INTERIM REPORT NO. 1

ROADWAY LIGHTING STUDY
(Rte. 264 in Downtown Norfolk)

by

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Virginia Highway Research Council
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SUMMARY

A study of roadway lighting is currently being conducted at several locations in Virginia by using a mobile illumination recording system to obtain lighting measurements. Areas being surveyed include the I-264 interchange area in downtown Norfolk and the Shirley Highway (I-95) between the Springfield and Glebe Road interchanges, which lie south of Washington, D. C.

Interim Report No. 1 presents the results of the study of the I-264 interchange area in downtown Norfolk. The illumination in the interchange area is provided by mercury type lamps whereas the adjacent streets in downtown Norfolk are illuminated with high pressure sodium lamps. The results of the survey indicate that the average level of illumination in the interchange area is lower than that which is recommended by the ASA standards. The uniformity of the lighting is also poor and does not meet the accepted standards. By contrast, the sodium lighting in certain areas of downtown Norfolk lying adjacent to the I-264 interchange was found to provide a high quantity and quality of illumination.

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BACKGROUND

As a result of the increased use of lighting on some of Virginia's urban and suburban highways and interchanges, there is considerable interest in the quantity and quality of the roadway lighting being provided at several different locations. Moreover, the general need for lighting on some freeways located in urban areas is often questioned by highway engineers. As a result, a long-range study of the continuous freeway lighting on Rte. 95 in Northern Virginia is being conducted to evaluate the effectiveness of the lighting in reducing the traffic accident rate during the hours of darkness. In order to determine the quantity and uniformity of the lighting as it varies with time, illumination measurements are being taken on selected sections of the Shirley Highway (Rte. 95) between the Springfield and the Glebe Road interchanges. In addition, some additional study areas in Virginia will be surveyed to determine the distribution and uniformity of the illumination for some particular lighting situations.

This report deals with the first study area surveyed, which comprises the lighting at the west end of Rte. 264 in downtown Norfolk. This interchange area connects Tidewater Drive, City Hall Avenue, and Waterfront Drive with the termination of Rte. 264 in downtown Norfolk.

SITE DESCRIPTION

According to the original lighting plans, the termination of I-264 is illuminated with 7,000 and 11,000 lumen mercury lamps within the interchange area involving the aforementioned streets of downtown Norfolk. (A view of the interchange area is shown in the Appendix.) Waterfront Drive and City Hall Avenue, which are adjacent to the interchange, however, are illuminated with higher intensity high pressure sodium lamps. This arrangement results in considerable contrast between the two adjacent but different illumination systems. Whereas the I-264 interchange area is illuminated with the mercury lamps, which emit energy principally in the violet, blue, green and yellow parts of the color spectrum, the sodium lamps in the downtown area emit energy principally in the yellow and orange parts of the spectrum.[1] The differences in the apparent illumination levels and in the color of the lighting between the two systems

gives one the impression that the interchange area is poorly illuminated. It is difficult, however, to judge the level and uniformity of roadway and street lighting by visual observation. This particular location, therefore, offered the opportunity to measure and compare the illumination levels on two adjacent but different lighting systems.

PURPOSE

Although roadway lighting installations are designed to provide a certain quantity and quality of illumination, it is impossible to tell if the objectives have been attained without actual lighting measurements. One of the objectives of the overall roadway lighting study is to determine the quantity and uniformity of some lighting installations currently in service. Data on these installations are being obtained in the form of field measurements of the illumination levels at the sites. The Rte. 264 site is one such study area that has been surveyed. Hopefully, the results of these type surveys will be useful as a guide for the selection and design of future lighting installations or for the improvement of existing systems.

INSTRUMENTATION

Due to the hazards associated with collecting roadway illumination measurements under traffic conditions after dark, a mobile illumination recording system has been developed. This system, with some modification, is modeled after one developed earlier by Wenner[2] and was assembled for the Research Council by the Cottrell Electronics Corporation of Richmond. Similar instrumentation has been used in Illinois.[3] The equipment can be mounted in a vehicle and is designed to record illumination levels on a continuous strip chart as the vehicle is driven on the roadway.

