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LIGHTING STUDIES AT TEXAS CITY WYE

in cooperation with the
Department of Commerce
Bureau of Public Roads

PROGRESS REPORT
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LIGHTING STUDIES AT TEXAS CITY WYE

By

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LIGHTING STUDIES AT TEXAS CITY WYE
(Intersection of Routes 3, 146, and 197 Near Texas City, Texas)

Introduction

The Texas City Interchange on Route 3 from Houston to Galveston was the subject of lighting research. The work was sponsored by the Texas Transportation Institute. The intersection was experimentally lighted with several arrangements of overhead luminaires so that many combinations of spacing and mounting heights could be employed. The visual effects of various combinations of lights from two of the approach directions are discussed in this publication.

The study considered the potential areas of conflict for a driver when approaching and passing through the intersection from either of two directions, vis., from Galveston or from Texas City. Evaluation of the approaches from Galveston and Texas City were made using the continuous, intermediate and minimum spacings of luminaires on 30- to 45-foot mounting heights in clear, dry weather.

At each location and for each lighting condition data were taken on:

1. The horizontal and vertical roadway illumination distribution.
2. The roadway brightness distribution.
3. The brightness and location of glare sources.
4. The brightness of at least 5 targets and their background at various locations.
5. The relative visibility of at least 5 targets.
6. The transition brightnesses of the roadway for several hundred feet ahead.
7. The roadway reflectance characteristics.
8. Other elements of visual guidance that may be present.

The analysis to consider the data for each lighting arrangement and to develop a comparative rating system was based upon:

a. The adequacy of the brightness pattern to reveal objects and to develop guidance information.
b. The variation in relative visibility within the central field of view.
c. The transition of brightness patterns from one zone to another.
d. The glare effect of the luminaires.
e. The magnitude of the driver's eye adaption and its rate of change.

Description of Test Site

The intersection is shown in plan view in Figure 1. The two approach directions are shown by the arrows on the above figure at locations A (Galveston approach) and B (Texas City Approach). The location and numbers of the lighting units are shown as well as the measuring stations for illumination and brightness readings. A series of photographs showing the daytime appearance of the two approach directions from stations approximately 100 feet apart are shown in Figures 2 and 3.

It may be noted that the area is almost flat and that from a normal driver's eye height above the road the perspective view of the intersection does not change very fast from 700 to 400 feet away. As the distance decreases to less than 400 feet the view changes much more rapidly. Within approximately 400 feet to the divider island the driver still has several seconds of decision and reaction time available before he has to begin his control operation through the maze of distribution roadways.

The preliminary studies of the intersection both by day and night indicated that for direction guidance most of the significant information should be available to a driver about 300 to 400 feet from the critical area in either approach direction. Most of the vehicles travel at moderate to high speeds. There are very few slow moving vehicles. The operating conditions dictated that an observation point should be used that was approximately 200 feet ahead of the first light in both the Galveston and Texas City approach directions which would locate the driver about 300 feet from the critical maneuvering area.

The Galveston Approach roadway is paved up to the first railway crossing with an asphaltic concrete material using relatively coarse aggregate. Beyond this point the roadway is concrete. Photographs of the asphaltic roadway surface between lights 7 and 8 are shown in Figure 17. This roadway is relatively new and was reported to have been laid 3 or 4 months prior to the lighting tests. Specific details of the surface reflection characteristics at Station 315 are given in the curves of Figure 18.

The Texas City Approach roadway is paved with concrete up to the second railway crossing. Beyond this point the roadway is asphaltic concrete. Photographs of the roadway near light 10 are shown in Figure 19. This roadway is quite old (20 years or more) and has been patched and the cracks have been filled many times. Specific details of the surface reflection characteristics at Station 1301 are given in the curves of Figure 20.

The daytime photographs show that there is normal contrast between the roadway foreground and the sky. The horizon is a primary reference throughout all of the daytime scenes. The other key elements in the visual scene are the skeletal lines forming the edges of the roadway, the edges of the shoulders, the painted lane lines, and the edges of the islands as they develop during the approach.

The other elements in the central field are mostly vertical in dimension and contribute little to the guidance pattern. The poles may actually detract since they form a pattern within which the driver must find the information and direction signs and other shapes such as railroad signals. The features associated with signing are very important in the over-all driving problem but they are not the subject of this investigation. The signing of intersections and the possible interference caused by advertising signs is a major research subject that is being studied separately.

The berm and surrounding areas are shown in the photographs to be sufficiently different in texture and reflectance from the roadway and islands so that good daytime contrast is available even on days having relatively low sky brightness. It may be noted that during daytime the surfaces forming the principal shapes in the scene are all quite uniform in brightness. This aspect of the scene holds for as far as one can see down the roadway. The uniformity of brightnesses in the daytime scene is one of its distinctive features and is one of the major differences between day and night seeing problems.

The nighttime scene is very different from the daytime scene and can be changed very greatly by the fixed lighting and by vehicle mounted lights. Aside from the tremendous reduction in the brightnesses of the principal areas at night there are other distinct differences. For instance, at night the sky brightness reverses from light to dark and the distinct horizon disappears. Distances become deceptive because of the lack of perceptible continuity of the surround. The familiar daytime lineal patterns are frequently not distinct at night and may be lost altogether in a series of bright splotches. Almost invariably at night one finds a pattern of extremely bright overhead sources distributed in a very dark surround. These may constitute an annoying and disabling source of glare. The photographs of the two approach directions used in the study are shown in the daytime and at night in Figures 4 to 15. The visual differences in pattern between the day and night scene are very apparent.

In all cases one can note the great reduction in the scope of the visual field at night compared to the day scene. Some horizon information is still present at night due to the distant industrial lights, but the extent of the horizon information is greatly reduced. For some lighting conditions, the foreground is not tied in with the more distant background, thus leaving an area of uncertainty and discontinuity. Also where the lighting is not properly distributed, the pools of brightness under each source may not develop a meaningful brightness pattern.

In all of the lighting arrangements of this report, the overhead luminaire brightnesses are several thousand times the roadway brightnesses. These bright sources have a seriously deleterious effect on visual conditions on the roadway. The nature and extent of the glare problem will be treated in a later section.

The lighting of the intersection is provided by pole mounted mercury vapor lights arranged as shown in Figure 1. The legend in Figure 1 shows the lights on both 30- and 45-foot mounting heights. Each light can be switched separately. All of the lamp and luminaires are the same, namely:

Lamps:	Kenrad, EH-1 Mercury Vapor, 400 W, 21,000 lumen, clear bulb.
Luminaires:	Westinghouse, OV-25, E 11-B1, Type III, with built-in voltage regulator. The manufacturer's data sheets showing dimensions and light distribution are shown in Appendix I.

TEST PROCEDURES AND RESULTS

Illumination Measurements

The roadway was laid out in a pattern of test stations approximately 20 feet apart in longitudinal spacings with the first observation station approximately 200 feet ahead of the first lamp. The key roadway areas were included for illumination measurements as may be noted on the layout drawing, Figure 1. All of the data are given in Appendix II. At each station the horizontal and vertical illumination was measured with a cosine corrected meter that was calibrated before and after the tests using a National Bureau of Standards reference lamp. Meter corrections were applied to account for the color of the mercury light sources.

Illumination measurements on roadways at night are difficult to make with a high degree of precision due to a number of factors. The lighting levels are generally low and are in the order of 0.01 to 3.0 lumens/ft^2 (foot candles). Thus a high output photo cell and a precision microammeter suitable for field use are necessary. A Greiback microammeter, model 510, with ranges from 10μa to 100 ma full scale was used with a special selenium photocell having cosine correction and approximate color correction. The photocell has a temperature coefficient that requires compensation and the mercury lights make a special calibration for color necessary. Considering all of the factors including the slight nonlinearity of the electrical circuit on the most sensitive ranges, the accuracy of the illumination measurements is estimated at ±10% for the standard deviation.

The horizontal illumination measurements were made with the photocell surface parallel to the plane of the roadway. Thus the values reported are for the normal component to the road surface and may be slightly different from a true horizontal reading due to the crown of the road or to minor surface irregularities. The error due to this cause would be very small and was considered negligible.

The vertical illumination measurements were made with the plane of the photocell at right angles to the roadway. Three orientations of the cell were used, (1) facing toward the nearside curb, (toward the right, looking at the intersection) (2) facing toward the intersection in the direction of traffic and (3) facing toward the farside curb (toward the left).

Horizontal Illumination Measurements

The horizontal illumination measurements for each approach direction and for each lighting condition are summarized in the following table. The complete data are given in Appendix II.

HORIZONTAL ILLUMINATION MEASUREMENTS

GALVESTON APPROACH

Lighting Condition M. H.	Spacing	E * Average	E Minimum	E Maximum	Ratio E Maximum / E Minimum	Ratio E Maximum / E Average
30 ft	continuous	0.80	0.05	4.78	90	6.0
30 ft	intermediate	0.44	0.01	3.49	349	8.0
30 ft	minimum	0.37	0.01	3.42	342	9.2
45 ft	intermediate	0.39	0.02	1.59	80	4.1
45 ft	minimum	0.30	0.01	1.39	139	4.6

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30 ft	continuous	0.84	0.04	4.74	118	5.6
30 ft	intermediate	0.46	0.01	4.55	455	9.9
30 ft	minimum	0.43	0.01	4.55	455	10.5
45 ft	intermediate	0.30	0.01	1.10	110	3.7
45 ft	minimum	0.30	0.01	1.10	110	3.7

* The roadway area considered in calculating the average illumination and in selecting the minimum and maximum values was from approximately 100 ft to approximately 500 ft ahead of the observer station. Measurement values were interpolated and extrapolated where necessary to avoid non-realistic weighting of the average by either the high or the low values.

Vertical Illumination Measurements

The vertical illumination measurements show the ability of the system to indicate objects on or above the roadway. The vertical components of the lighting are partially revealed by the three vertical illumination readings that were made. The modelling effect on objects above the roadway and the highlights and shadows are governed by the relative distribution of the vertical illumination. Detail values of all of the measurements are given in Appendix II.

Vertical illumination measurements are not normally reported for roadway lighting systems and therefore these data are treated, analysed and presented in this report in the author's own format. The values are mostly useful as individual readings at a given point since they reveal something about the directional luminous flux incident on objects above the roadway. The individual data for each lighting system at each station as given in Appendix II should be reviewed for conditions at a specific location.

Relationships can be developed for the vertical illumination components that have significance. The average vertical illumination in the direction of traffic gives an indication of the direct light available on object with surfaces more or less perpendicular to the direction of traffic flow. The average vertical illumination from the right or left side will give a measure of the highlights and the modelling available. These measurements are designated E_{ve} (facing east) and E_{vw} (facing west).

Modelling is the effect created by directional light that aids in recognition of form and shape by developing texture and giving nonuniform brightness patterns to objects; thereby helping to create a three-dimensional impression. For this report the over-all modelling factor will be taken as the ratio of the maximum to the minimum vertical illumination.

The averages are computed for the same area as used for the average horizontal illumination, viz., 100 to 500 feet ahead of the observer station.

The average data for each lighting condition are tabulated on the next page.

VERTICAL ILLUMINATION MEASUREMENTS
(in foot candles)

GALVESTON APPROACH

Lighting Condition M. H.	Lighting Condition Spacing	Average Vertical Illumination Traffic Direction E_{vt}	Average Vertical Illumination East E_{ve}	Average Vertical Illumination West E_{vw}	Modelling Factor $\frac{E_{maximum}}{E_{minimum}}$	Average Vertical Illumination All Directions E_v
30 ft	continuous	0.36 fc	0.33 fc	0.19 fc	1.8 fc	0.29
30 ft	intermediate	0.10	0.07	0.22	3.1	0.13
30 ft	minimum	0.09	0.07	0.19	2.7	0.12
45 ft	intermediate	0.15	0.23	0.18	1.5	0.19
45 ft	minimum	0.14	0.19	0.11	1.7	0.15

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Lighting Condition M. H.	Lighting Condition Spacing	Average Vertical Illumination Traffic Direction E_{vt}	Average Vertical Illumination East E_{ve}	Average Vertical Illumination West E_{vw}	Modelling Factor $\frac{E_{maximum}}{E_{minimum}}$	Average Vertical Illumination All Directions E_v
30 ft	continuous	0.54	0.08	0.54	6.8	0.39
30 ft	intermediate	0.37	0.04	0.19	9.0	0.20
30 ft	minimum	0.32	0.04	0.19	8.0	0.18
45 ft	intermediate	0.23	0.03	0.58	19.0	0.28
45 ft	minimum	0.22	0.03	0.55	18.0	0.27

E_{ve} = vertical illumination--photocell facing east

E_{vt} = vertical illumination--photocell facing traffic direction

E_{vw} = vertical illumination--photocell facing west

ROADWAY BRIGHTNESS MEASUREMENTS

Roadway brightnesses were measured for each lighting condition and approach direction at a station A and B shown in Figure 1, approximately 200 feet ahead of the first light in the center of the outside (right) traffic lane using a meter height of 48 inches. The instrument was a Pritchard spectra brightness meter using a 6-minute aperture. A reference calibrator was used before and after each series of measurements to check the instrument. The instrument has a color correcting filter which adjusts its response to approximately the visual response function. An additional correction was applied to bring the field measurements into agreement with laboratory values.

The complete data for the brightness measurements are given in Appendix II. The data are shown visually on the photos in Figures 4 to 15 for all of the test conditions. The photographs give a pictorial view that is helpful in visualizing each scene but it must be realized that even with the special techniques that were used for these photographs, the negatives and the printing paper have a very restricted range of densities and reflectances. This limits the contrast in the prints to far less than can be measured or accommodated by an eye at the actual scene. Therefore the numerical brightness values should be studied carefully in analyzing the scenes.

