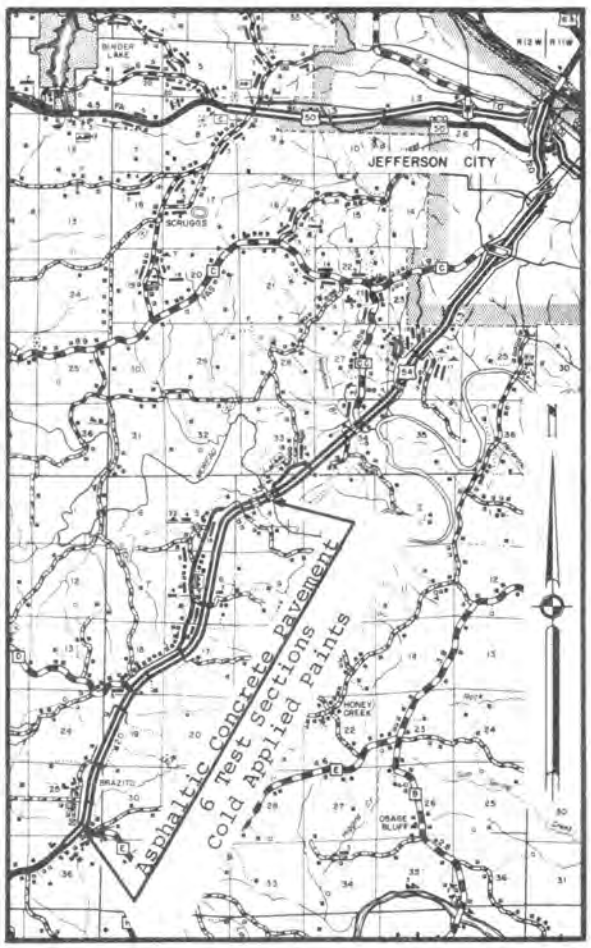


Figure 4 - Location of Test Sections for Cold Applied Paints
on Asphaltic Concrete Pavement, Cole County, Route 54

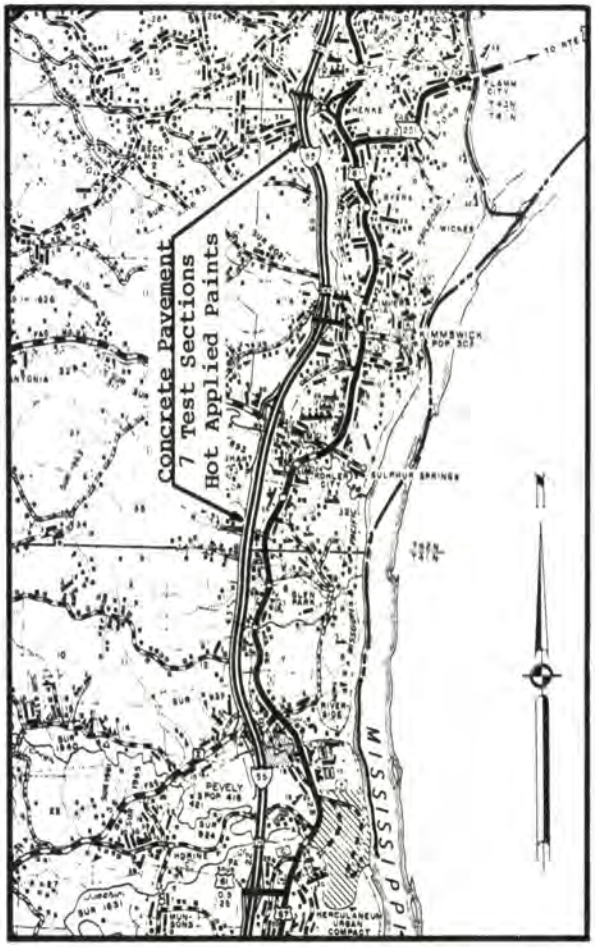


Figure 5 - Location of Test Sections for Hot Applied Paints
on Concrete Pavement, Jefferson County, Route I-55