Basically, the instrumentation is composed of dual photoelectric color and cosine corrected light sensors which can be mounted on the roof of a standard size automobile (Figure 1). Signals from the photocells are amplified and then recorded by a direct inking, continuous strip chart recorder. The small amount of power required for the system is supplied by a bank of 12 volt D. C. batteries.

The photocells are calibrated by using a known level of illumination as a reference. The reference level of illumination can be established from a variable control lamp that can be set at the desired footcandle level by use of a Vactec Photometer.

The recorder is driven mechanically by a linkage that couples the strip chart drive to the linear speed of the vehicle. Thus, the strip chart drive is synchronized with the speed of the vehicle such that the major divisions on the chart paper are proportional to the distance traveled on the roadway. In the longitudinal (distance) direction four different scale factors can be applied to the strip chart recorder by changing the drive gear ratios. The equipment can be calibrated to record on a variety of footcandle scales in the vertical direction on the strip chart paper. In

addition, the calibrated scale factor can be increased by a multiple of five with a direct switching control. Typical strip chart records are shown later in Figures 2-4.

Figure 1. Mobile illumination recording instrumentation with photocells mounted on the roof of the vehicle.

ILLUMINATION MEASUREMENTS

Illumination measurements were taken on both the westbound and eastbound lanes of I-264. Each of these lanes crosses Main Street and terminates onto Waterfront Drive. In addition, measurements were taken on the westbound ramp off I-264, which terminates at City Hall Avenue; and on the ramp connections between Tidewater Drive and the eastbound lane of I-264, which terminates at Waterfront Drive. Due to the large amount of driving required to turn the vehicle around for each test run, data were not collected on one ramp that connects Tidewater Drive with City Hall Avenue. The considerable amount of data taken, however, adequately define the illumination levels existing in the interchange area.

Measurements were also taken in the downtown area on Waterfront Drive, City Hall Avenue, and several other streets during the data collection process. These sections, as indicated earlier, have a different lighting system than that of I-264.

Three test runs were made through each of the lanes, ramps, and streets on which measurements were taken. These runs covered the right, center and left lanes of the roadway. Since the dual photocells are mounted on the car roof and spaced 4 ft. apart, each test run actually represents the average footcandles of illumination taken at two lateral positions along the roadway. It should be noted, therefore, that all of the data collected represent illumination levels taken at a height of approximately 5 ft. above the pavement surface, whereas lighting is normally designed for illumination provided on the pavement surface. Since illumination varies inversely with the square of the distance from the light source,[4] the quantity of light measured in horizontal fc. on the pavement would differ in most instances from those values reported herein. The difference between the illumination on the roof of the car and that on the roadway surface is greatest directly beneath the light source and decreases as the distance between the luminaire and the point under consideration increases. For example, the horizontal fc. level at 38ft. longitudinal distance from a luminaire mounted at 30 ft. height is approximately the same on the pavement surface as that 5 ft. vertically above the surface. At points beyond 38 ft. the horizontal fc. values measured are slightly lower than those on the pavement surface. The overall uniformity, average order of magnitude, and general distribution of the illumination, therefore, are generally representative of those at the pavement surface, although the data are recorded in a horizontal plane 5 ft. above the pavement.

Depending to some degree on the footcandle scale factor being used, it is difficult to accurately estimate very low footcandle values from the strip chart data. In order to obtain more accurate data in the 0.01 to 0.10 footcandle range, spot readings were taken manually in selected areas where low levels of illumination were indicated on the data charts. This is a standard procedure that is accomplished by using the calibration standard Vactec Photometer. The lower readings are used primarily in calculating the uniformity ratios discussed in more detail later.

RESULTS

Mercury Lamps

On both the eastbound and westbound lanes of Rte. 264 the maximum level of illumination provided by the mercury lamps was on the order of 1.9 footcandles (fc), and values of this order of magnitude were obtained only at several points directly under the luminaires and in the right-hand driving lanes. In most cases the peak values measured in these lanes were on the order of 1.5 fc or less, with many being less than 1 fc. The highest peak values were measured on the ramps connecting Tidewater Drive and Waterfront Drive and on the ramp connecting the eastbound lane with City Hall Avenue. At several points directly beneath a few of the ramp luminaires peak values on the order of 1.9 to 2.3 fc were recorded. Since all values were measured from the roof of the instrumentation vehicle, the peak level of illumination on the pavement surface would be lower.