The brightness data are summarized in the following table. The average brightness values were computed to include the roadway surface from approximately 50 to 400 feet ahead of the observer. The adaptation brightness was computed as the approximate average brightness within a conical solid angle having an apex angle of 30°. The adaptation brightness measurement technique has not been standardized by any recognized national or international organization, therefore the above is an arbitrary method based upon the writer's experience. No special weighting function was used for the brightnesses at different parts of the field. The total flux within a large central cone is probably as good a measure of eye adaptation level as any other single number.

This statement is at variance with some research investigators who have used location indices for performance and comfort effects. However, the average brightness over a 30° cone angle is considered valid for roadway studies because of the brightness pattern and the shielding that occurs with a driver sitting inside a vehicle. The state of the art does not justify an attempt to use a complex weighting function on the brightnesses at various locations in the field of view for purposes of determining the adaptation level under roadway conditions.

BRIGHTNESS MEASUREMENTS

GALVESTON APPROACH

Lighting Condition M.H.	Spacing	Adaptation Brightness B_a	Measured Average Brightness $B_{r(average)}$	B_r (maximum)	B_r (minimum)	$\frac{B_{r(maximum)}}{B_{r(average)}}$
30 ft	continuous	3.1	0.18	2.56	0.04	14.3
30 ft	intermediate	1.5	0.02	1.31	<.01	65.5
30 ft	minimum	1.2	0.01	1.31	<.01	131.0
45 ft	intermediate	2.1	0.03	0.70	0.01	23.3
45 ft	minimum	1.5	0.02	0.52	<.01	26.0

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30 ft	continuous	2.3	0.08	1.18	0.02	14.8
30 ft	intermediate	1.5	0.06	0.72	0.01	12.0
30 ft	minimum	1.3	0.05	0.72	0.01	14.4
45 ft	intermediate	2.2	0.08	0.63	0.02	7.9
45 ft	minimum	1.8	0.06	0.49	0.02	8.2

VISIBILITY MEASUREMENTS

Target Brightness and Contrast

At locations 100, 200, and 300 feet ahead of the observation station along each side of the roadway, brightness measurements were made on 12-inch diameter circular targets. The target locations are shown in Figure 1. The targets were black discs painted to have a 7% diffuse reflectance. The background brightness was measured around the target so that a representative value could be used for the contrast calculations. All brightness readings were taken with the Pritchard spectra brightness meter using a 6-minute aperture.

The data are shown in the following table:

TARGET DATA*

GALVESTON APPROACH

Lighting Condition M.H. Spacing	TARGET 1			2			3			4			5			6		
	B_t	B_g	C	B_t	B_g	C	B_t	B_g	C	B_t	B_g	C	B_t	B_g	C	B_t	B_g	C
30 ft continuous	.02	.77	> .95	.06	.24	.75	.05	1.31	> .95	.04	.07	≈ .40	.11	.35	.69	.05	.15	.67
30 ft intermediate	---	.01	< Th.	---	.06	< Th.	.03	1.31	> .95	---	.01	< Th.	---	.02	< Th.	.02	.09	.78
30 ft minimum	---	---	---	---	---	---	.02	1.31	> .95	---	---	---	---	---	---	.03	.10	.70
45 ft intermediate	---	---	---	.01	.26	> .95	.02	.80	> .95	---	---	---	.01	.06	.83	.02	.10	.80
45 ft minimum	---	---	---	.01	.15	.93	.01	.77	> .95	---	---	---	---	.03	≈ .80	.01	.13	.92

B_t = Target Brightness (fl) B_g = Average Background Brightness (fl) C = Contrast $= \frac{B_t - B_g}{B_g}$

* Data for B_t and B_g are in foot-lamberts

≈ = approximately equal to
> = greater than
< = less than
Th. = threshold

TARGET DATA*

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TARGET

Lighting Condition M.H.	Spacing	1 B_t	1 B_g	1 C	2 B_t	2 B_g	2 C	3 B_t	3 B_g	3 C	4 B_t	4 B_g	4 C	5 B_t	5 B_g	5 C	6 B_t	6 B_g	6 C
30 ft	continuous	.01	.11	.91	.02	.57	$>$ .95	.07	1.27	.94	.01	.03	.67	.02	.16	.87	.06	.42	.86
30 ft	intermediate	.02	.16	.88	.05	.59	.91	---	---	---	.01	.03	.67	.06	.38	.84	.01	.09	.89
30 ft	minimum	.02	.16	.88	.05	.59	.91	---	---	---	.01	.03	.67	.06	.38	.84	.01	.09	.89
45 ft	intermediate	---	.31	$\approx$ .95	.01	.26	$\approx$ .95	.04	.05	.20	---	.07	$\approx$ .90	.01	.31	.95	.09	.08	0.0
45 ft	minimum	---	.33	$\approx$ .95	.01	.23	$\approx$ .95	.04	.06	.33	---	.06	$\approx$ .83	.01	.31	.95	.06	.21	.72

B_t = Target Brightness (fl) B_g = Average Background Brightness (fl) C = Contrast = $\frac{B_t - B_g}{B_g}$

* Data for B_t and B_g are in foot-lamberts

$\approx$ = approximately equal to
$>$ = greater than
$<$ = less than
Th. = Threshold

Visibility Measurements on Targets

The six targets mentioned in the previous section and located as shown in Figure 1 were set up for the brightness measurements and were then evaluated with the Finch-Simmons visibility meter. This instrument permits the contrast within the central field of view to be decreased to threshold conditions while the adaptation brightness and the surround brightness pattern remain unchanged. The extent of the mechanical motion required to reduce the central scene to threshold is used as a measure of the visibility of the object. The instrument was calibrated in terms of a circular object $1^{\circ}33'$ of arc in diameter at various background brightnesses. A contrast, C_{vm}, as determined by the visibility meter, means that the actual object under test has the equivalent contrast, and therefore the equivalent visibility, of the reference circular disc viewed against a specified uniform background brightness. For example, a measured value $C_{vm} = 79\%$ at a background brightness of 0.03 fl means that the target on the roadway would be equivalent in visibility to $1^{\circ}33'$ disc with 79% contrast seen against a uniform background of 0.03 fl.

Previous investigations by other researchers and the author have developed the limits for acceptable contrast of roadway objects at various background brightnesses. An empirical relationship for the required contrast of a $1^{\circ}33'$ disc has been developed using the Finch-Simmons visibility meter. These data are shown in Figure 16 in which a curve is drawn to indicate the borderline between adequate and inadequate contrast at various background brightnesses. These data are not as precise as might be implied by the curve. The curve incorporates a statistical spread of many variables and is drawn through a supra-threshold region representing contrasts 3 to 5 times the minimum threshold values. Therefore, Figure 16 has a built-in "field factor."

Using the borderline between adequate and inadequate contrast, C_{bai} as a guide, the values found with the visibility under different lighting conditions can be compared. Also the actual measured value of contrast, C_{phot}, as found with the Pritchard brightness meter can be checked against C_{vm} and C_{bai}. These data are tabulated for each lighting condition and approach direction in the following table.

VISIBILITY METER DATA

GALVESTON APPROACH

Lighting Condition		Left Side: Avg B_g	C_{bai}	C_{vm}	C_{phot}	C_{vm}/C_{bai}	C_{phot}/C_{bai}	C_{vm}/C_{phot}	Right Side: Avg B_g	C_{bai}	C_{vm}	C_{phot}	C_{vm}/C_{bai}	C_{phot}/C_{bai}	C_{vm}/C_{phot}
30 ft continuous	100 ft ahead	.08	.38	<Th	≈.40	--	1.8	--	.62	.10	.80	.95	8.0	9.5	.84
	200 ft ahead	.39	.12	.60	.69	5.0	5.7	.83	.23	.12	≈.60	.75	≈5.0	6.2	≈.80
	300 ft ahead	.16	.14	≈.50	.67	3.6	4.8	≈.75	1.02	.10	.55	>.95	5.5	9.6	.58
30 ft inter-mediate	100 ft ahead	.01	.90	<Th	<Th	---	---	---	.01	.90	<Th	<Th	---	---	---
	200 ft ahead	.02	.72	<Th	<Th	---	---	---	.04	.60	<Th	<Th	---	---	---
	300 ft ahead	.11	.23	≈.50	.78	≈2.2	≈3.4	≈.64	.98	.10	≈.80	>.95	≈8.0	≈9.8	≈.82
30 ft minimum	100 ft ahead	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	200 ft ahead	.02	.72	<Th	<Th	---	---	---	.03	.66	<Th	<Th	---	---	---
	300 ft ahead	.12	.26	≈.50	.70	≈1.9	≈3.5	≈.71	.98	.10	≈.80	>.95	≈8.0	≈8.0	≈.82
45 ft inter-mediate	100 ft ahead	.02	.72	<Th	<Th	---	---	---	.02	.72	<Th	<Th	---	---	---
	200 ft ahead	.05	.55	.83	.83	1.5	1.5	1.0	.14	.25	.87	>.95	3.5	4.0	.83
	300 ft ahead	.20	.13	.83	.80	6.4	6.2	≈1.0	.57	.11	.71	>.95	6.5	8.6	.75
45 ft minimum	100 ft ahead	.01	>.95	<Th	<Th	---	---	---	.01	>.95	<Th	<Th	---	---	---
	200 ft ahead	.03	.65	.79	≈.80	1.4	1.2	≈1.0	.10	.28	≈.90	.93	3.2	3.3	.97
	300 ft ahead	.19	.13	.85	.92	6.5	7.1	.92	.50	.11	.55	≈.95	5.0	8.6	.58

< = less than
> = greater than
≈ = approximately equal to
Th = threshold (minimum measurable)

VISIBILITY METER DATA

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Lighting Condition		Left Side: Avg B_g	C_{bai}	C_{vm}	C_{phot}	$\frac{C_{vm}}{C_{bai}}$	$\frac{C_{phot}}{C_{bai}}$	$\frac{C_{vm}}{C_{phot}}$	Right Side: Avg B_g	C_{bai}	C_{vm}	C_{phot}	$\frac{C_{vm}}{C_{bai}}$	$\frac{C_{phot}}{C_{bai}}$	$\frac{C_{vm}}{C_{phot}}$
30 ft continuous	100 ft ahead	.04	.60	< Th	.67	---	1.1	---	.08	.37	.76	.91	2.1	2.5	.84
	200 ft ahead	.30	.12	.80	.87	6.7	7.3	.92	.87	.12	.67	.96	5.6	8.0	.70
	300 ft ahead	.29	.12	.76	.86	6.3	7.2	.88	.95	.12	.64	.94	5.3	7.8	.68
30 ft intermediate	100 ft ahead	.01	.60	< Th	.67	---	1.1	---	.09	.31	< Th	.88	---	2.8	---
	200 ft ahead	.31	.12	≈ .70	.84	≈ 5.8	7.0	≈ .83	.57	.12	≈ .70	.91	≈ 5.8	7.6	≈ .77
	300 ft ahead	.06	.49	> .90	.89	≈ 2.0	1.8	1.0	.01	≈ .90	< Th	< Th	---	---	---
30 ft minimum	100 ft ahead	.04	.60	< Th	.67	---	1.1	---	.09	.31	< Th	.88	---	2.8	---
	200 ft ahead	.31	.12	≈ .70	.84	≈ 5.8	7.0	≈ .83	.57	.12	≈ .70	.91	≈ 5.8	7.6	≈ .77
	300 ft ahead	.06	.49	> .90	.89	≈ 2.0	1.8	1.0	.01	≈ .90	> .90	.89	≈ 1.0	≈ 1.0	≈ 1.0
45 ft intermediate	100 ft ahead	.07	.42	.79	≈ .90	1.9	2.0	.88	.19	.13	.84	≈ .95	6.5	7.3	.88
	200 ft ahead	.30	.12	.80	≈ .95	6.7	7.9	.83	.25	.12	.85	≈ .95	7.1	7.9	.89
	300 ft ahead	.09	.31	< Th	< Th	---	---	---	.12	.20	< Th	.20	---	1.0	---
45 ft minimum	100 ft ahead	.08	.38	.62	.83	1.6	2.2	.75	.19	.13	.85	≈ .95	6.5	7.3	.89
	200 ft ahead	.31	.12	.82	≈ .95	6.8	7.9	.86	.25	.12	.71	≈ .95	6.0	8.0	.74
	300 ft ahead	.09	.31	< Th	.72	---	2.3	---	.12	.20	< Th	.33	---	1.6	---

< = less than

> = greater than

≈ = approximately equal to

Th = threshold (minimum)

ROADWAY REFLECTANCE CHARACTERISTICS

The reflectance properties of the roadway were measured at two locations, one in the asphaltic concrete in the Galveston approach direction and one on the concrete in the Texas City approach direction. Photographs of the test areas are shown in Figures 17 and 19. Measurements were made using a form of a goniophotometer in which the reflected light was viewed with a Pritchard brightness meter using a 30-minute aperture. The brightness meter was placed in a fixed position to view a spot on the roadway 12 feet ahead and 3 degrees up from the plane of the roadway. The viewing direction represents an average vertical angle for a driver looking at the road ahead. The light source was arranged to illuminate the roadway from all positions on a hemisphere centered over the measuring area viewed by the photometer. This technique yields the directional reflectance data on the roadway surface and permits the brightness of the roadway to be determined for a driver when the light sources are located in any configuration above the road.

The brightness factor data for the two roadway locations are shown in Figures 18 and 20.

The above figures show the brightness factor vs horizontal and vertical angles of the source for a fixed viewing direction. The brightness factor is defined as the ratio of the roadway brightness (in fl) to the horizontal illumination (in fc). This information can be used to predetermine a brightness pattern on a roadway and therefore can be used for design purposes. If the luminaire distribution data are available from the manufacturer, the horizontal illumination can be calculated for any point on the roadway. Then the brightness factor can be found from the curves. The roadway brightness at a given location is then found by multiplying the horizontal illumination times brightness factor.

$$B_{\text{(roadway)}} = E_{\text{horizontal}} \times \text{B. F.}$$

The application of the data will be discussed in a later section of the report.