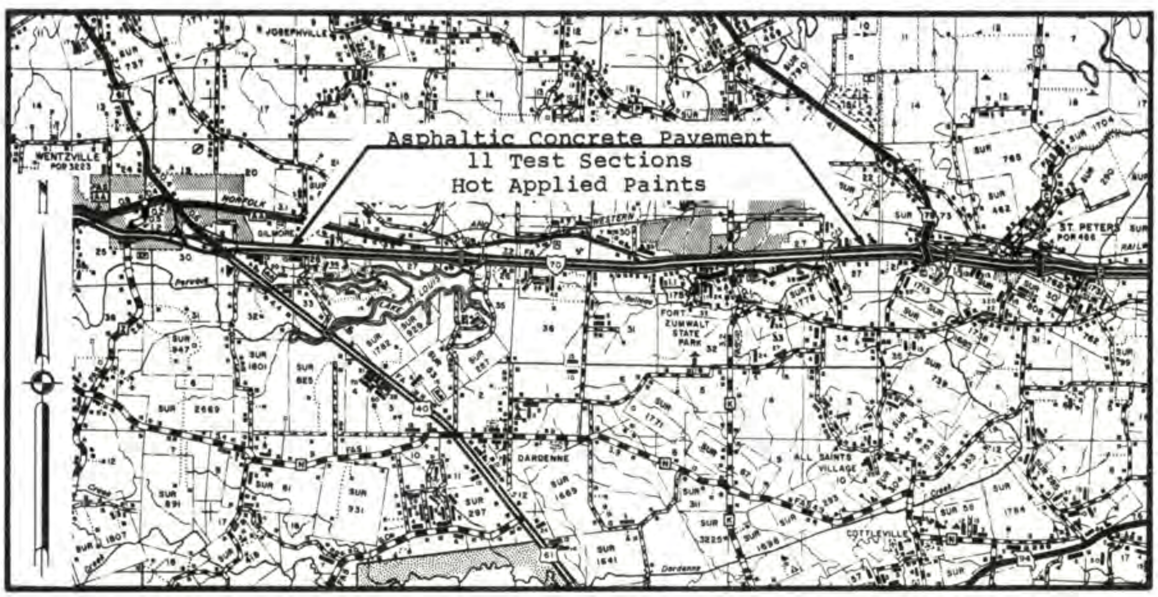


Figure 6 - Location of Test Sections for Hot Applied Paints
on Asphaltic Concrete Pavement, St. Charles County, Route I-70

Table 4

Hourly Temperature and Relative Humidity Readings During Placement of the Stripes[a]

District 5 - Rtes. 50 & 54				District 6 - Rtes. I-55 & I-70			
Date	Time	Temp. (Deg. F)	R.H. (%)	Date	Time	Temp. (Deg. F)	R.H. (%)
June 7	9:00 AM	78	58	June 22	9:00 AM	75	52
	10:00 AM	80	58		10:00 AM	76	45
	11:00 AM	86	51		11:00 AM	81	38
	12:00 AM	86	48		12:00 AM	81	38
	1:00 PM	89	42		1:00 PM	82	38
	2:00 PM	89	45		2:00 PM	83	38
	3:00 PM	90	42		3:00 PM	81	42
	4:00 PM	88	42		4:00 PM	82	48
June 8	9:00 AM	73	62	June 23	9:00 AM	79	79
	10:00 AM	72	62		10:00 AM	84	67
	11:00 AM	76	48		11:00 AM	88	57
	12:00 AM	78	46		12:00 AM	91	50
	1:00 PM	82	43		1:00 PM	94	43
	2:00 PM	83	44		2:00 PM	93	41
	3:00 PM	75	43		3:00 PM	94	43
	4:00 PM	75	43		4:00 PM	95	40
June 9	9:00 AM	70	66	June 24	9:00 AM	80	77
	10:00 AM	75	62		10:00 AM	84	67
	11:00 AM	78	58		11:00 AM	86	61
	12:00 AM	80	52		12:00 AM	87	62
	1:00 PM	81	51		1:00 PM	93	43
	2:00 PM	83	51		2:00 PM	94	39
	3:00 PM	85	46		3:00 PM	96	34
	4:00 PM	84	45		4:00 PM	96	32
				June 25	9:00 AM	74	85
					10:00 AM	76	79
					11:00 AM	78	77
					12:00 AM	77	77
					1:00 PM	79	69
					2:00 PM	81	63
					3:00 PM	84	57
					4:00 PM	87	52
				June 28	9:00 AM	81	64
					10:00 AM	83	59
					11:00 AM	87	55
					12:00 AM	90	52
					1:00 PM	93	51
					2:00 PM	91	51
					3:00 PM	90	48
					4:00 PM	-	-

(a) Weather data obtained from United States Weather Bureaus located at Columbia, Missouri for District 5 and Lambert Field for District 6.