Several lamps were burnt out when the data were collected in September 1973. In those regions which would ordinarily be served by these particular luminaires the illumination on the pavement was, for all practical purposes, nil. In areas served by operative luminaires the lowest levels of illumination usually occurred, as would be expected, at points furthest from the light sources. However, very low levels were recorded in some areas that are generally located midway between the average 125-150 ft. spacing of the luminaires. In these particular regions readings taken manually were on the order of 0.04 to 0.12 fc. The peak values measured beneath the luminaires that are nearest the darker regions were on the order of 1 to 1.5 fc. The rather low peak values alone tend to indicate a generally low overall level of illumination or a need for relamping.

As an indication of the levels of illumination recorded in the interchange area, the right-hand and left-hand lanes (RHL and LHL) of the WBL are shown in Figure 2. The direction of travel on the data chart is from right to left with each horizontal division representing approximately 35.2 ft. of distance traveled on the roadway. The vertical scale on the chart is in footcandles with each major division equal to 1 fc. Thus, the chart indicates the footcandles of illumination recorded at any point along the roadway in the lane being traversed.

Beginning at the east end of the interchange, the first and second lamps on the right side of the WBL were out. Therefore, the first operative luminarie was on the left side and registered a peak value of 0.4 fc in the RHL and 0.8 fc in the LHL. These values can be located in Figure 2 as the first peaks from the right end of the data chart for each respective lane. Between the first three lights that were operative the illumination was virtually zero in both driving lanes over a length of 75-100 ft. of roadway. This was largely due to the right side lights being out. The peak values under the first operative luminaires were, as indicated on the data charts of Figure 2, higher in the LHL than in the RHL as would be expected. Beyond this point, however, all the luminaires except one are installed on the right side of the WBL and the average illumination levels and the peak values (except one) are higher in the RHL since this lane is closer to the light sources. In the RHL the highest peak value was approximately 1.9 fc, whereas the low levels in between the luminaires were on the order of 0.1 to 0.2 fc. In the LHL at regions furthest from the light sources the illumination level is more uniform but quite low with an average range of approximately 0.3 fc. This fact is indicated on the left end of the data chart for the LHL.

Using typical data charts such as those demonstrated in Figure 2 and a reference starting point for distance measurements, the fc values for each test run can be plotted on a plan view of the roadway and lines of equal fc levels (isofootcandle diagrams) constructed. An isofootcandle diagram was developed from the measurements taken in the interchange area and is included in the Appendix. In general, the diagram indicates poor lighting in regions between the luminaires, which appears to be due to some of the lamps being out and to the relatively low candlepower of the light sources.