BRIGHTNESS AND LOCATION OF GLARE SOURCES

At each of the observation stations in both of the approach directions, the brightness of each overhead light source was measured and its position located by a vertical and horizontal angle. The brightnesses were measured using a Pritchard spectra brightness meter equipped with a 15-minute aperture. The aperture acceptance angle included a portion of the surround in its field plus the complete luminaire except for the nearest light which was about 2/3 covered by the field of the instrument. The brightness measured within the 15-minute cone angle is an average value and is considered to be representative for the luminaires even though the values may be slightly low for the distant sources because some of the dark surround is included. The average brightness for the nearest light is satisfactory because the field of view includes only the central region of the luminaire. The data for all of the light sources are shown in the following table.

LUMINAIRE LOCATION AND BRIGHTNESS

GALVESTON APPROACH

Light No.	30 ft Mounting Height: Vertical Angle	30 ft Mounting Height: Horizontal Angle	30 ft Mounting Height: Brightness (fl)*	45 ft Mounting Height: Vertical Angle	45 ft Mounting Height: Horizontal Angle	45 ft Mounting Height: Brightness (fl)*
1	≈ 2°	≈ 23° 00' L	≈ 3000			
2	≈ 2°	20° 30' L	≈ 3000	3° 20'	20° 30' L	3000
3	≈ 2°	≈ 21° 00' L	≈ 3000			
4	≈ 2°	21° 30' L	≈ 3000	3° 20'	21° 30' L	3000
5	≈ 9°	26° 20' L	≈ 3000	13° 00'	26° 20' L	3000
6	--	---	--	--	--	--
7	6° 30'	2° 45' R	12800			
8	3° 30'	2° 45' R	6680	5° 15'	2° 45' R	7690
9	2° 30'	5° 30' R	2940			
10	1° 30'	9° 00' R	3620	2° 15'	9° 00' R	5650
11	1° 40'	5° 00' R	2600			
12	2° 00'	0° 00'	2830			
13	1° 35'	7° 30' L	3620	2° 15'	7° 30' L	5650
15	3° 35'	3° 00' L	1430	5° 15'	3° 00' L	1620
16	2° 30'	7° 10' L	4520	3° 45'	7° 10' L	4750

TEXAS CITY APPROACH

Light No.	30 ft Mounting Height: Vertical Angle	30 ft Mounting Height: Horizontal Angle	30 ft Mounting Height: Brightness (fl)*	45 ft Mounting Height: Vertical Angle	45 ft Mounting Height: Horizontal Angle	45 ft Mounting Height: Brightness (fl)*
1	1° 50'	44° 45' R	3160			
2	1° 50'	28° 10' R	2370	3° 45'	27° 15' R	4860
3	1° 40'	20° 35' R	1620			
4	1° 40'	6° 50' R	1500	2° 45'	6° 50' R	3760
5	1° 30'	0° 25' R	1320	2° 30'	0° 25' R	2260
6	1° 15'	4° 10' L	1130			
7	1° 30'	7° 35' L	735			
8	1° 50'	5° 00' L	1280	3° 10'	5° 00' L	3620
9	2° 30'	3° 20' L	3120			
10	7° 15'	2° 20' R	12000	11° 40'	2° 25' R	12000
12	3° 10'	8° 25' R	2820			
13	3° 00'	25° 00' R	1500	5° 05'	25° 05' R	2780
15	2° 00'	4° 25' R	3760	3° 50'	4° 25' R	---
16	2° 15'	8° 10' R	1810	4° 00'	8° 15' R	4970

* Average brightness was measured within a 15 minute cone angle. The values are accurate to ± 20%. Errors are due to alignment difficulties, calibration, color correction and voltage regulation during the test. The relative values are ordered in accordance with field conditions even though the absolute values may be in error by the above amount.

Other Visual Observations

During one of the series of measurements on the Texas City approach, fog began to form in the early morning hours before sunrise. The fog forced a halt in the scheduled measurements but it did provide an opportunity to observe one of the lighting patterns under adverse weather. Two photographs of the 30-foot minimum system are shown in Figures 21 and 22. The halation around the sources and the build-up of background brightness due to scattering are very evident. The subsequent loss of contrast and reduction in visibility are pictorially very clear. More will be said about the effects of fog in the section discussing the results.

There are numerous elements in the visual scene other than the roadway and the contiguous surfaces that provide guidance information to the driver. The photographs of the daytime scene reveal the principal elements such as route markers and directional arrows, railroad crossbars, railroad crossing lights, buildings and structures in the distance and in line with the road, advertising signs on the side, and the many vertical poles in the local area of the intersection.

The night photographs retain a few of the extra elements in the visual scene but except for one or two signs and the railroad crossing bars almost all of the fringe elements have disappeared. No satisfactory technique is currently available to evaluate the visual benefits or distractions of the fringe elements in the scene. Therefore, no data were taken on any of these elements except for the photographs and the brightnesses of the signs on the island in each approach direction. These data are reported with the roadway brightness values.

ANALYSIS AND DISCUSSION OF RESULTS

Illumination--Horizontal

The data on horizontal illumination are shown in Appendix II and are summarized in the previous section. They show that the individual luminaires are acting almost independently in developing the illumination pattern for the 30-foot mounting height units. The spacing along each lane is 5 to 6 times the mounting height for the 30-foot mounting height luminaires and, therefore, adjacent light sources contribute very little beyond the midpoint between luminaires. A comparison of the pattern of the measured values with the manufacturer's reported values for a single luminaire indicates nominal agreement. See Appendices I and II.

The 45-foot mounting height has a more favorable ratio of spacing to mounting height, viz., about 3.5. Therefore, although the values of horizontal illumination for the 45-foot mounting height are lower than the corresponding 30-foot mounting height units, the uniformity is better.

The average values of horizontal illumination for the continuous systems are higher than for either the intermediate or the minimum systems. This would be expected since more light is available within a given roadway area. The intermediate and minimum systems differ very little in average horizontal illumination. This is because the intermediate and minimum patterns use practically the same lights to illuminate the approach directions considered in this study. When the system is switched from intermediate to minimum, only two lights are turned off (numbers 13 and 4) and these two are so far away from the roadway areas under consideration that they contribute practically nothing to the horizontal illumination.

Horizontal illumination measurements are convenient to make and give an indication of luminaire performance. For acceptance tests and for other measures of luminaire efficiency such as the coefficient of utilization, the horizontal illumination measurements are useful. From the viewpoint of a motor vehicle driver, illumination measurements have no significance because they are not directly related to what he sees.

The values reported for average horizontal footcandles indicate that the levels are generally lower than the latest recommendations of the IES-ASA Committee on Roadway Lighting. In the latest report the above group recommends 1.2 fc (average) for a rural interchange. The method of computing this average is not stated. If the area used to compute the average is restricted to the roadway in the immediate vicinity of the islands, the calculated values of average horizontal illumination would be higher than those reported herein and would be more in line with recommended practice.

Illumination -- Vertical

The actual data shown for the vertical illumination in Appendix II give the details at each measuring station. The summary and averages given in the preceding section may be helpful in forming some general conclusions. The data on the 30-foot intermediate and minimum systems show that direct object visibility can be expected to be poor since the vertical illumination is generally low (average in the traffic direction).

The 30-foot continuous and the 45-foot intermediate systems are better insofar as vertical illumination is concerned, but only the 30-foot continuous system is reasonably satisfactory.

The directional characteristics of the light, as revealed by the modelling factor, show that all systems have a reasonable probability of developing highlights, shadows, form and texture in objects located above the roadway.

The modelling factor should be greater than 1.5 for good object visibility. An object uniformly illuminated from all directions would have a modelling factor of 1.0 and would tend to have a flat two-dimensional appearance.

All of the systems meet the modelling condition but all except the 30-foot continuous and 45-foot intermediate systems have vertical illumination values that are on the low side.

DISCUSSION OF BRIGHTNESS PATTERNS

The data on brightness collected and reported in the preceding section are quite extensive. At the present time there is no standard procedure for analysis nor formula to use to arrive at an over-all appraisal of a brightness pattern. However, there are three basic requirements that must be met by an installation if it is to be satisfactory for drivers of motor vehicles: viz., (1) there shall be adequate guidance information, (2) forms and objects on the roadway should be readily perceived, and (3) the pattern should be understandable, unambiguous and not deleterious to easy, pleasant seeing.

Many factors contribute to these aspects of the visual problem. The incident light effects have been reviewed in the discussion of the horizontal and vertical illumination. The characteristics of the roadway in terms of its directional reflectance will be considered later. The final result of incident light on surfaces is the brightness pattern as seen by the driver. In this study we were restricted to a set of ten static scenes as seen by a driver from a point about 300 feet ahead of an area of decision. In actual driving the scene is continually changing as may be noted in the series of photographs in Figures 2 and 3.

The problem here is to examine each brightness pattern and to extract the key information, then to evaluate the over-all scene in terms of the above basic requirements.

The individual conditions for each lighting arrangement are shown in Figures 4 to 15 and are tabulated in Appendix III. Also data on the six targets for contrast and visibility at each location are given in the previous section. Each lighting condition will be discussed for guidance, object recognition and pavement brightness in the following paragraphs. The glare effects are briefly mentioned in connection with the adaptation brightness and visibility meter readings, but they will be discussed separately later.

GALVESTON APPROACH

THIRTY-FOOT MOUNTING HEIGHT CONTINUOUS SYSTEM

Surface Brightness

The roadway surface has an average brightness of 0.18 fl with a ratio of maximum to average of 14.3 over the roadway from 50 to 400 feet ahead. This level is in reasonable agreement with recommended values now being proposed in the IES-ASA Recommended Practice which shows a range of 0.30 to 0.15 fl with transition sections. The ratio of maximum to average is high but not excessive for a long transition zone covering 50 to 400 feet. The minimum value of 0.04 fl is low. About 0.10 fl is as low as one should find at any point on the roadway for reasonable object recognition.

Note that the roadway brightness is developed to some extent by each source in the field of view. There are specular streaks on the roadway that may be noticed from the closer lights. Even though the horizontal illumination may be small from a distant light, its contribution to the total pavement brightness may be appreciable. A comparison of the Galveston and Texas City approaches shows the differences in the brightness factors. The Galveston pavement is quite black in the daytime, but it has a higher average and a higher maximum brightness than the concrete roadway in the Texas City approach. The lighting units and spacing and mounting heights are about the same in each case.

The surface brightness of the roadway using the 30-foot continuous system would be quite acceptable if the remaining elements were all in balance.

Guidance

The principal lines along the edges and around the turns are essentially continuous. The island curbs are evident although not too sharply defined. The fringe elements such as the island sign, the railroad cross bars and the berm are reasonably well outlined. The painted center line can be followed as a dashed line for several hundred feet.

The foreground and distant objects are tied together visually into a fairly satisfactory and complete scene. The large brightness variation immediately ahead of the island with the excessive brightness ahead of the dark region are the most serious criticisms of the roadway pattern.

Form and Detail Perception

The targets placed along the edges of the roadway had adequate contrast for easy detection at all of the locations used. The visibility meter readings also show that all of the targets except the first one on the left at 100 feet were well above borderline seeing levels.

Adaptation Brightness and Visibility

The total flux entering the eye of a driver at the observation station used for these tests is almost wholly due to the direct light from the luminaires. When this flux is averaged over a 30° cone angle it may be noted that the average brightness is still 3.1 fl. This level is much higher than the average roadway at 0.18 fl and therefore makes objects on the roadway more difficult to see. This creates the same effect as trying to see out a window from the inside of a lighted room at night. These conclusions are borne out by the visibility meter readings wherein the equivalent contrast of the targets is less than the measured contrast. The reduction in contrast is due to the disabling effect of the glare sources.

THIRTY-FOOT MOUNTING HEIGHT INTERMEDIATE SYSTEM

Surface Brightness

The average brightness of the roadway is very low at 0.02 fl and the ratio of maximum to average is 65.5. As can be noted in Figure 6, the brightness is concentrated around the nose of the island. The minimum value was too low to measure at less than 0.01 fl.

In this case the brightness factor of the asphalt is such that the pavement brightness is much less than the average for the corresponding Texas City approach condition. The maximum brightness is 1.31 fl on the asphalt compared to 0.72 fl for the corresponding lighting system on the concrete.

The surface brightness should be considered inadequate in both magnitude and distribution.

Guidance

The edges of the roadway between the observer station and the island are not defined. A splotchy bright pattern around the center of the intersection can be seen but there is no continuity to the scene from the observer station. The fringe information is very meager. The only extra visual element clearly remaining is the sign on the nose of the island. Guidance information is not adequate.

Form and Detail Perception

The measurements on the targets were only possible at the 300-foot locations in the region of high brightness in the roadway. Due to the relatively small size of the brightness patch and the irregular outline of the bright area it was difficult to recognize shapes and to see details of objects.

The visibility meter readings also show that at the 100- and 200-foot locations the targets were below the threshold of the instrument. At 300 feet on the left side the equivalent contrast is lower than desirable. Except for objects in the small bright patch about 300 feet ahead and toward the right, the form and detail perception is poor.

Adaptation Brightness and Visibility

The adaptation brightness is lower than for the continuous system because the number of light sources directly in the field of view has been reduced from 15 to 7. At a value of 1.5 fl the adaptation brightness is still many times greater than the average roadway brightness at 0.02 fl. Seeing conditions are difficult. For the two targets at 300 feet that could be measured the visibility meter readings show a loss of contrast of 18% to 36%.

THIRTY-FOOT MOUNTING HEIGHT MINIMUM SYSTEM

Surface Brightness

The roadway brightness pattern and measurements are almost the same as for the intermediate system because within the principal field of view only one light, no. 13, was turned off. The average roadway brightness was only 0.01 fl and the ratio of maximum to average increased to 131. The pattern is poor and the levels are low. The surface brightness conditions are not satisfactory.

Guidance

The same comments apply for the intermediate system. The lights that were turned off in going from the intermediate to the minimum system do not affect the guidance from the observer station used in these tests. The lights would have effects at other locations. Guidance is not satisfactory with the minimum system.