Table 5

Wet and Dry Film Thickness Measurements of Stripes

Test Section	Lane	Plate No.	Paint Type	Bead Code	Bead Conc.(a)	Film Thickness Wet(b)	Film Thickness Dry(c)	Percent Reduction
a. District 5 - Route 50, Concrete Pavement								
T-1	EB	82	B	I	5	20+	5.57	72.15
	WB	79				18.0	6.88	61.77
T-2	EB	76	D	I	5	16.0	6.00	62.50
	WB	73				15.0	6.69	55.40
T-3	EB	70	D	I	4	(d)	-	-
	WB	67				16.0	5.56	65.25
T-4	EB	64	D	I	3	(e)	-	-
	WB	61				16.0	5.82	63.62
T-5	EB	58	D	II	5	14.0	7.25	48.21
	WB	55				16.0	6.75	57.81
T-6	EB	52	D	II	4	16.0	7.57	52.68
	WB	49				(d)	-	-
T-7	EB	46	D	II	3	14.0	6.06	56.71
	WB	43				(d)	7.19	48.64
T-8	EB	40	D	III	5	15.0	6.25	58.33
	WB	37				16.0	6.82	57.37
T-9	EB	31	D	IV	5	15.0	6.87	54.20
	WB	34				16.0	6.94	56.62
T-10	EB	85	F	I	5	15.0	6.19	58.73
	WB	88				15.0	8.62	42.53
b. District 5 - Route 54, Asphaltic Concrete Pavement								
T-1	NB	94	F	I	5	14.0	6.37	54.50
	SB	91				14.0	7.75	44.64
T-2	NB	5	B	I	5	15.0	7.62	49.20
	SB	1				16.0	8.57	46.43
T-3	NB	10	D	I	5	15.5	7.56	51.22
	SB	7				16.0	8.13	49.18
T-4	NB	13	D	II	5	13.5	8.13	39.77
	SB	16				16.5	8.63	47.69
T-5	NB	22	D	III	5	15.5	8.25	46.77
	SB	19				16.5	7.69	53.39
T-6	NB	28	D	IV	5	15.0	7.07	52.86
	SB	25				14.0	7.18	48.71
c. District 6 - Route I-55, Concrete Pavement								
T-1	NB	204	B	I	5	13.5	3.43	74.59
	SB	201				15.5	6.62	57.29
T-2	NB	210	O	I	5	(e)	-	-
	SB	207				(e)	-	-
T-3	NB	240	K	I	5	15.0	6.62	55.86
	SB	225				15.0	5.13	65.80
T-4	NB	237	G	I	5	15.0	9.00	40.00
	SB	228				15.0	7.44	50.40
T-5	NB	234	G	II	5	16.5	-	-
	SB	231				15.0	9.31	37.93
T-7	NB	127	G	III	5	18.0	8.94	50.33
	SB	121				14.0	8.25	41.07
T-8	NB	139	G	IV	5	15.5	6.00	61.29
	SB	133				13.0	5.74	55.84
d. District 6 - Route I-70, Asphaltic Concrete Pavement								
T-2	EB	213	B	I	5	13.5	4.56	66.22
	WB	216				14.0	4.26	69.57
T-3	EB	219	O	I	5	(e)	-	-
	WB	222				(e)	-	-
T-4	EB	243	G	II	5	16.0	8.44	47.25
	WB	258				15.0	8.62	42.53
T-5	EB	246	G	II	4	15.0	7.56	49.60
	WB	255				14.5	9.50	34.48
T-6	EB	249	G	II	3	17.5	8.13	53.54
	WB	252				16.5	8.93	45.87
T-7	EB	261	G	I	5	14.0	8.56	38.85
	WB	100				16.0	8.44	47.25
T-8	EB	264	K	I	5	15.5	6.69	56.83
	WB	273				14.0	6.50	53.57
T-9	EB	267	G	I	4	15.0	7.31	51.26
	WB	270				14.5	8.38	42.20
T-10	EB	103	G	I	3	17.0	8.69	48.88
	WB	112				18.0	6.19	65.61
T-11	EB	107	G	IV	5	16.0	7.50	53.12
	WB	110				16.0	6.25	60.93
T-12	EB	115	G	III	5	16.5	7.56	54.18
	WB	118				15.5	8.19	47.16

(a) Bead concentrations given in pounds per gallon.
(b) Determined by one measurement only with the interchemical gage.
(c) Determined by average of eight determinations with a laboratory thickness gage.
(d) Some beads were accidentally sprayed on the metal plate; therefore, measurements could not be taken.
(e) Striper missed the plate.

Table 6

Dry Time to No-Track and No-Pick-Up

Test Section	Lane	Plate No.	Paint Type	Bead Code	Bead Conc.(a)	Dry Time No-Track (Min-Sec)	Dry Time No-Pick-Up (Min-Sec)
			a. District 5 - Route 50, Concrete Pavement				
T-1	EB	84	B	I	5	14-52	15-57
	WB	80				-	18-51
T-2	EB	78	D	I	5	3-22	4-44
	WB	74				-	5-26
T-3	EB	72	D	I	4	4-00	4-27
	WB	68				5-42	6-25
T-4	EB	66	D	I	3	3-35	4-59
	WB	62				2-40	3-18
T-5	EB	60	D	II	5	3-08	4-07
	WB	56				6-15	7-12
T-6	EB	54	D	II	4	7-05	7-25
	WB	50				-	21-05
T-7	EB	48	D	II	3	-	4-31
	WB	44				3-00	5-57
T-8	EB	42	D	III	5	4-45	5-06
	WB	38				3-40	4-18
T-9	EB	32	D	IV	5	-	6-20
	WB	36				-	3-25
T-10	EB	86	F	I	5	-	1-53
	WB	89				2-53	3-06
			b. District 5 - Route 54, Asphaltic Concrete Pavement				
T-1	NB	95	F	I	5	1-26	1-40
	SB	92				-	1-47
T-2	NB	3	B	I	5	-	17-45
	SB	2				14-55	15-16
T-3	NB	12	D	I	5	3-30	4-45
	SB	8				-	13-52
T-4	NB	14	D	II	5	-	8-07
	SB	18				5-10	5-25
T-5	NB	24	D	III	5	-	4-48
	SB	20				4-45	7-12
T-6	NB	30	D	IV	5	4-15	4-35
	SB	26				3-40	4-06
			c. District 6 - Route I-55, Concrete Pavement				
T-1	NB	205	B	I	5	9-15	9-45
	SB	202				-	17-46
T-2	NB	212	O	I	5	0-09	0-14
	SB	208				0-12	0-16
T-3	NB	241	K	I	5	3-10	4-43
	SB	226				-	1-47
T-4	NB	238	G	I	5	8-45	9-02
	SB	229				-	7-49
T-5	NB	235	G	II	5	6-41	7-29
	SB	232				-	7-49
T-7	NB	128	G	III	5	10-10	11-00
	SB	122				9-24	10-03
T-8	NB	140	G	IV	5	3-41	4-01
	SB	134				4-21	4-38
			d. District 6 - Route I-70, Asphaltic Concrete Pavement				
T-2	EB	214	B	I	5	8-07	11-05
	WB	217				8-45	9-15
T-3	EB	220	O	I	5	0-10	0-15
	WB	223				0-08	0-15
T-4	EB	244	G	II	5	8-36	9-15
	WB	259				8-26	8-49
T-5	EB	247	G	II	4	7-30	8-10
	WB	256				6-45	13-00
T-6	EB	250	G	II	3	6-46	7-36
	WB	253				9-41	10-14
T-7	EB	262	G	I	5	3-55	7-56
	WB	101				6-25	7-07
T-8	EB	265	K	I	5	3-25	3-49
	WB	274				-	3-25
T-9	EB	268	G	I	4	-	7-57
	WB	271				-	9-30
T-10	EB	104	G	I	3	8-35	8-55
	WB	113				8-05	8-30
T-11	EB	106	G	IV	5	4-46	5-47
	WB	109				-	14-13
T-12	EB	116	G	III	5	12-26	12-43
	WB	119				-	8-39