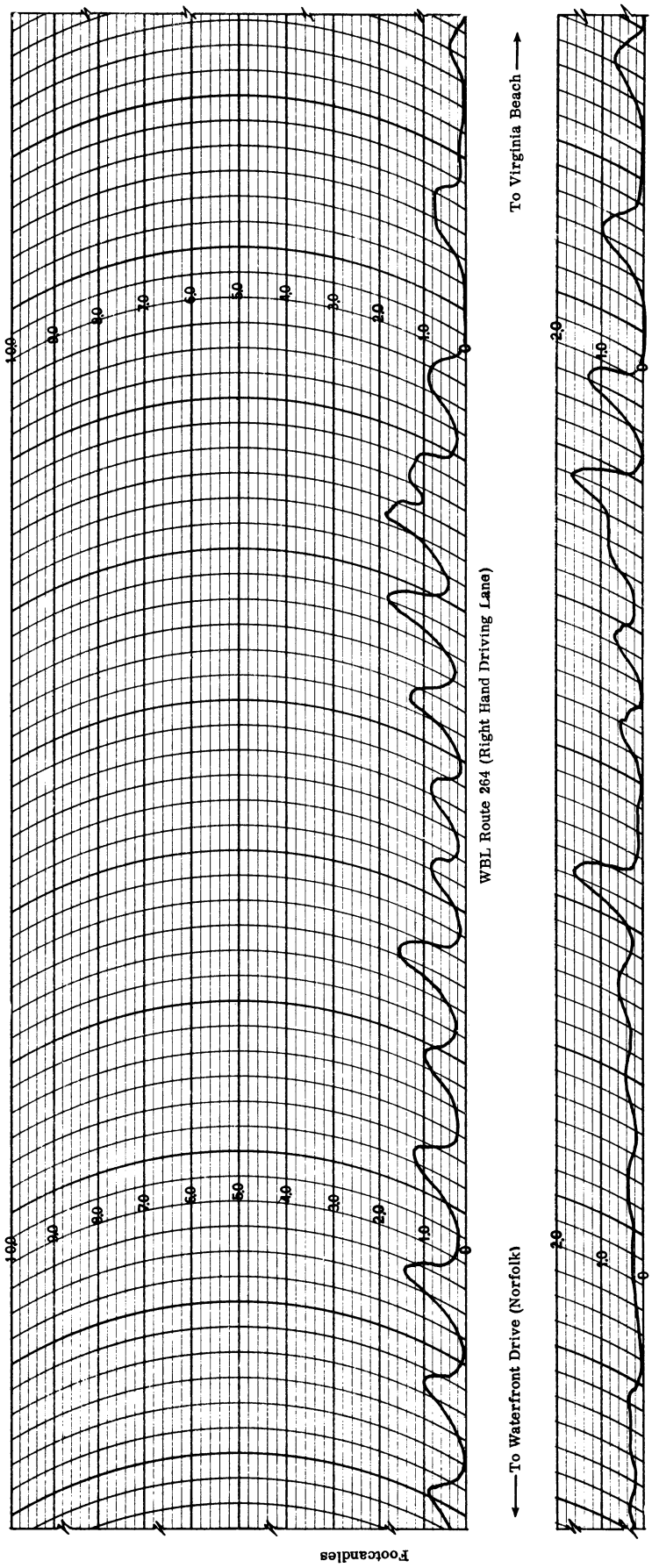

Figure 2. Typical strip chart footcandle vs. distance data for the right- and left-hand driving lanes of the WBL of I-264.

Sodium Lamps

Peak illumination levels in the downtown Norfolk area, which is lit by high pressure sodium lamps, were on the order of 12-15 fc at many points. At points of minimum illumination seldom do the fc levels go below 1 fc, with the lowest values recorded being above 0.6 fc. A typical data chart for the center of the EBL of Waterfront Drive is shown in Figure 3. Due to the higher fc levels being measured, the vertical scale on this data chart is twice that of the charts shown in Figure 2. Consequently, each major division is equal to 2 fc but the horizontal distance scale factor is the same as previously. From a review of the data in Figure 3 it can be seen that several peak values are in the 15 fc range. The lowest readings were just slightly less than 1 fc but these were in two areas where the lamps were inoperative. In regions where all the lights were operative, the lowest illumination levels in the center of the lane were 2 fc and above. Thus, the lowest levels of illumination on the streets in the downtown Norfolk areas are, for the most part, higher than the peak values measured in the Rte. 264 interchange area.

Comparison of the Sodium and Mercury Lighting Systems

The contrast between the two adjacent lighting systems is best indicated by the data shown in Figure 4. These data show the illumination levels in the right and center lanes of the WBL of I-264 as they terminate onto Waterfront Drive. The differences between the lighting on the interchange and that on the adjacent areas in downtown Norfolk are considerable. Within a distance of approximately 275 ft. the level of illumination changes from a peak of 1 fc to approximately zero then up to 7 fc in the RHL, and from 0.60 fc to approximately zero then up to 12 fc in the center lane. The sodium lighting provides a higher level of illumination in the center lane than in the RHL whereas the opposite is true for the mercury luminaires on the interchange lanes, which suggests that the higher luminaire mounting heights and greater output of the sodium lighting system are much more effective in providing light to areas more distant from the light sources. With respect to the center lanes, however, the sodium luminaires are closer laterally than are the mercury luminaires.