Form and Detail Perception

The target measurements for contrast and visibility were essentially the same as for the intermediate system. The seeing conditions are very poor except in the region around the nose of the island.

Adaptation Brightness and Visibility

The adaptation brightness for the minimum system remains high compared to the average roadway brightness. B_a is 1.2 fl compared to B_r at 0.01 fl. Visibility Meter readings show losses in contrast of 18% to 29%. The glare effect is slightly reduced over the intermediate system due to the use of 5 instead of 7 lights. The roadway brightness conditions changed very little. Although the glare is less, the brightnesses are lower so there was practically no change in measured visibility. Very little can be said that is favorable to the 30-foot minimum system.

FORTY-FIVE-FOOT MOUNTING HEIGHT INTERMEDIATE SYSTEM

Surface Brightness

The higher mounting height of this system decreases the illumination values compared to the 30-foot systems but as shown for the surface brightness data, the average brightness of 0.03 fl is actually higher than for the 30-foot intermediate system at 0.02 fl. Also the maximum is lower at 0.70 and the ratio of maximum to average is lower at 23.3. The photographs of Figure 8 show that the brightness distribution in the 45-foot system has longer and therefore superior gradients than the 30-foot system.

Guidance

The 45-foot intermediate system is considerably better than the 30-foot intermediate system in developing the edges, the center line and the curbs on the islands. It is not as good as the 30-foot continuous system in this respect. As noted in the photographs, the continuity of the pattern around the La Marque turnoff is reasonably good but in the Texas City turnoff direction the guidance is lacking.

The foreground brightness is low and the continuity between the near-field and the far-field around the island is not satisfactory.

Form and Detail Perception

The target measurements at 200 and 300 feet indicated that the contrast was quite good, (0.80 to 0.95), and that the visibility was fairly high. At 100 feet the targets were not measurable. Many more of the fringe features of the roadway are visible with this system than with the corresponding 30-foot installation.

Adaptation Brightness and Visibility

The adaptation brightness is high at 2.1 fl compared to the average roadway brightness at 0.03 fl. It is about one third less than the 30-foot continuous system at 3.1 fl which is a good feature. The lower adaptation brightness partially compensates for the lower pavement brightness and may make visual conditions superior to the 30-foot continuous system. Actual observations in the field indicate that many observers perfer the seeing conditions for this system over the 30-foot continuous system. The lower adaptation brightness is one reason for this.

The visibility meter readings show that for the positions where the targets can be measured, there is less loss in contrast for the 45-foot system than for the corresponding 30-foot system. The 45-foot system had contrast losses from 0 to 25% whereas the 30-foot system had from 16 to 42% losses.

FORTY-FIVE-FOOT MOUNTING HEIGHT MINIMUM SYSTEM

Surface Brightness

The average roadway brightness was 0.02 fl which was slightly less than the intermediate system. Two less lights are used in this pattern which accounts for the decrease in some of the more distant brightnesses. The foreground pattern and the area around the nose of the island are almost identical with the intermediate pattern. The ratio of maximum to average is 26.0 which is high but very much better than the value of 131 found for the 30-foot minimum system.

Guidance

The foreground to about 200 feet ahead has poor guidance information. The edges and painted lines are not well defined. Around the island marking the La Marque turn, guidance is fair but much poorer than with the intermediate system. In the direction of the Texas City turnoff beyond the first railroad crossing there is inadequate guidance. Fringe elements in the scene are very low in contrast and provide minimum aid.

Form and Detail Recognition

Target and visibility meter readings show substantially the same values as for the intermediate system. This is because the foreground brightnesses were changed very little.

The visibility meter gave the same or slightly higher readings than for the intermediate system. This is an indication that the glare effect is less and that the lower adaptation brightness more than compensates for a small loss in average roadway brightness.

Adaptation Brightness and Visibility

The adaptation brightness is 1.5 fl compared to the average roadway brightness of 0.02 fl. This is the same as reported for the 30-foot intermediate system but the distribution of roadway brightness is more uniform and the light sources are farther removed from the line of sight. Therefore the seeing conditions for this system can be rated better than for either the 30-foot intermediate or the 30-foot minimum systems. The visibility meter readings also bear out the above conclusion.

TEXAS CITY APPROACH

THIRTY-FOOT MOUNTING HEIGHT CONTINUOUS SYSTEM

The discussion of the Texas City approach lighting and visibility conditions is basically the same as for the Galveston approach but with several important variations.

Note that the average roadway brightness is 0.08 fl compared to 0.18 fl for the corresponding Galveston condition. Also the maximum brightness is 1.18 fl compared to 2.56 fl and the ratio of maximum to average is approximately 14 for each. The uniformity of the roadway brightness is improved for the concrete surface in the Texas City approach but the brightness is lower. This is explained by the differences in the directional reflectances as shown in the brightness factor curves in Figures 18 and 20.

The guidance information is reasonably good as may be noted by examination of Figure 11. The edges, curbs, berm, railroad crossbars, island sign and other fringe objects are easily seen. The foreground to 150 feet ahead has a good transition brightness.

Form and detail can be picked up with relative ease as noted by the target and visibility meter data. All targets from 100 to 300 feet were measurable and had good contrast and visibility except that the 100-foot left side target was somewhat marginal.

Adaptation brightness was high at 2.3 fl but is less than the corresponding Galveston approach system. The same number of lights were in the field of view but their orientations were different. Thus less total flux entered the eye.

The over-all visual conditions in the Texas City approach are approximately comparable to the Galveston approach. The lower pavement brightness is offset by its greater uniformity and the lower adaptation brightness.

THIRTY-FOOT INTERMEDIATE AND MINIMUM SYSTEMS

Both of these systems are almost identical in the Texas City approach direction. Small differences occur in the more distant areas so that the average brightness, maximum brightness and ratio of maximum to average are almost equal. Target contrasts and visibility meter readings are practically the same.

A comparison with the corresponding Galveston approach systems shows that the average roadway brightness is higher for the Texas City approach and that the ratio of maximum to average brightness is very much lower, i.e., 12 and 14 compared to 65 and 131. Adaptation brightness for the two approaches is the same.

Therefore it may be concluded that the over-all visual conditions for the 30-foot intermediate and minimum systems are better in the Texas City approach than in the Galveston approach. The most important single factor that influences the brightness pattern is the roadway surface.

FORTY-FIVE-FOOT INTERMEDIATE AND MINIMUM SYSTEMS

These two systems demonstrate an important aspect of lighting design that is frequently overlooked. For example, the roadway surface at the Texas City approach location as well as for the Galveston approach, has a higher average roadway brightness for the 45-foot mounting height than for the 30-foot mounting height. The maximum brightness is lower, however, in each case and the distribution is more extended; therefore the average brightness turns out to be higher and the ratio of maximum to average is lower. This is a highly desirable feature and will usually occur with higher mounting heights regardless of the type of roadway surface.

It should be realized that the illumination on the roadway will decrease and the coefficient of utilization will decrease with increased mounting heights, but the average brightness and the uniformity of brightness will usually increase. The foregoing statement applies within normal mounting heights from 20 to 50 feet.

Guidance information, form and detail recognition and visibility meter indices are generally good in the near and intermediate distances up to 300 feet. The brightness pattern beyond the first railroad crossing is not adequate when viewed from the observer station used in this series of measurements.

Roadway Reflectance Discussion

The photographs of Figures 17 and 19 and the curves of Figures 18 and 20 show the type of surfaces and their directional reflectance characteristics at typical locations on each approach roadway.

The previous material on the results of the pavement brightness measurements pointed up the role played by the pavement surface in developing the brightness pattern. Most roadway lighting layouts are not made with the roadway brightness pattern as a design parameter. The final brightness distribution is usually not predetermined. Such does not have to be the case. Calculations can be made to predetermine the roadway brightnesses.

The information needed to proceed with the calculation is: (1) The luminaire distribution data. This should be in the form of an isocandle diagram giving the candle power of the luminaire for all directions toward the roadway. (2) The geometry of the installation. This should include the mounting height, spacing of the luminaire and the location of the observer. (3) Values of roadway brightness factors. These should be available for the particular surface that is involved.

To make effective use of the foregoing information, the following procedure should be used for calculating the composite brightness of each point in the scene for all observer positions.

Items 1 and 2 mentioned above are generally available from the manufacturer of the lighting equipment and from the proposed preliminary plans for the roadway. Item 3 and the calculating procedure need clarification and will be explained.

Roadway Brightness Factors

It has been known for many years that roadway surfaces have peculiar directional reflectance properties, particularly when the light is incident at angles approaching grazing incidence and when the viewing direction is close to the plane of the roadway. As the angle of incidence and viewing approach grazing directions, even normally nonspecular surfaces begin to act like mirrors. Under some conditions even gravel roadways will have high specular components. These characteristics of the roadway surface are extremely important in developing brightness patterns. Directional reflectance data have not been available in the past and even now are not available for many surfaces. But the technique for accumulating such data is established. A brief description of the method follows:

If the normal illumination at a particular point on a surface is known; if the direction from which that light comes is know; if the spot on the surface is viewed from a particular direction, then its brightness will be directly proportional to the illumination and will be a function of the roadway directional reflectance. Therefore, the following equation applies:

$$B_{\alpha, \beta} = E_{\phi, \theta} \times BF_{(\alpha, \beta, \phi, \theta)} \qquad (1)$$

where:

$B_{\alpha,\beta}$ = Brightness of the particular point observed from the observer position, in directions α, β.

$E_{\phi,\theta}$ = The Horizontal illumination at the point due to light from a particular source at angles ϕ, θ.

$BF_{\alpha,\beta,\phi,\theta}$ = The Brightness factor equals the directional reflection characteristic of the roadway for the specified angles of incidence ϕ, θ and observation angles α, β.

To obtain brightness factor data for a given roadway, a light source is set up to provide illumination on a given small surface. The light source is arranged to move so that the surface can be illuminated from all directions in space above the plane of the surface. In other words, the light source should be able to rotate in azimuth angles through 360° and in vertical angles through 90°. The light can then be made to be incident from all of the possible directions that a street light could provide on any point of a roadway. The photometer for measuring the brightness of the spot should be set at various angles that are typical of a motorist observing the roadway. Typical observation angles will be from 0° to 6° above the vertical plane and will be from 0° to $\pm 30^{\circ}$ azimuth angle.

Calculation Procedure

The steps required to calculate the brightness pattern on the roadway are as follows:

1. Make a scale layout of the roadway showing a plan view and a typical elevation. On the layout, establish typical observer locations and fix points on the roadway that are to be used to evaluate the roadway brightness. The points should be close enough together to develop a reasonable pattern of brightness for comparison purposes and to show maximum, minimum and average values.

2. Calculate and tabulate the observation angles to each point on the roadway from each observation station. This will develop a table of angles for α and β.

3. Determine angles for the light from the luminaire to each point on the roadway. This will give a table of values of ϕ and θ.

4. From the tabulated values of ϕ and θ, obtain the candle power of the light in the direction ϕ, θ, from the isocandle diagram. Note that the azimuth angle ϕ may have to be adjusted by $\pm 90^{\circ}$ to correspond to the horizontal angles on the isocandle diagram.

5. Calculate the illumination $E_{h, \phi, \theta}$ at the point from the candle power and the distance from the luminaire to the point. This is developed from the angles ϕ, θ, the mounting height, and the location and spacing of the light source for the roadway at the point in question.

6. Determine the brightness factor from the empirical data for the roadway for the observation angles α, β and incident angles ϕ and θ.

7. Calculate the incremental brightness at each point by multiplying the horizontal illumination at the point times the brightness factor at the point. This gives the incremental brightness at the point for each luminaire that contributed.

8. Determine the composite brightness: i.e., the sum of the incremental brightnesses due to each luminaire. This value is the total brightness of the point for all contributing luminaires in the area. The procedure is then repeated for each point in the field of view to determine the brightness from the one observation station selected.

9. Repeat the whole procedure for as many different observation stations as may be desired.

GLARE DISCUSSION

As stated in the IES Lighting Handbook, "No single factor in roadway lighting is as detrimental to visibility as glare. Glare may be produced in several different ways, but the effect of each is to reduce visibility and cause ocular discomfort. Glare, as encountered in roadway lighting, has two principal effects: discomfort and blinding effects."

In all cases in street lighting, the discomfort aspect of glare is the governing one since the borderline brightness of a light source for discomfort is lower than for disability. Many researches have been conducted on the relationships among the variables and include the work of Holladay, Harrison, Guth, Hopkinson, DeBoer, Fry, Stiles, Logan, Moon, Spencer, and others. All of these indicate that the glare is:

1. Directly proportional to the brightness of the source.
2. Directly proportional to the size of the source.
3. Inversely proportional to the field brightness.

The above relationships are nonlinear and are mutually dependent. In addition, the location of each source in the field of view is important and the time of exposure and transient adaptation are factors. Individual glare effects are not usually additive in the ordinary sense and the method of combining the individual glare effects has not been developed into a generally agreed upon technique. But the IES Handbook, Guth, DeBoer and others state that the individual glare effects can be added arithmetically to obtain a numerical rating that is useful for comparison purposes. This later method will be used in this report.

The IES formula for the glare effect of a single source is:

$$G = \frac{\omega}{\overline{\omega}}$$

where ω = solid angle of the source.

$\overline{\omega}$ = solid angle the source would have to subtend to provide a glare sensation at the borderline between comfort and discomfort (BCD).

$$\overline{\omega} = \left[\frac{\frac{B}{P}}{108\ F^{0.44}} + 1.28 \right]^{-4.76}$$

where B = Brightness of source in fl.

P = Position index (Fig. 2-27 in IES handbook).

F = Field Brightness in fl.

The IES glare rating for a group of sources is:

$$G_{total} = G_1 + G_2 + G_3 + \dots G_n$$

The smaller the value of G_{total} the better the system is rated.