(a) Bead concentrations given in Pounds per Gallon.

APPENDIX D

Statistical Analysis and Evaluation Data

Table 7

Failure Computations for Each Test Section Based on ASTM Suggested Method

(Failure in Weeks)

Test Section	Paint Type	Bead Code	Bead Conc.(a)	Failure at 3.0 for Appearance(b)	Failure at 3.0 for Durability(b)	Failure at 3.0 for Night Visibility $\bar{x}$(b)	Failure at 3.0 for Night Visibility $\bar{x}$(c)	Failure By Weighted Rating 4.0
a. District 5 - Route 50, Concrete Pavement								
T-1	B	I	5	33.32	34.14	22.42	22.30	28.06
T-2	D	I	5	32.00	33.63	21.14	20.89	26.50
T-3	D	I	4	31.98	35.70	22.50	22.33	27.62
T-4	D	I	3	33.18	35.33	21.51	21.22	26.86
T-5	D	II	5	33.35	35.62	33.33	33.01	30.64
T-6	D	II	4	34.12	35.46	29.24	29.11	29.06
T-7	D	II	3	37.52	43.39(d)	21.30	21.33	25.40
T-8	D	III	5	31.22	39.21	19.73	21.78	24.11
T-9	D	IV	5	30.91	37.25	20.00	19.71	23.66
T-10	F	I	5	28.27	34.76	10.00	11.37	19.98
b. District 5 - Route 54, Asphaltic Concrete Pavement								
T-1	F	I	5	23.50	24.72	16.71	16.56	17.82
T-2	B	I	5	50.26(d)	50.25(d)	45.28(d)	45.28(d)	39.44
T-3	D	I	5	49.67(d)	49.13(d)	56.54(d)	56.54(d)	46.19(f)
T-4	D	II	5	35.92	38.51	34.50	33.67	33.80
T-5	D	III	5	26.44	33.77	25.14	25.17	22.40
T-6	D	IV	5	23.90	29.42	25.79	26.31	20.86
c. District 6 - Route I-55, Concrete Pavement								
T-1	B	I	5	26.87	28.22	15.36	15.33	19.78
T-2	O	I	5	28.22	29.25	25.81	25.67	25.67
T-3	K	I	5	32.84	35.97(e)	6.33	6.38	15.76
T-4	G	I	5	36.39(e)	40.78(e)	29.00	29.00	29.78
T-5	G	II	5	43.16(e)	49.29(e)	38.96(e)	38.96(e)	39.84(f)
T-7	G	III	5	48.92(e)	54.54(e)	32.08	32.06	32.71
T-8	G	IV	5	27.06	28.41	21.57	21.53	21.22
d. District 6 - Route I-70, Asphaltic Concrete Pavement								
T-2	B	I	5	26.09	27.67	13.51	13.33	19.51
T-3	O	I	5	33.14	44.18(e)	11.67	10.10	25.62
T-4	G	II	5	33.65	48.37(e)	27.59	27.51	30.88
T-5	G	II	4	51.63(e)	56.41(e)	29.92	29.67	36.91(f)
T-6	G	II	3	53.92(e)	58.74(e)	27.54	27.40	33.84
T-7	G	I	5	45.94(e)	48.35(e)	27.67	27.67	31.12
T-8	K	I	5	29.21	34.66(e)	10.00	7.00	21.25
T-9	G	I	4	46.54(e)	47.83(e)	24.28	22.00	28.30
T-10	G	I	3	46.34(e)	42.81(e)	23.67	22.61	27.23
T-11	G	IV	5	53.73(e)	52.21(e)	22.20	21.58	29.37
T-12	G	III	5	82.88(e)	59.92(e)	26.20	26.11	31.39

(a) Given in Pounds per Gallon of Paint applied.
(b) Determined by interpolation between average observer test section ratings of two or three observers per observation.
(c) Determined by averaging the interpolated values between observation per observer.
(d) After 40 weeks exposure were still rated higher than 3.0. Value shown was extrapolated by regression analysis.
(e) After 34 weeks exposure were still rated higher than 3.0. Value shown was extrapolated by regression analysis.
(f) Values computed as of termination of the test did not fall below 4.0. Value shown was extrapolated by regression analysis.