Uniformity and Average Illumination Levels

One of the measures of the quality of a lighting system is the uniformity ratio, which is defined as the ratio of the average to the minimum fc of illumination on a given area. The uniformity ratio is an important lighting factor since high ratios indicate substantial variations in the level of illumination. Frequent variations in illumination would in turn require frequent changes in the eye adaptation mechanism, which is too slow to react to rapidly changing visual conditions. Uniformity can be determined from the data charts or from the isofootcandle diagrams by first determining the average level of illumination on a given area. If the data charts are used, the area bounded by the continuous curve and the base line is determined by planimeter and converted to units of fc-ft. by using the appropriate scale factor. For typical test runs such as those shown in Figure 2, for example, there are 312.89 fc-ft. per square inch of area bounded by the continuous data curve and the zero base line. Thus, by multiplying the

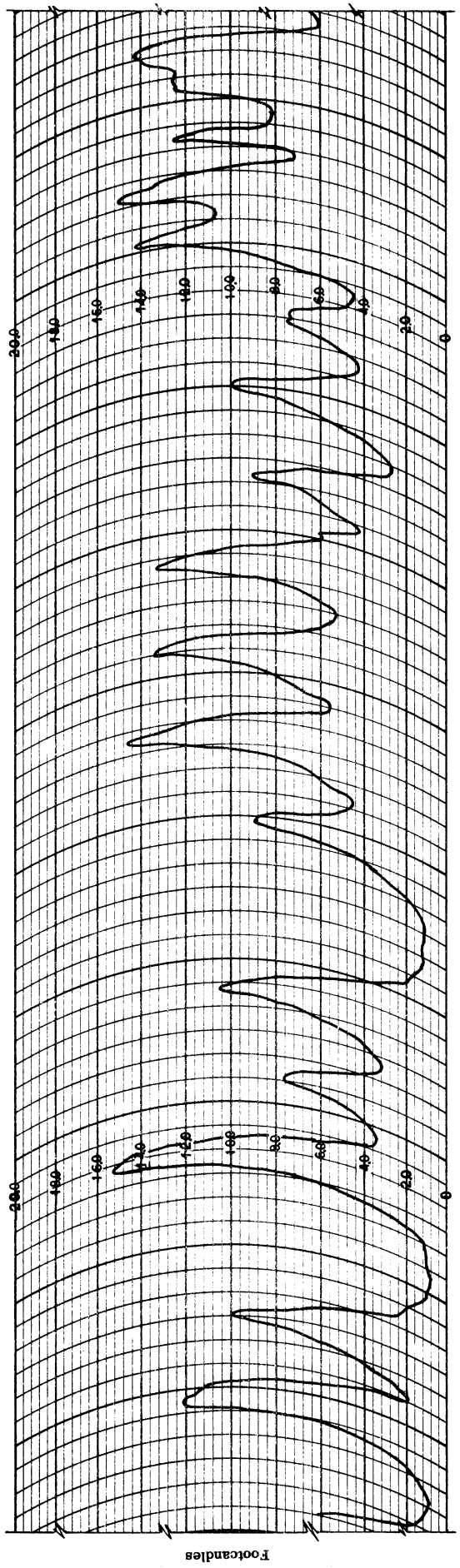

Figure 3. Illumination provided by high pressure sodium lamps in downtown Norfolk, (center of the EBL of Waterfront Drive).