For the values of source brightness, field brightness, position index and solid angle found in these roadway lighting conditions, the above formula gives values that indicate an extremely high level of discomfort for all systems. The values of the parameters are outside of the range of the data used to establish the equation.

Another method of rating a given system is to use Hopkinson's formula to compute the equivalent average roadway brightness that would be necessary to bring the glare to a "tolerable" or "satisfactory" level. This may be found from the formula:

$$B'_r \text{ (average) (roadway)} = \sum \frac{1700 \quad B_s^{1.3} \quad \omega}{A^{0.75}}$$

where B'_r (average) (roadway) = required average brightness of the roadway in fl.

B_s = brightness of the source in C/in^2.

ω = solid angle of the source in steradians.

A = angle of source from the line of sight in degrees.

1700 = glare constant for the "tolerable" or "satisfactory" level.

For all of the lighting conditions used in these studies, the required average roadway brightness, B'_r, to bring the viewing conditions into the tolerable range would have to be greater than 1.0 fl. None of the average roadway brightnesses even approach this value (range 0.01 to 0.18 fl) so all should be considered as unsatisfactory from discomfort glare considerations as calculated by the Hopkinson method.

DISCUSSION

Fog, Rain and Adverse Weather

The visual conditions may change very greatly in weather other than the clear and dry atmosphere that existed during the tests reported herein. Water, snow, or ice on the roadway will change the reflection characteristics in unpredictable ways. Fog, rain, snow or dust in the air will change the atmospheric transmission and the scattering. The composite effect is one wherein the brightness patterns are so much different under adverse weather conditions that a given installation that is acceptable under normal conditions may not be satisfactory or even usable. For example, during one of the early morning test periods on the Texas City approach, fog began to develop. Testing work had to stop since only data for clear, dry conditions were being collected. Photographs of the visual conditions in several fog densities were made for the record. These are shown in Figures 21 and 22.

One of the significant effects to note in the fog pictures is the scattering pattern. A large fraction of the total scattering is concentrated in the immediate vicinity of each light. This implies that the light sources should be as far removed from the line of sight as possible. Also the background brightness has been found, in other tests, to increase by several orders of magnitude at lateral distances up to 40 to 50 feet. For most fogs, the forward scatter along a beam is greater than the side or back scatter.

From the photographs and from an understanding of the scattering characteristics of fog, two alternate mounting arrangements are suggested. (1) The lights should be as high and as far to the side as possible: The 30-foot mounting height is too low for best results. (2) Or the lights should be as low as possible and the beam should be directed toward the road at as close to 90° to the centerline as practical. The latter has been found, in other experiments, to yield minimum scatter along the roadway.

For the installation as it now exists, the 45-foot mounting height units would probably be superior to the 30-foot mounting height units in fog.

Other adverse conditions were not investigated in the intersection during these tests.

SUMMARY OF DATA

The lighting data for the two approach directions and for the five lighting conditions in each approach direction have been presented and discussed in the preceding sections. A summary of the significant data is presented in the following tables with an over-all rating based upon a weighted appraisal of all factors. Roadway brightness, adaptation brightness, visibility index and glare have been considered to have greater weighting than the factors associated directly with illumination quantities.

SUMMARY

GALVESTON APPROACH

Quantity	Lighting System: 30 ft continuous	30 ft intermediate	30 ft minimum	45 ft intermediate	45 ft minimum
Horizontal Illumination E_h (average)	0.80 fc	0.44 fc	0.37 fc	0.39 fc	0.30 fc
Ratio $\frac{E \text{ maximum}}{E \text{ (average)}}$ (horizontal only)	6.0	8.0	9.2	4.1	4.6
Vertical Illumination, E_v (average)	0.29 fc	0.13 fc	0.12 fc	0.19 fc	0.15 fc
Modelling Factor (vertical illumination ratio)	1.8	3.1	2.7	1.5	1.7
Adaptation Brightness, B_a	3.1 fl	1.5 fl	1.2 fl	2.1 fl	1.5 fl
Average Roadway Brightness, B_r	0.18 fl	0.02 fl	0.01 fl	0.03 fl	0.02 fl
Ratio $\frac{B_r \text{ (maximum)}}{B_r \text{ (average)}}$	14.3	65.5	131.0	23.3	26.0
Transition Brightness	Good	Poor	Poor	Fair	Fair
Object Contrast	Good	Poor	Poor	Fair	Fair
Visibility Index	Good	Poor	Poor	Fair	Fair
Glare Rating	Poor	Poor	Poor	Poor	Poor
Overall Rating	Fair	Poor	Poor	Fair	Poor

SUMMARY

TEXAS CITY APPROACH

Quantity	Lighting System 30 ft continuous	30 ft intermediate	30 ft minimum	45 ft intermediate	45 ft minimum
Horizontal Illumination E_h (average)	0.84 fc	0.46 fc	0.43 fc	0.30 fc	0.30 fc
Ratio $\frac{E\ maximum}{E\ average}$ (horizontal only)	5.6	9.9	10.5	3.7	3.7
Vertical Illumination, E_v (average)	0.39	0.20	0.18	0.28	0.27
Modeling Factor (vertical illumination ratio)	6.8	9.0	8.0	19.0	18.0
Adaptation Brightness, B_a	2.3 fl	1.5 fl	1.3 fl	2.2 fl	1.8 fl
Average Roadway Brightness, B_r	0.08 fl	0.06 fl	0.05 fl	0.08 fl	0.06 fl
Ratio $\frac{B_r(maximum)}{B_r(average)}$	14.8	12.0	14.4	7.9	8.2
Transition Brightness	Good	Poor	Poor	Fair	Fair
Object Contrast	Good	Poor	Poor	Fair	Fair
Visibility Index	Fair	Poor	Poor	Fair	Poor
Glare Rating	Poor	Poor	Poor	Poor	Poor
Overall Rating	Fair	Poor	Poor	Fair	Poor

CONCLUSIONS AND RECOMMENDATIONS

The lighting studies at the Texas City Wye on Route 3 from Houston to Galveston, Texas, have developed a mass of data that have been used to demonstrate a number of significant lighting design features. Some of these are listed below.

1. The complete brightness pattern of the roadway and the surround is the all inclusive concept to keep in mind for design, evaluation or use purposes.
2. The brightness pattern must include elements for orientation and guidance as well as provide the necessary contrasts for form perception and detail visibility.
3. The complete roadway scene from the driver to 400 or 500 feet ahead should be tied together visually by a meaningful array of continuous lines, areas and shapes all with adequate contrast well above threshold levels.
4. On the roadway area between the entrance and the exit regions of the intersection, objects on or above the roadway should be readily visible.
5. The extraneous brightnesses in the field of view such as the overhead lights should be reduced as much as possible to provide relief from discomfort glare.
6. The brightest area in the field of view should be along the line of sight at the roadway level. All entrance and exit directions to the intersection should decrease in brightness away from the central area.
7. The brightness levels within and on the approaches to the intersection should be adjusted in accordance with the driver's adaptation level determined from his prior exposure preceding his approach to the lighted area. The adaptation brightness should be mainly determined by the roadway brightness and should be two to three times the brightness of the adjacent areas.

The above seven statements are in accordance with the definition of the desired visual conditions as given in the IES Handbook: "Good Visibility on Roadways at night results from lighting which provides adequate pavement brightness with good uniformity and appropriate illumination of adjacent areas, together with reasonable freedom from glare."

The individual lighting conditions in each approach direction have been examined and compared with the above generalized statements.

The 30-foot continuous system in either approach direction is generally superior to the others except that the glare is highest for this system.

The 45-foot intermediate system is better than the 30-foot continuous system insofar as glare is concerned. It also has more uniform pavement brightness distribution and better brightness transitions but the brightness pattern does not extend far enough ahead of the intersection.

The other systems are generally inadequate and should not be considered for other areas that are to be lighted in the future.

Recommended Changes

In order to improve the lighting conditions at the intersection, several features could be added and several modifications could be made to the existing installation. A few ideas are listed below for the Galveston approach direction. The same principles could be extended to the other approach directions.

Galvestion approach:

1. Improve the transition zone lighting by adding one luminaire, 100 feet ahead of light no. 7. This should have a shielded 175 Hg lamp mounted at 25 feet. Change light no. 7 to a 250 W Hg lamp at 30 feet. Use 400 W Hg lamps mounted at 45 feet in both no. 8 and 9 luminaires.
2. Shield all luminaires to cut off the main beam at approximately 3.5 times the mounting height along the roadway.
3. Add reflex reflector roadway delineators on the center lines out to 500 feet from the island. Install where painted lines are now used.
4. Add lighted delineator guidance lights on the curbs around the islands.

The above minor changes plus new signing should greatly improve the Galveston approach direction. The principles established in this report and demonstrated by such a modified system could lead to a set of ground rules that could be applied to other similar areas in the future.

LIGHT NO.	MOUNTING HEIGHT	CONTINUOUS SYSTEM	INTERMEDIATE SYSTEM	MINIMUM SYSTEM
1	30'	✓		
2	30' & 45'	✓	✓	✓
3	30'	✓		
4	30' & 45'	✓	✓	
5	30' & 45'	✓	✓	✓
6	30'	✓		
7	30'	✓		
8	30' & 45'	✓	✓	✓
9	30'	✓		
10	30' & 45'	✓	✓	✓
11	30'	✓		
12	30'	✓		
13	30' & 45'	✓	✓	
14	30'			
15	30' & 45'	✓	✓	
16	30' & 45'	✓	✓	✓

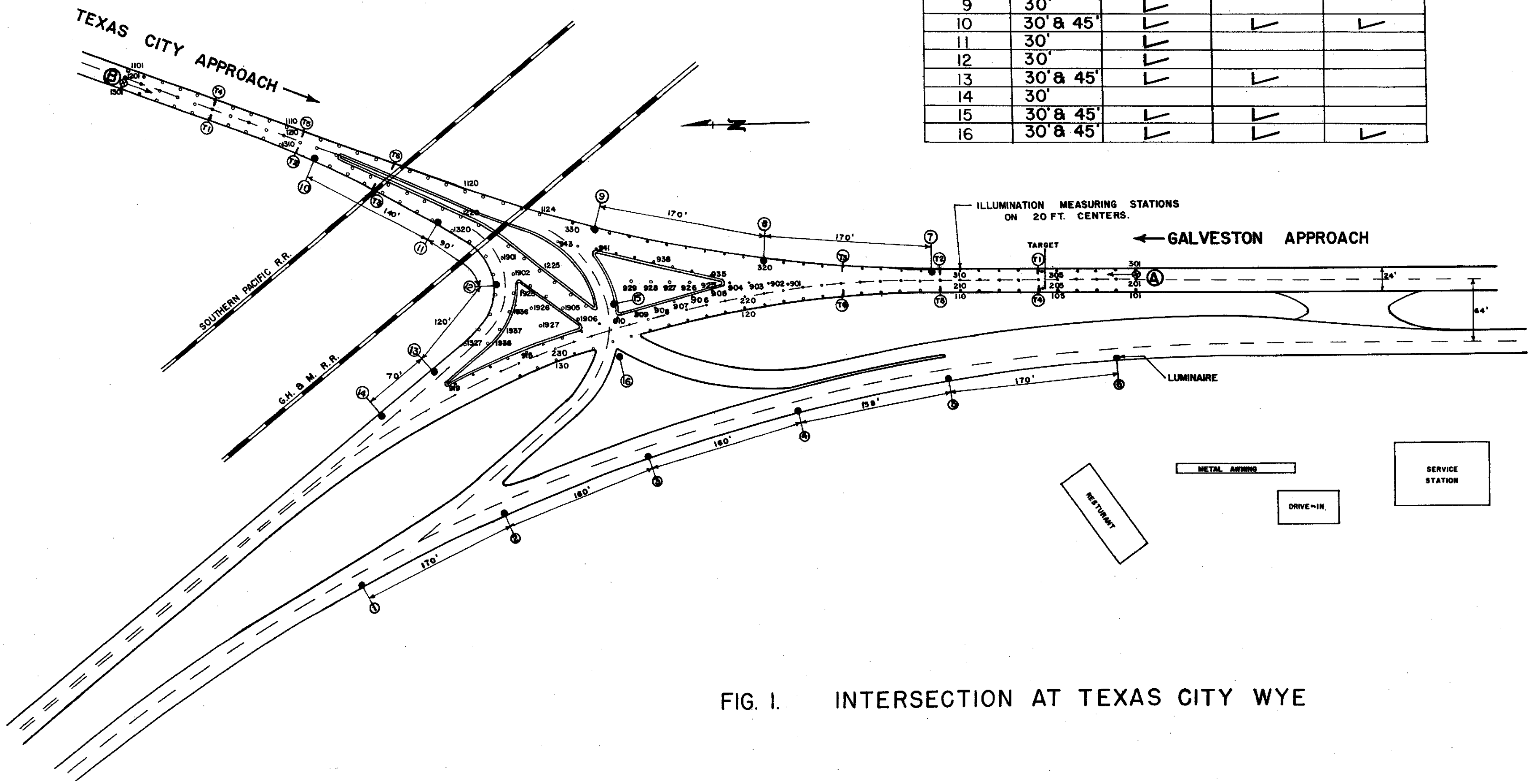
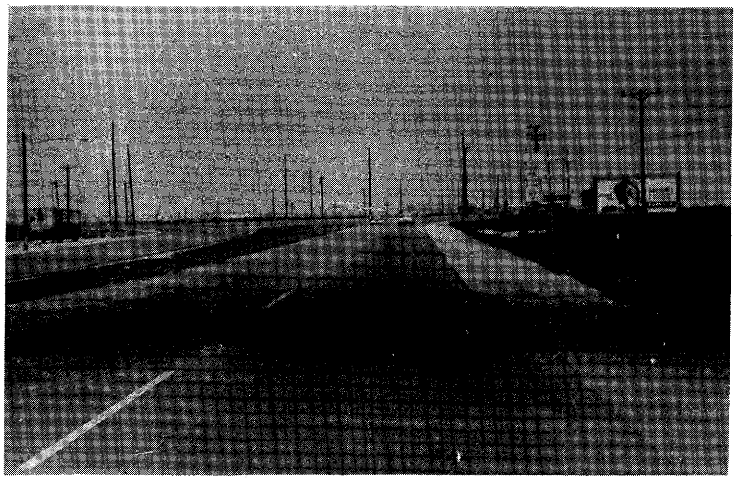
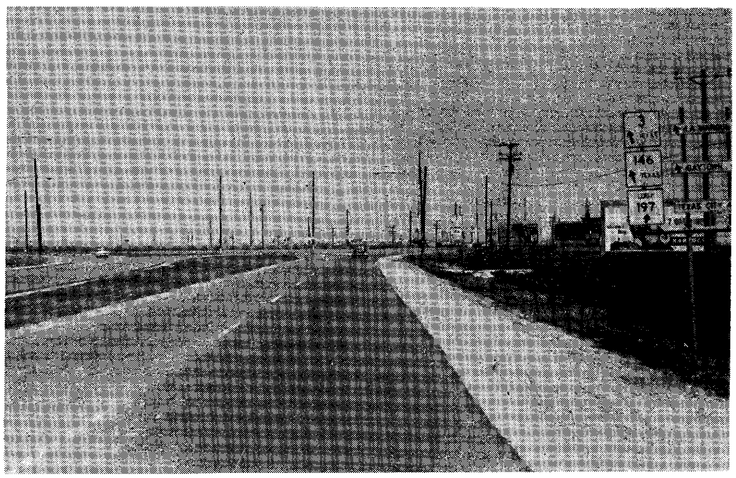