Table 8

Notation for Statistical and Regression Analyses

These symbols will be used in the following analyses:

DF = Degrees of freedom
SS = Sum of squares or residuals
MS = Average mean square (SS $\div$ DF)
F = Ratio of two mean squares (two variances)
α = Probability level of significance of the test
Sig. = Significance Level
B = Glass Bead variable, type or concentration
O = Observer
W = Within cells variation
R = Residual error
X = Recorded high beam counts
Y_C = Computed night visibility rating
r^2 = Coefficient of Determination
$\sigma_{y \cdot x}$ = Standard Error of Estimate
$\overline{y} = \sum Y \div N$
$\overline{x} = \sum X \div N$
CV = Coefficient of Variation in percent = $(\sigma_{y \cdot x} \div \overline{y})100$
N = Number of observations

$k_{.01} = k^*_{.01} \sqrt{MS_R \div df}$; where df = the number of observations used to compute each mean value being compared. From Engineering Statistics, Second Edition, by Albert J. Bowker and Gerald J. Lieverman, page 386. This equation is a measure of significance for making multiple comparisons.

$k^*_{.01}$ = A percentile of the Studentized Range for the .01 level of significance.

Significant = In testing significance a value below the 5% level will be considered not significant (NS), a value between the 5% and 1% level of questionable significance (QS), a value between 1% and 0.1% level as significant (S), and a value above 0.1% as being highly significant (HS).

Table 9

Data and Analysis of Variance Tables for Paint Type Based on the ASTM Night Visibility Rating[a]

a. Route 50 - Concrete Pavement - Type I Glass Bead at 5 lbs/gal.

Data:

Obser.	Kind of Paint B	D	F
1	22.00	20.00	10.00
2	22.00	20.67	14.11
3	22.89	22.00	10.00
$\bar{X}$	22.30	20.89	11.37

Analysis of Variance Table:

Source	DF	SS	MS	F	α	Sig.
K	2	212.00	106.00	45.88	.001	HS
W	6	13.86	2.31			
Total	8	225.86	28.23			

$k_{.01} = 5.55$[b]

b. Route 54 - Asphaltic Concrete Pavement - Type I Glass Bead at 5 lbs/gal.

Data:

Obser.	Kind of Paint B	D	F
1	46.11	57.54	17.00
2	45.28	56.54	17.67
3	44.45	55.55	15.00
$\bar{X}$	45.28	56.54	16.56

Analysis of Variance Table:

Source	DF	SS	MS	F	α	Sig.
K	2	2550.83	1275.41	1060.33	.001	HS
W	6	7.22	1.20			
Total	8	2558.04	319.76			

$k_{.01} = 4.00$[b]

Table 9

Data and Analysis of Variance Tables for Paint Type Based on the ASTM Night Visibility Rating[a] (Continued)

c. Route I-55 - Concrete Pavement - Type I Glass Bead at 5 lbs/gal.

Data:

Obser.	Kind of Paint B	G	O	K
1	15.25	29.00	27.00	6.40
2	15.50	29.00	25.00	6.50
3	15.25	29.00	25.00	6.25
$\overline{X}$	15.33	29.00	25.67	6.38

Analysis of Variance Table:

Source	DF	SS	MS	F	α	Sig.
K	3	951.10	317.03	925.64	.001	HS
W	8	2.74	0.34			
Total	11	953.84	86.71			

$k_{.01} = 2.09$[b]

d. Route I-70 - Asphaltic Concrete Pavement - Type I Glass Bead at 5 lbs/gal.

Data:

Obser.	Kind of Paint B	G	O	K
1	14.00	27.67	7.00	7.00
2	13.00	27.67	11.50	7.00
3	13.00	27.67	11.80	7.00
$\overline{X}$	13.33	27.67	10.10	7.00

Analysis of Variance Table:

Source	DF	SS	MS	F	α	Sig.
K	3	751.25	250.42	132.44	.001	HS
W	8	15.13	1.89			
Total	11	766.38	69.67			

$k_{.01} = 4.92$[b]

(a) Data derived for test sections where the Type I Glass Bead was held at a constant concentration of 5 pounds per gallon of paint.

(b) The absolute difference between means must exceed this value to establish significance between variables.

Table 10

Ranking of Paint Types By Failure in Weeks and Significant Differences in Mean Failures Based On Simultaneous Comparisons[a]

a. Route 50 - Concrete Pavement - Type I Glass Bead at 5 lbs/gal.

Paint Type	Mean Failure in Weeks
B	22.30
D	20.89
F	11.37

b. Route 54 - Asphaltic Concrete Pavement - Type I Glass Bead at 5 lbs/gal.

Paint Type	Mean Failure in Weeks
D	56.54
B	45.28
F	16.56

c. Route I-55 - Concrete Pavement - Type I Glass Bead at 5 lbs/gal.