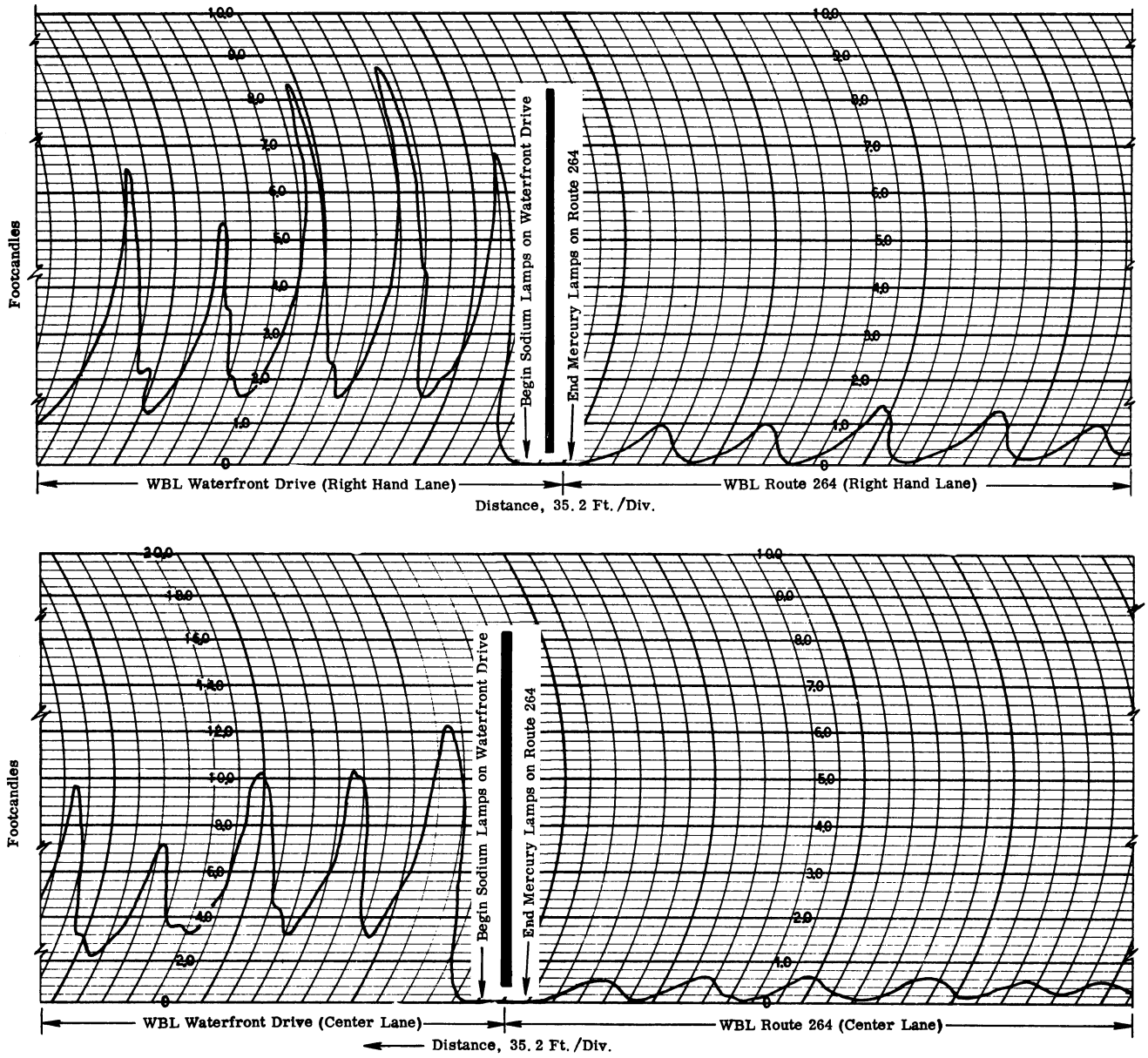

Figure 4. Contrasting illumination levels in the transition area between the mercury lighting on I-264 and the sodium lighting on Waterfront Drive. (Note the difference in the fc. scale factor for the sodium lights in the RHL as opposed to the center lane.)

scale factor by the area in square inches and dividing by the length in feet, the average level of illumination in fc can be obtained for each test run or lane. If all three lanes are considered, an overall average can be determined from the lane averages. The average fc values are then divided by a typical minimum value for a given area to determine the uniformity ratio.

Typical average fc values and uniformity ratios for the WBL of I-264 and the EBL of Waterfront Drive are given in Table 1. In the WBL of I-264, the average lane horizontal footcandles of illumination range from 0.61 in the LHL to 0.76 in the RHL. It should be noted that the LHL average is higher than might be expected because some of the luminaires are mounted on the left side on the eastern half of the WBL lane. Referring to Figure 2, it can be seen that the level of illumination on the western half of the WBL lane would average only about half of the value given in Table 1 since the luminaires are mounted on the right side of the lane. Therefore, the values given in Table 1 for the WBL of I-264 are somewhat deceptive and must be viewed in terms of the total length of the WBL. At any rate, the overall average for all three lanes of the WBL was 0.68 fc. Since the recommended average horizontal footcandles for urban interchanges is 2 fc[4], the existing illumination level could be considered inadequate. If the commonly used value of 0.6 fc average maintained illumination for freeways is accepted as the criterion, however, the average level of 0.68 fc might be considered acceptable. Due to the urban location of this particular interchange the 2 fc level would appear to be the more appropriate criterion.