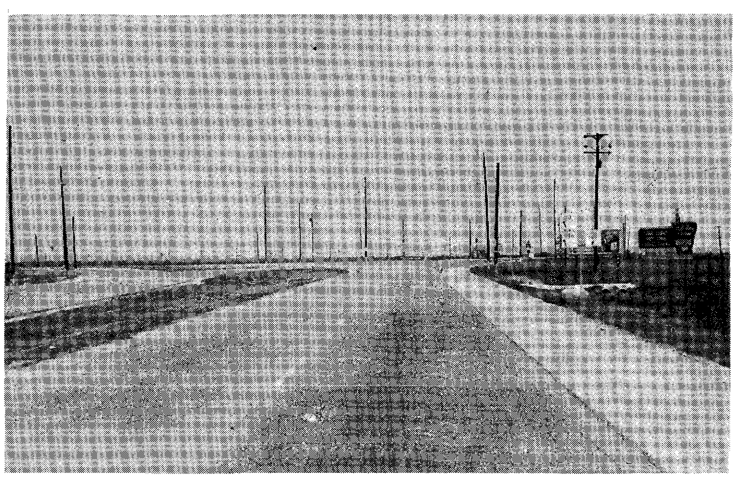
FIG. 1. INTERSECTION AT TEXAS CITY WYE



500 ft from
First Light (#7)

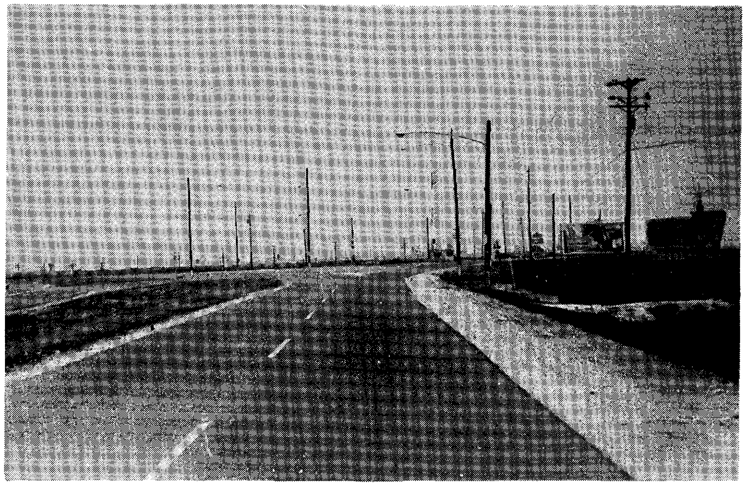


400 ft from
First Light (#7)

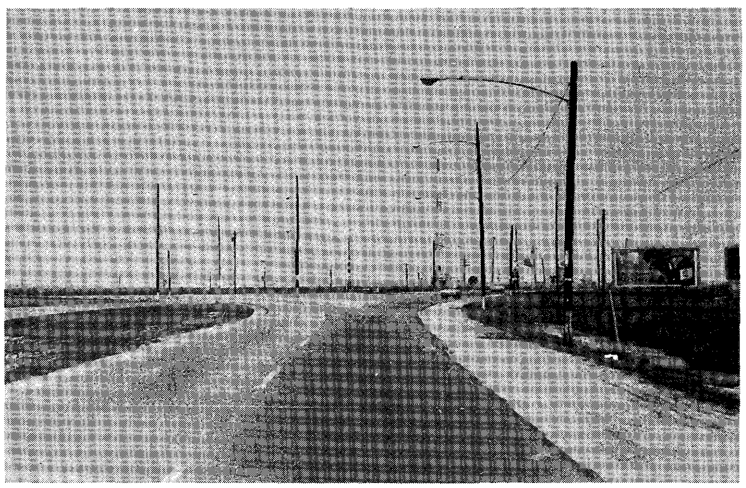


300 ft from
First Light (#7)

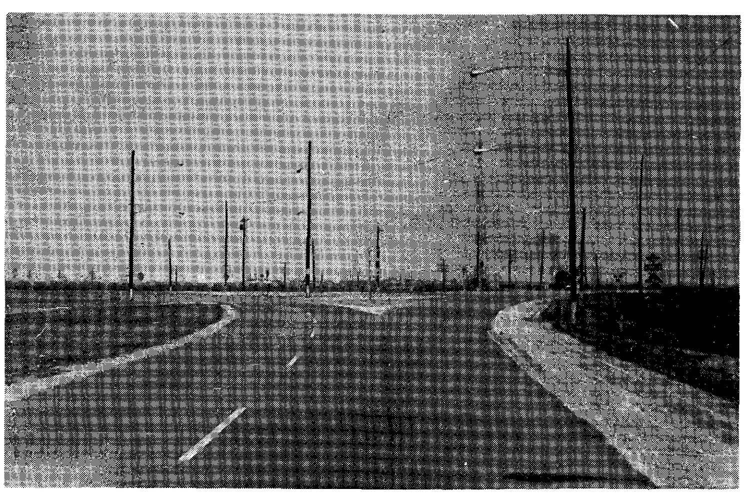
Fig. 2a Galveston Approach



200 ft from
First Light (#7)
Location for
Nighttime
Brightness
Measurements

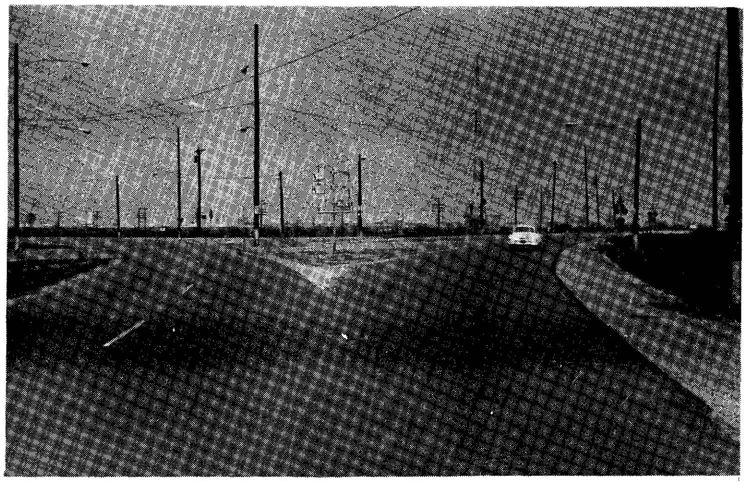


100 ft from
First Light (#7)

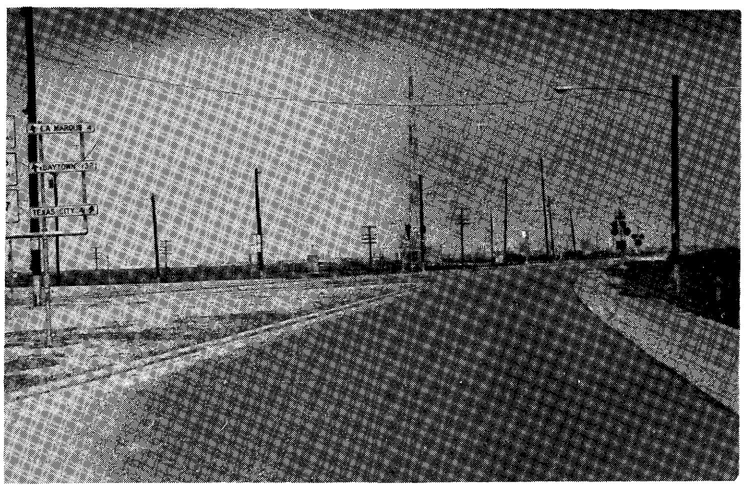


Under First
Light (#7)

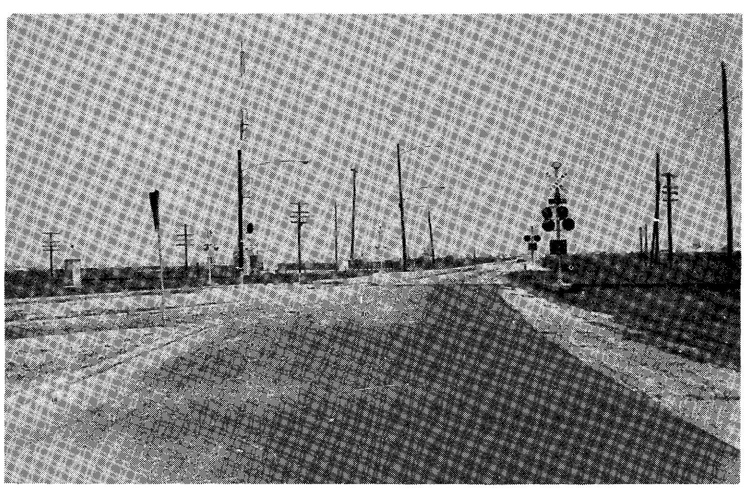
Fig. 2b Galveston Approach



100 ft Beyond
First Light (#7)
on Texas City
Turn-off

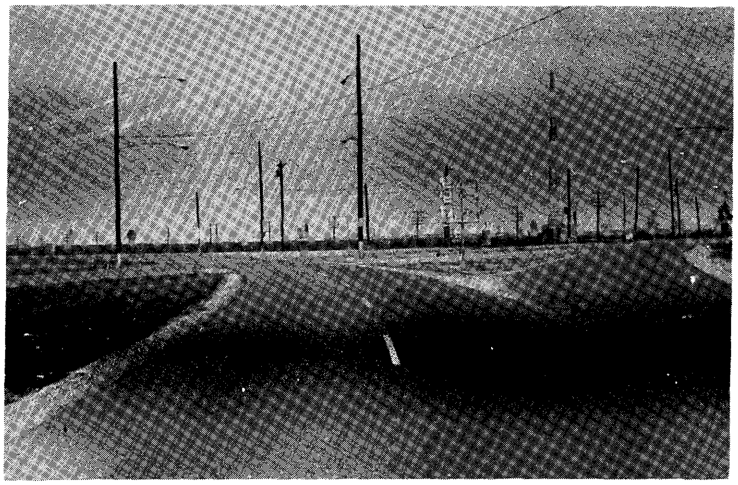


200 ft Beyond
First Light (#7)
on Texas City
Turn-off

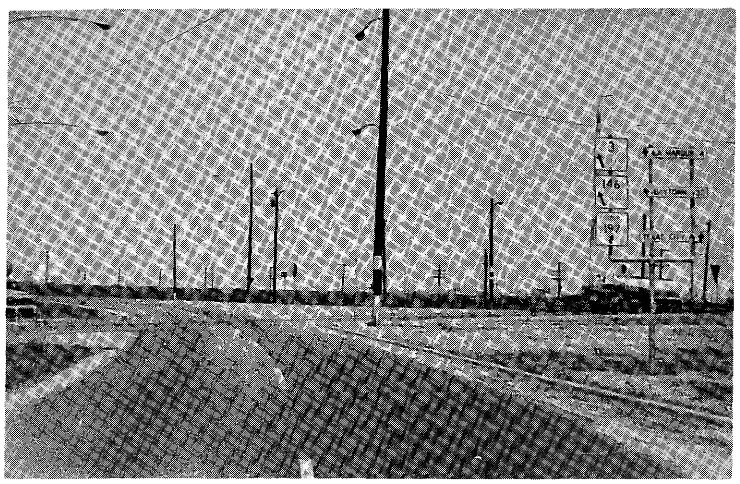


300 ft Beyond
First Light (#7)
on Texas City
Turn-off

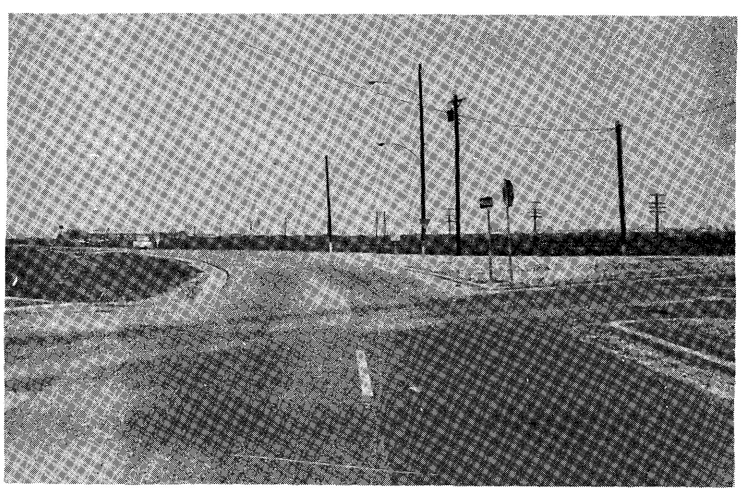
Fig. 2c Galveston Approach



100 ft Beyond
First Light (#7)
on La Marque
Turn-off

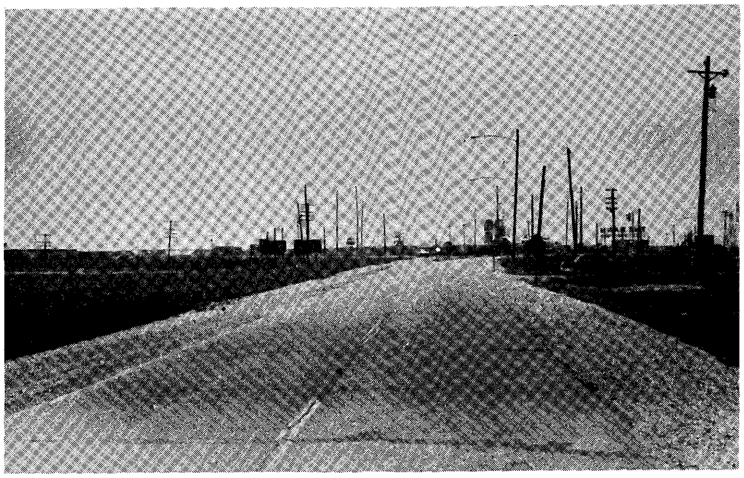


On La Marque
Turn-off
200 ft Beyond
First Light (#7)