Paint Type	Mean Failure in Weeks
G	29.00
O	25.67
B	15.33
K	6.38

d. Route I-70 - Asphaltic Concrete Pavement - Type I Glass Bead at 5 lbs/gal.

Paint Type	Mean Failure in Weeks
G	27.67
B	13.33
O	10.10
K	7.00

(a) The vertical lines shown to the right of the Mean Failure connect the variables for which no claim can be made as to any difference in their behavior, at the 0.01 level.

Table 11

Data and Analysis of Variance Tables For Bead Type And Concentration Based on the ASTM Night Visibility Rating

a. Route 50 - Concrete Pavement - Paint D

Data:

	Bead Type and Concentration[a]							
Obser.	I(5)	I(4)	I(3)	II(5)	II(4)	II(3)	III(5)	IV(5)
1	20.00	22.75	20.67	32.44	28.00	21.50	20.67	19.00
2	20.67	21.50	21.50	33.00	29.67	21.50	19.00	19.00
3	22.00	22.75	21.50	33.60	29.67	21.00	20.67	21.14
$\overline{X}$	20.89	22.33	21.22	33.01	29.11	21.33	20.11	19.71

Analysis of Variance Table:

Source	DF	SS	MS	F	α	Sig.
B	7	497.59	71.08	138.57	0.001	HS
O	2	4.00	2.00	3.90	0.05	QS
R	14	7.18	0.51			
Total	23	508.77	22.12			

$k_{.01} = 2.59$[b]

b. Route 54 - Asphaltic Concrete Pavement - Paint D

Data:

	Bead Type and Concentration			
Obser.	I(5)	II(5)	III(5)	IV(5)
1	57.54	32.00	23.50	25.33
2	56.54	34.50	26.00	28.00
3	55.55	34.50	26.00	25.60
$\overline{X}$	56.54	33.67	25.17	26.31

Analysis of Variance Table:

Source	DF	SS	MS	F	α	Sig.
B	3	1912.18	637.39	421.53	0.001	HS
O	2	5.56	2.78	1.84		NS
R	6	9.07	1.51			
Total	11	1926.81	175.16			

$k_{.01} = 4.99$[b]

Table 11

Data and Analysis of Variance Tables For Bead Type And Concentration Based on the ASTM Night Visibility Rating (Continued)

c. Route I-55 - Concrete Pavement - Paint G

Data:

	Bead Type and Concentration			
Obser.	I(5)	II(5)	III(5)	IV(5)
1	29.00	39.26	31.86	21.00
2	29.00	39.26	32.33	21.58
3	29.00	38.35	32.00	22.00
$\overline{X}$	29.00	38.96	32.06	21.53

Analysis of Variance Table:

Source	DF	SS	MS	F	α	Sig.
B	3	470.04	156.68	921.10	0.001	HS
O	2	0.15	0.08	0.45		NS
R	6	1.02	0.17			
Total	11	471.21	42.84			

$k_{.01} = 1.67$ (b)

d. Route I-70 - Asphaltic Concrete Pavement - Paint G

Data:

	Bead Type and Concentration							
Obser.	I(5)	I(4)	I(3)	II(5)	II(4)	II(3)	III(5)	IV(5)
1	27.67	23.40	20.50	27.00	29.00	27.00	25.00	21.14
2	27.67	25.00	23.67	27.67	31.00	28.20	27.00	21.00
3	27.67	25.00	23.67	27.86	29.00	27.00	26.33	22.60
$\overline{X}$	27.67	24.47	22.61	27.51	29.67	27.40	26.11	21.58

Analysis of Variance Table:

Source	DF	SS	MS	F	α	Sig.
B	7	161.16	23.02	38.58	0.001	HS
O	2	7.73	3.86	6.47	0.025	QS
R	14	8.36	0.60			
Total	23	177.25	7.71			

$k_{.01} = 2.79$ (b)

(a) The values shown in parenthesis are the concentration of glass beads in pounds per gallon of paint applied.

(b) The absolute difference between means must exceed this value to establish significance between variables.

Table 12

Ranking of Bead Types and Concentrations
By Failure in Weeks and Significant Differences in
Mean Failures Based on Simultaneous Comparisons(a)

Bead Type (Conc. in lbs/gal.)	Mean Failure in Weeks
a. Route 50 - Concrete Pavement - Paint D	
Type II (5)	33.01
Type II (4)	29.11
Type I (4)	22.33
Type III (5)	21.78
Type II (3)	21.33
Type I (3)	21.22
Type I (5)	20.89
Type IV (5)	19.71
b. Route 54 - Asphaltic Concrete Pavement - Paint D	
Type I (5)	56.54
Type II (5)	33.67
Type IV (5)	26.31
Type III (5)	25.71
c. Route I-55 - Concrete Pavement - Paint G	
Type II (5)	38.96
Type III (5)	32.06
Type I (5)	29.00
Type IV (5)	21.53
d. Route I-70 - Asphaltic Concrete Pavement - Paint G	
Type II (4)	29.67
Type I (5)	27.67
Type II (5)	27.51
Type II (3)	27.40
Type III (5)	26.11
Type I (4)	24.47
Type I (3)	22.61
Type IV (5)	21.58

(a) The vertical lines shown to the right of the Mean Failure connect the variables for which no claim can be made as to any difference in their behavior, at the 0.01 level.