Table 1

Average Illumination and Uniformity Ratios

Designation	Average Lane Footcandles			Overall Average Footcandles	Average Uniformity Ratio
	RHL	CL	LHL		
WBL I-264	0.76	0.68	0.61	0.68	11.6:1
EBL, Waterfront Dr.	4.18	7.88	5.92	5.99	2.7:1

Considering the average uniformity of lighting on the WBL the ratio of 11.6:1 would be considered inadequate by all recommended standards. Ketvirtis[6], for example, recommends a uniformity ratio of 2.5:1 for a roadway of this type and location. It should be noted in this instance that the uniformity ratio shown is lower than it could have been since the minimum values were taken at points where some illumination existed, i.e., areas where lamps were not operative were avoided. In addition, the value shown is an average for all three driving lanes and does not indicate the very worst uniformity ratio that could be determined. Obviously, under the circumstances that have been described, a uniformity ratio approaching infinity could be reported. Consequently, the 11.6:1 value reported in Table 1 is considered a reasonable evaluation of the designated area.

On the EBL of Waterfront Drive, the average lane horizontal footcandles range from 4.18 in the RHL to 7.88 in the center lane, with an overall average of 5.99 fc. These levels exceed the 2 fc American Standards Association (ASA) recommended level for roadways in downtown areas by a substantial margin.[5] The average uniformity ratio of 2.7:1 is very close to the 2.5:1 recommended by Ketvirtis,[6] and better than the commonly used design value of 3.0:1. Comparable results were obtained on other streets in the downtown area. Thus, the sodium lighting on Waterfront Drive and in other adjacent areas in downtown Norfolk could be considered excellent based on these criteria.

CONCLUSIONS

It should be restated that the purpose of the lighting survey reported herein and in a future interim report is to supply information on existing systems that may be useful in the planning and design of future systems. The data presented herein indicate that the lighting system on the I-264 interchange in downtown Norfolk is inadequate by all the commonly recommended design standards for average horizontal footcandles and uniformity of illumination.

It can be concluded from the results that the lumen output and the mounting height of the existing mercury type luminaires are too low in relation to the spacing between the luminaires to provide the recommended average maintained illumination level and uniformity ratio for this particular interchange location. Increasing the lumen output of the lamps alone, however, could possibly correct the inadequacies and should be investigated. The abrupt transition from the low level of illumination developed by the mercury lighting on the I-264 interchange to the higher illumination level sodium lighting on Waterfront Drive also presents an undesirable situation which might be improved by increasing the level of illumination in that region.

On several streets surveyed in the downtown Norfolk area the average horizontal footcandles and uniformity of illumination provided by the high pressure sodium lighting meet the recommended standards. The sodium lighting in these areas provides a high quantity and quality of illumination.

RECOMMENDATION

The possibility of converting the mercury luminaires in the I-264 interchange area to the high pressure sodium type luminaires should be investigated. If such a conversion could be economically accomplished the level of illumination could be increased, the uniformity of the lighting improved, and the lighting system made to be more compatible with that existing in the adjacent areas of downtown Norfolk. Since the efficiency of the high pressure sodium lamp is higher than that of the mercury vapor lamp, roughly twice as much illumination could be provided with no increase in power consumption if sodium luminaires were employed.

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APPENDIX

ISOFOOTCANDLE DIAGRAM

Figure A-1 represents an isofootcandle diagram for the I-264 interchange in downtown Norfolk. The interchange is illuminated by 11,000 and 7,000 lumen mercury luminaires.

The data used to construct the diagram were obtained from strip charts typical of those shown in Figure 2 of this report. Since it is difficult, for reasons described earlier, to read very low levels of illumination from the data charts, it is probable that some of the zero footcandle lines shown on the diagram actually have very low levels of illumination. Random measurements taken manually with a highly sensitive photometer, however, indicate that some points within these areas have footcandle values of only 0.05 or less.