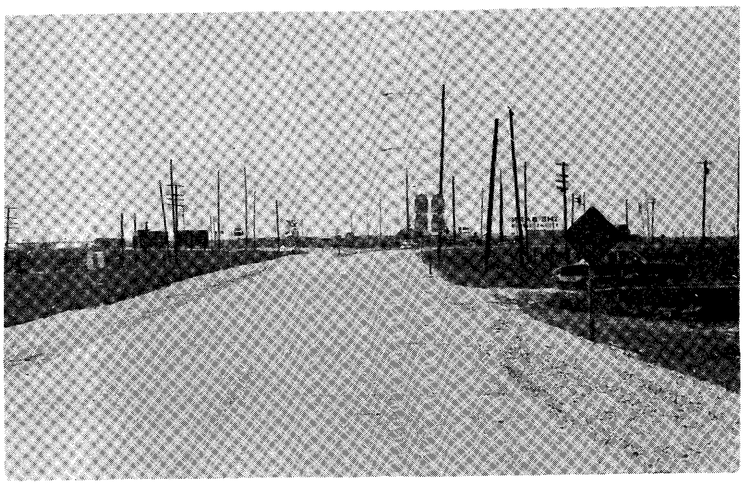


On La Marque
Turn-off
300 ft Beyond
First Light (#7)
At Texas City--
Galveston
Cross Road

Fig. 2d Galveston Approach



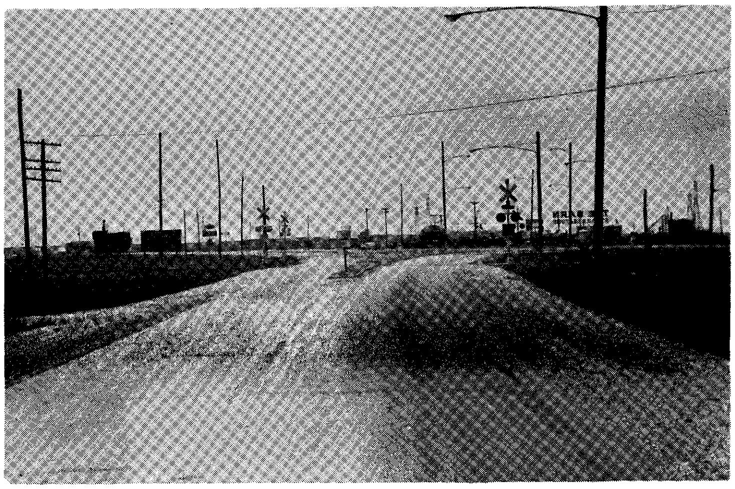
400 ft from
First Light (#10)



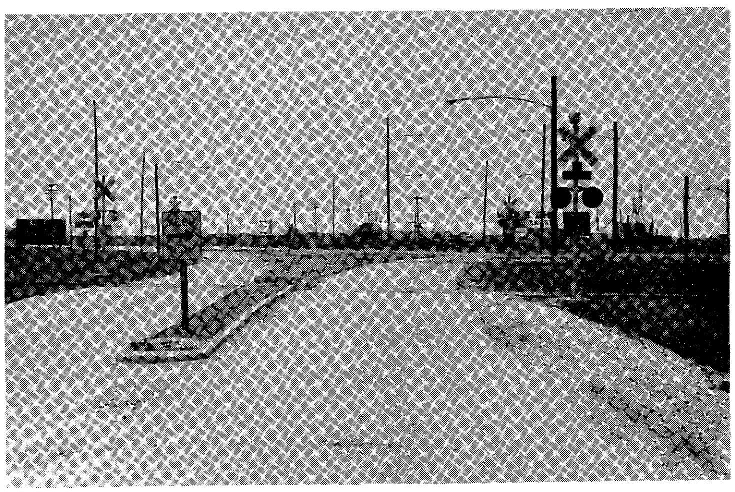
300 ft from
First Light (#10)

200 ft from
First Light (#10)
Location for
Nighttime
Brightness
Measurements

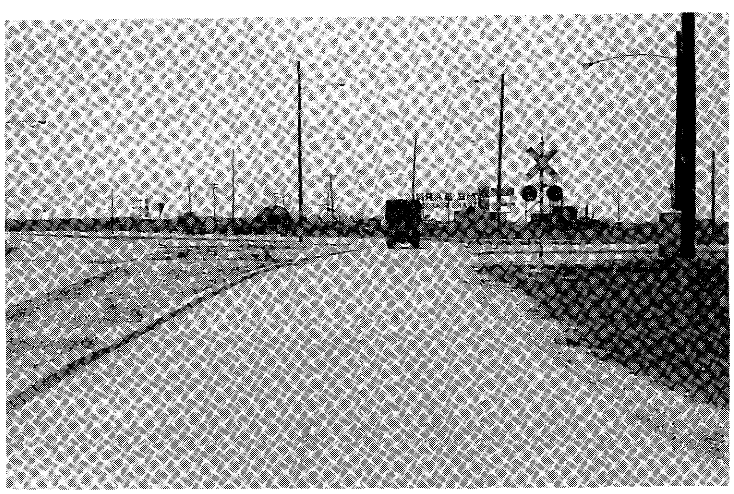
Fig. 3a   Texas City Approach



100 ft from
First Light (#10)

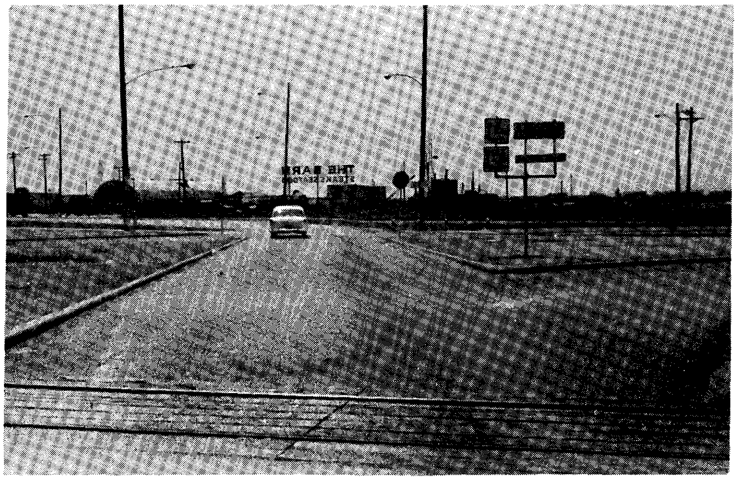


Under First
Light (#10)

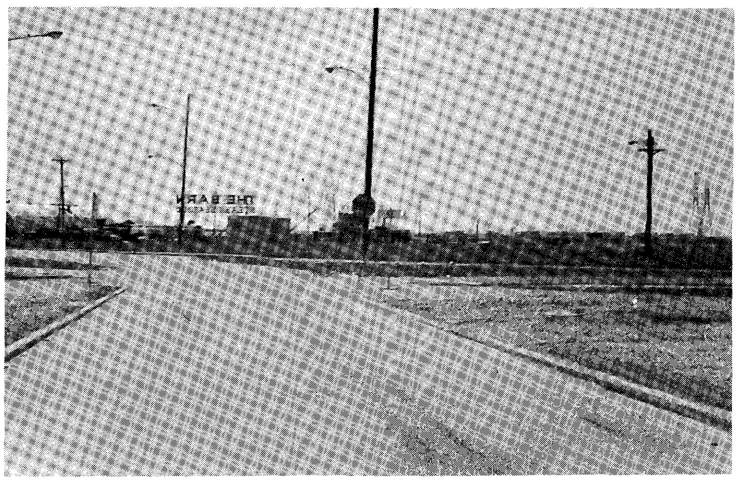


At First Railroad
Crossing

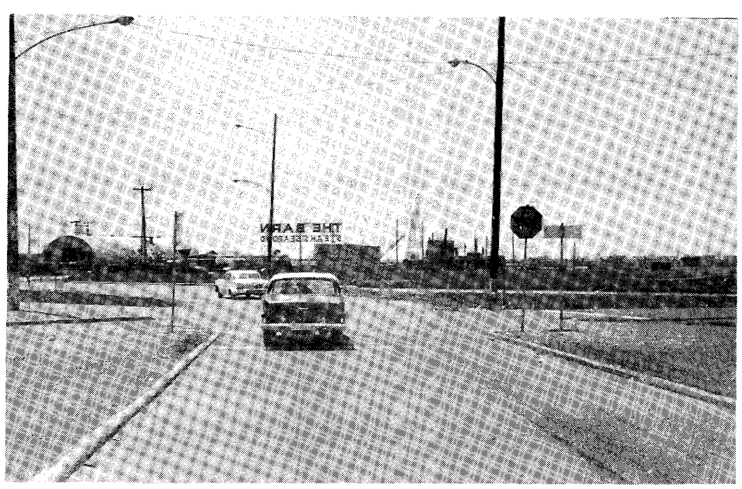
Fig. 3b Texas City Approach



At Second Railroad Crossing



Toward Galveston 100 ft Beyond Second Railroad Crossing

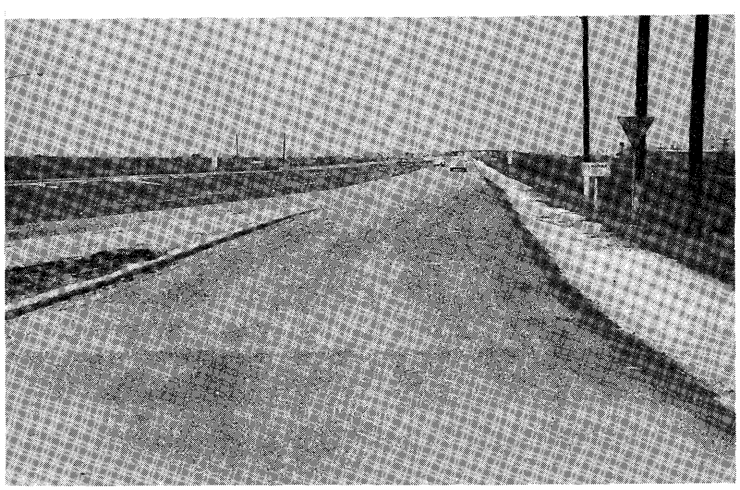


Toward Galveston at La Marque-- Texas City Cross Roadway 200 ft Beyond Second Railroad Crossing

Fig. 3c Texas City Approach

At La Marque
Turn-off

On Turn-off
to La Marque



Around Turn-off
Toward La Marque

Fig. 3d Texas City Approach

Fig. 4 Galveston Approach 200 ft Ahead of First Light (#7)