Figure 7 - Regression Analysis of High Beam Point Count and ASTM Night Visibility Ratings

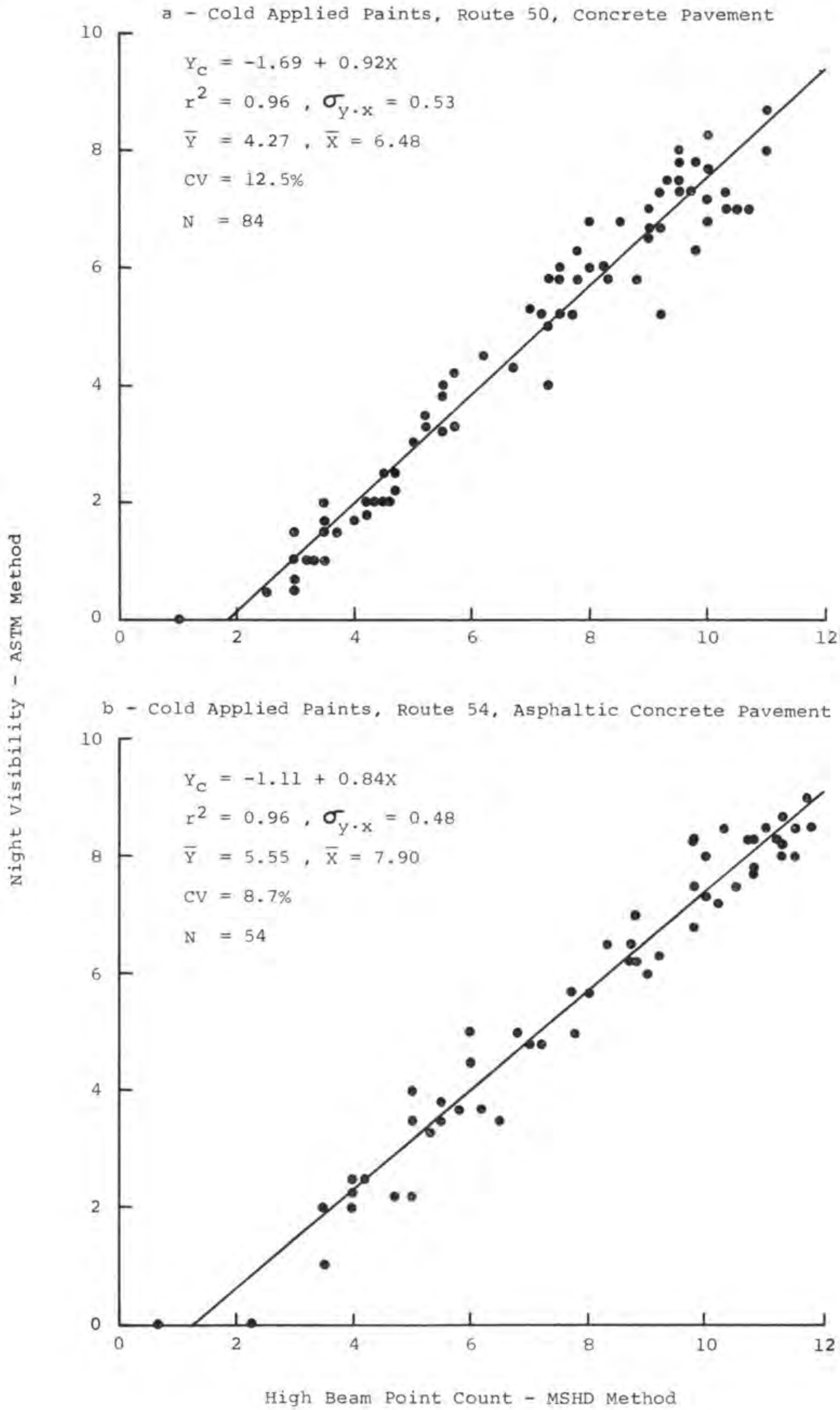
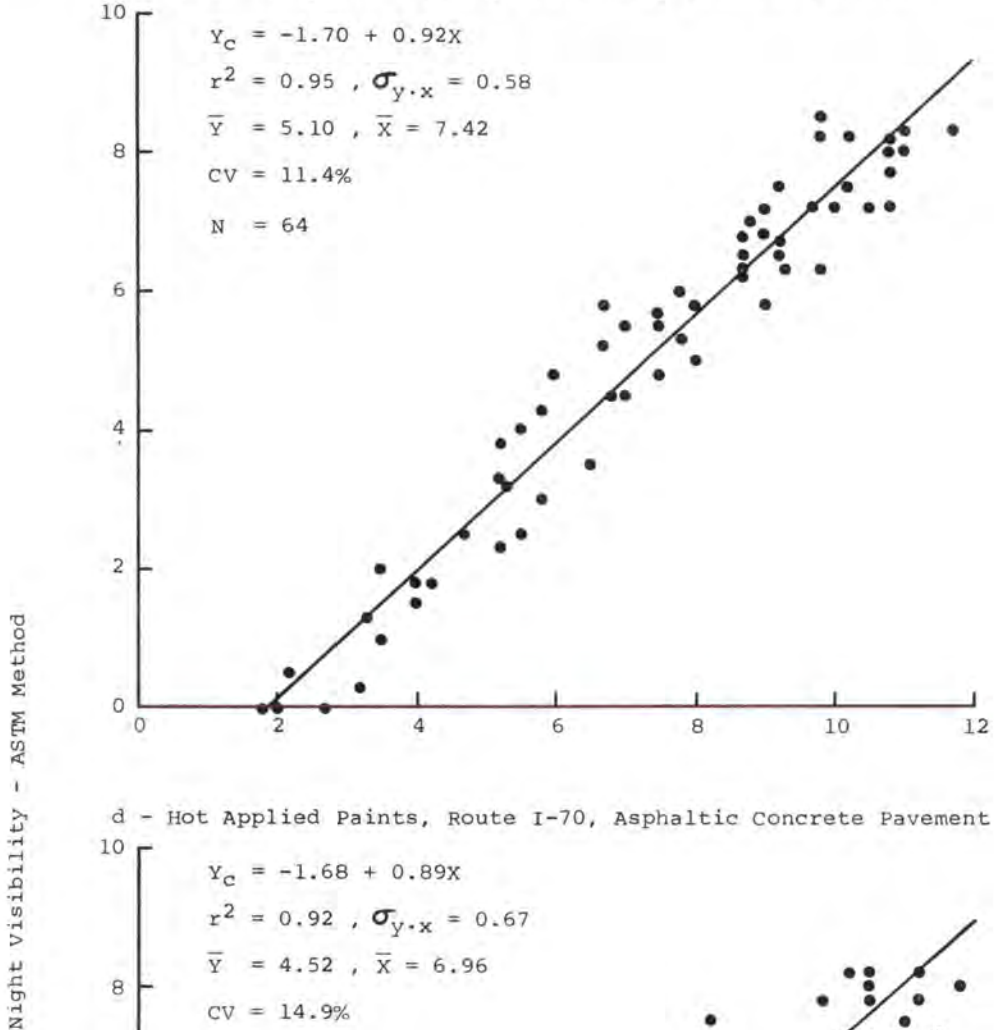


Figure 7 - Regression Analysis of High Beam Point Count and ASTM Night Visibility Ratings (Continued)

c - Hot Applied Paints, Route I-55, Concrete Pavement



d - Hot Applied Paints, Route I-70, Asphaltic Concrete Pavement

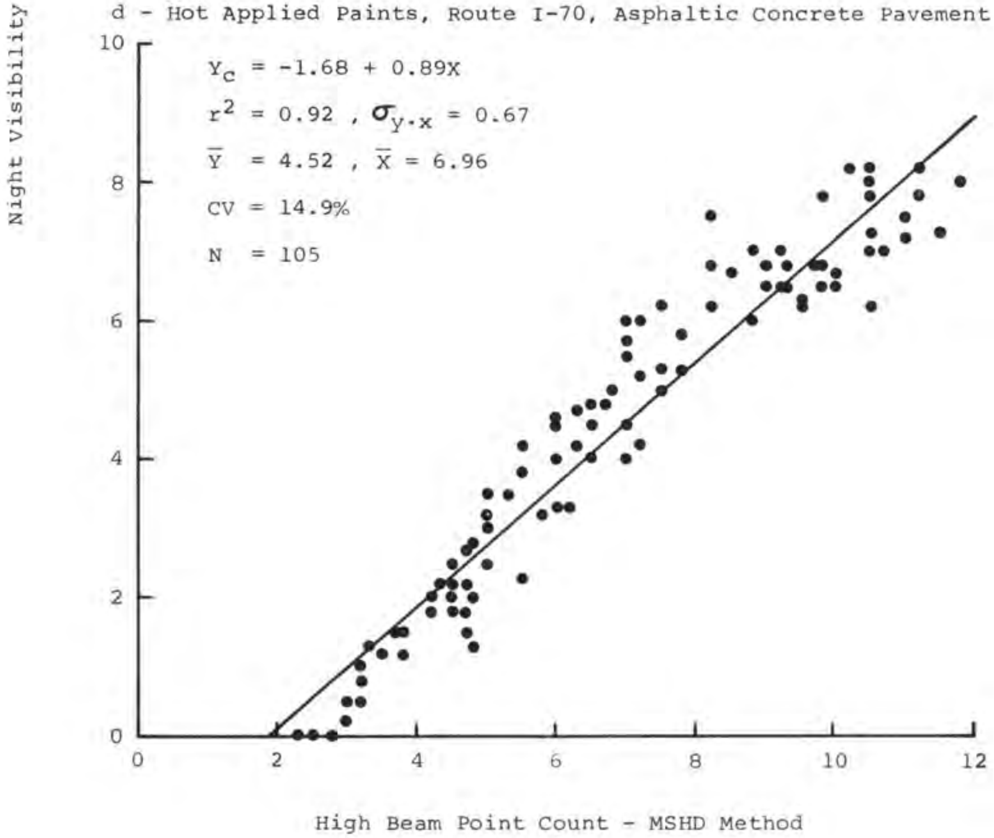


Figure 8 - Combined Regression Analysis of High Beam Point Count and ASTM Night Visibility Ratings