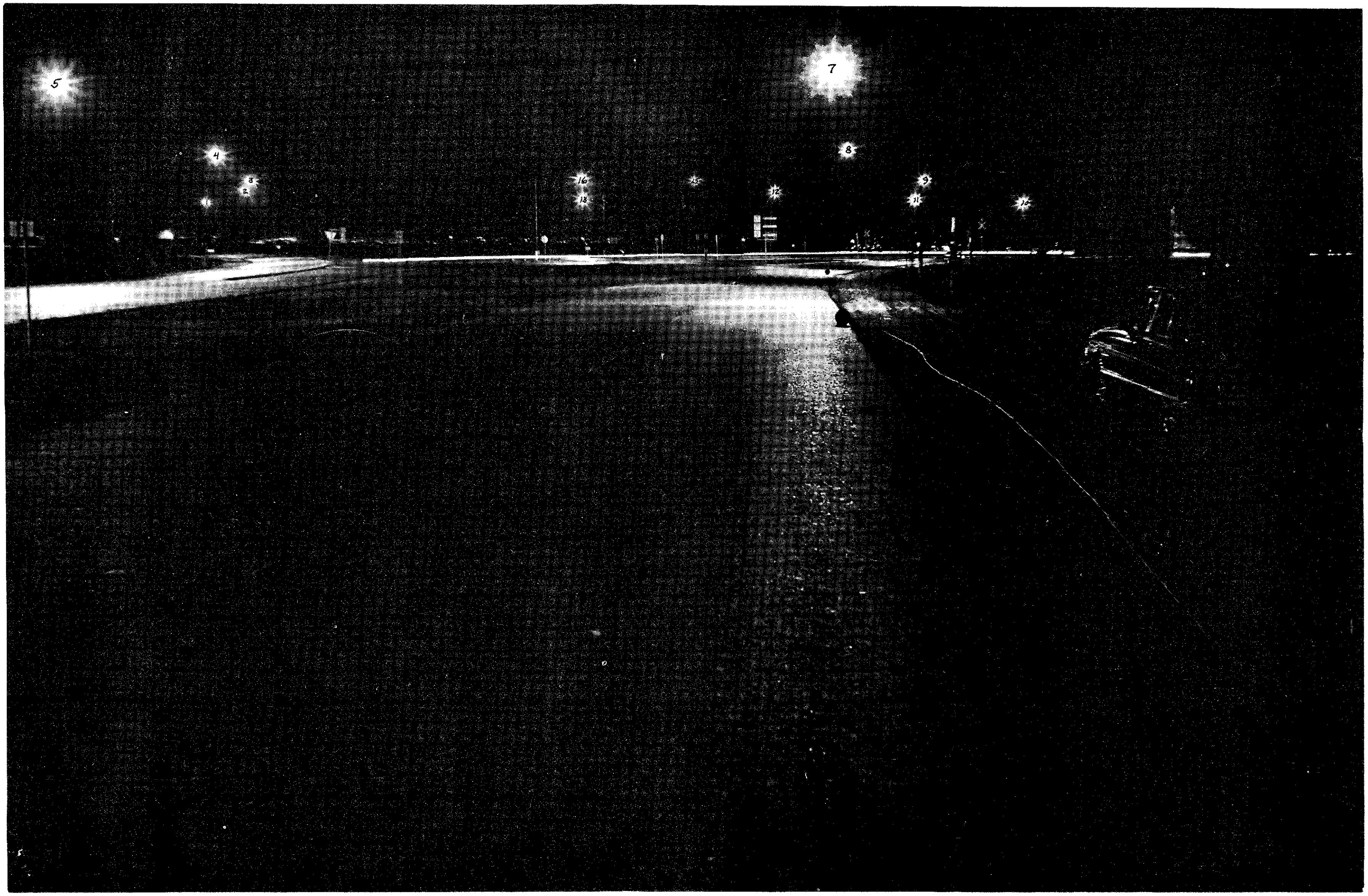


Fig. 5 Galveston Approach 30 ft Continuous System

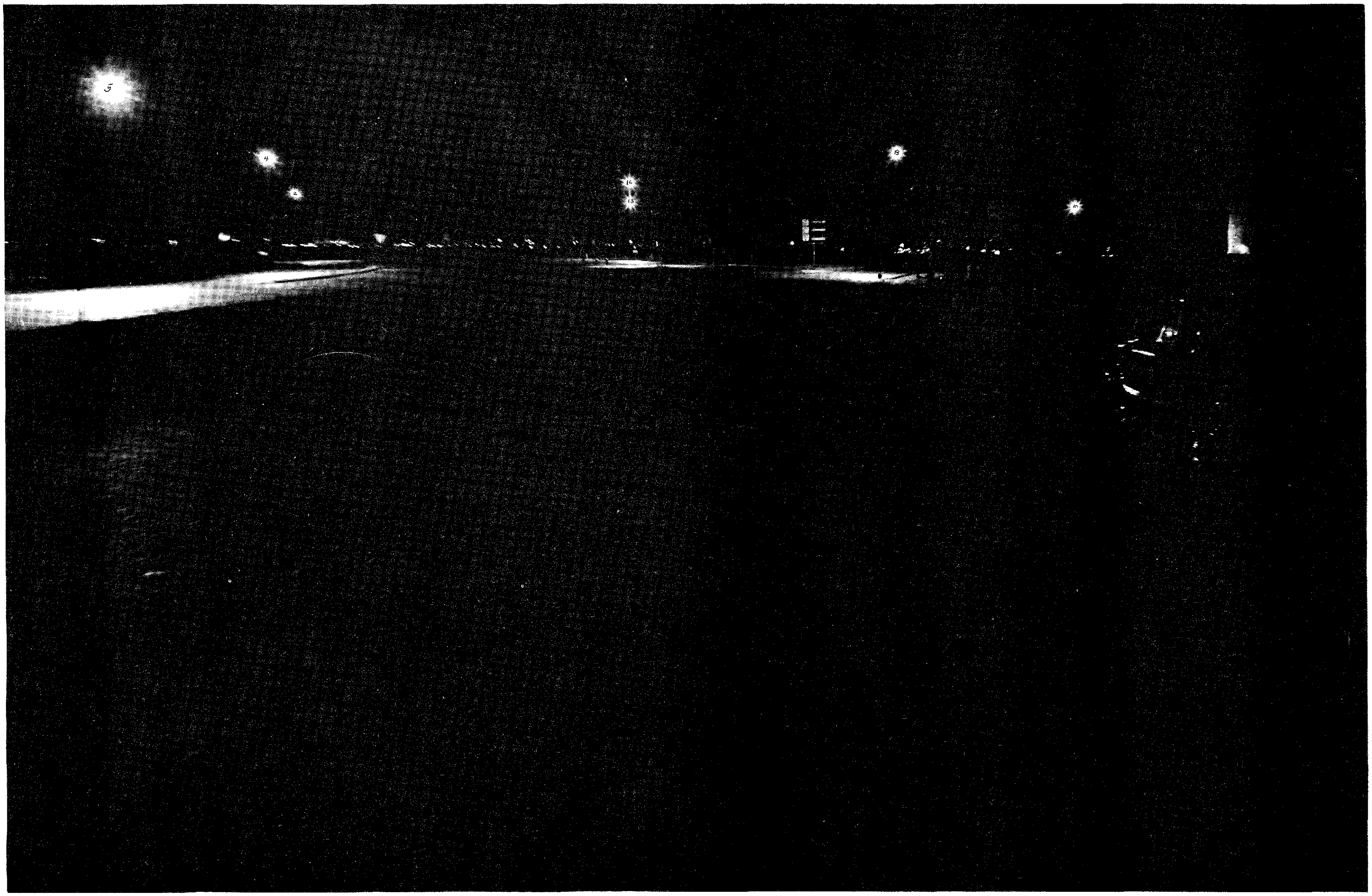


Fig. 6 Galveston Approach 30 ft Intermediate System

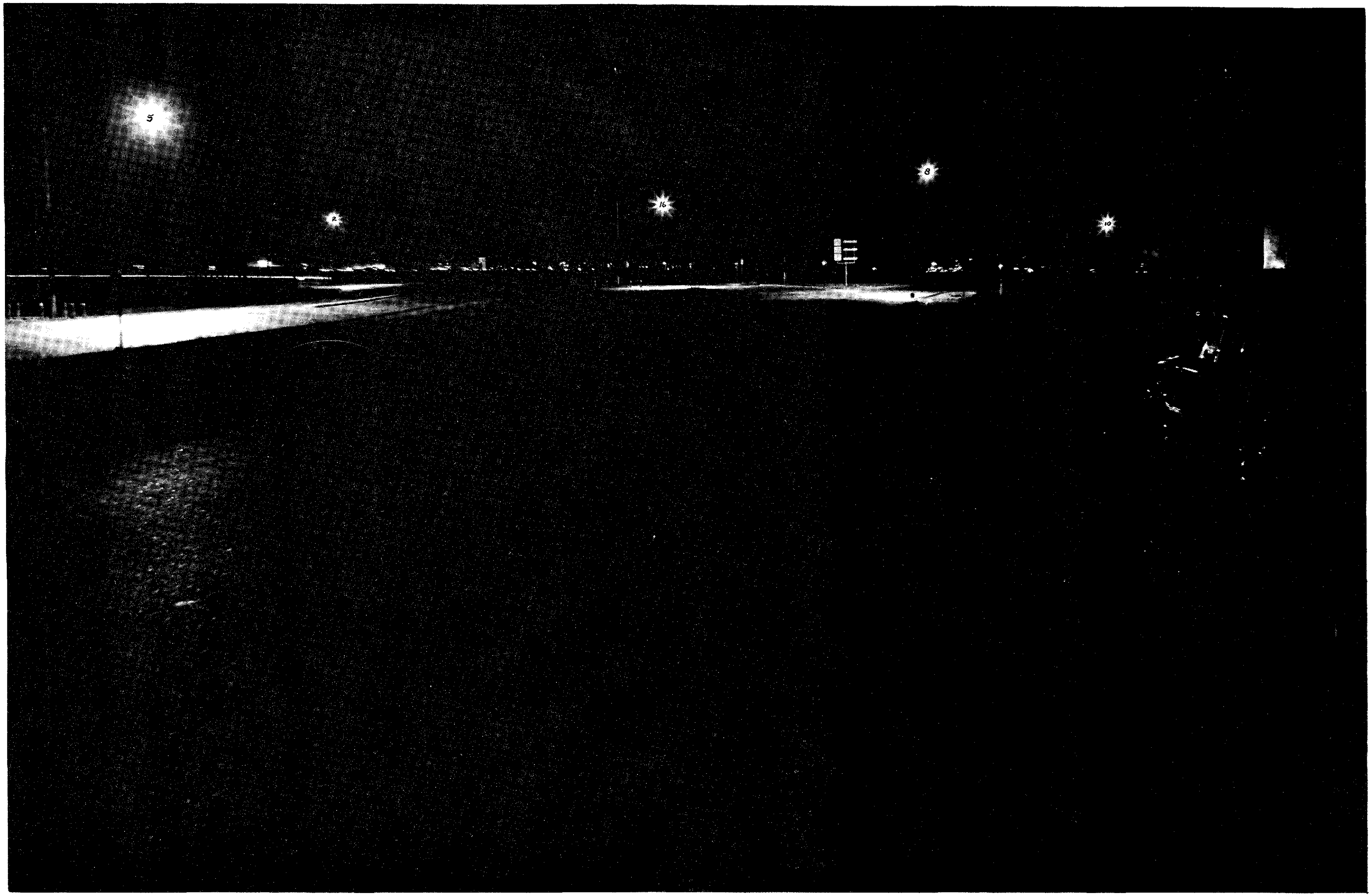


Fig. 7 Galveston Approach 30 ft Minimum System

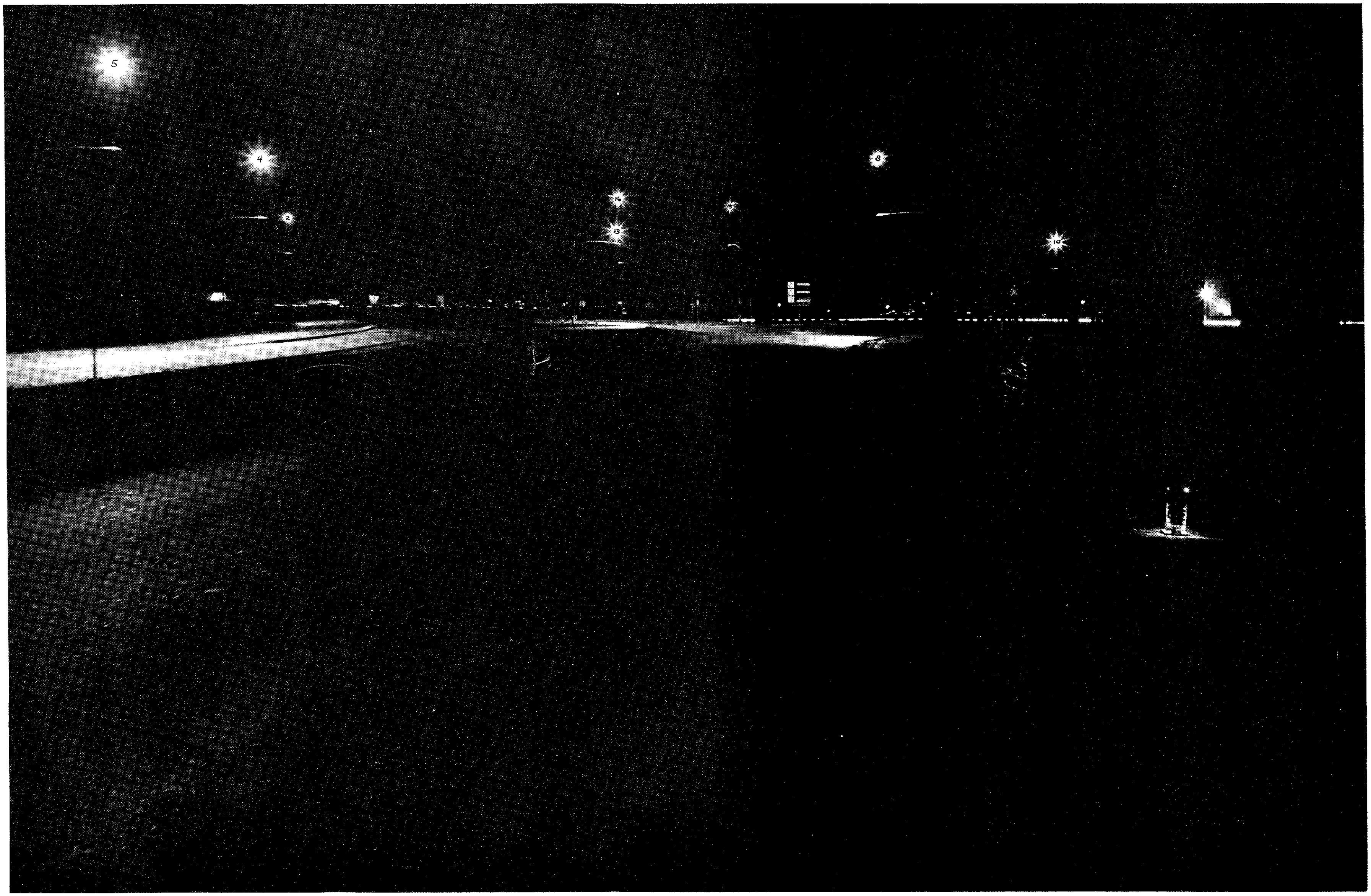


Fig. 8 Galveston Approach 45 ft Intermediate System

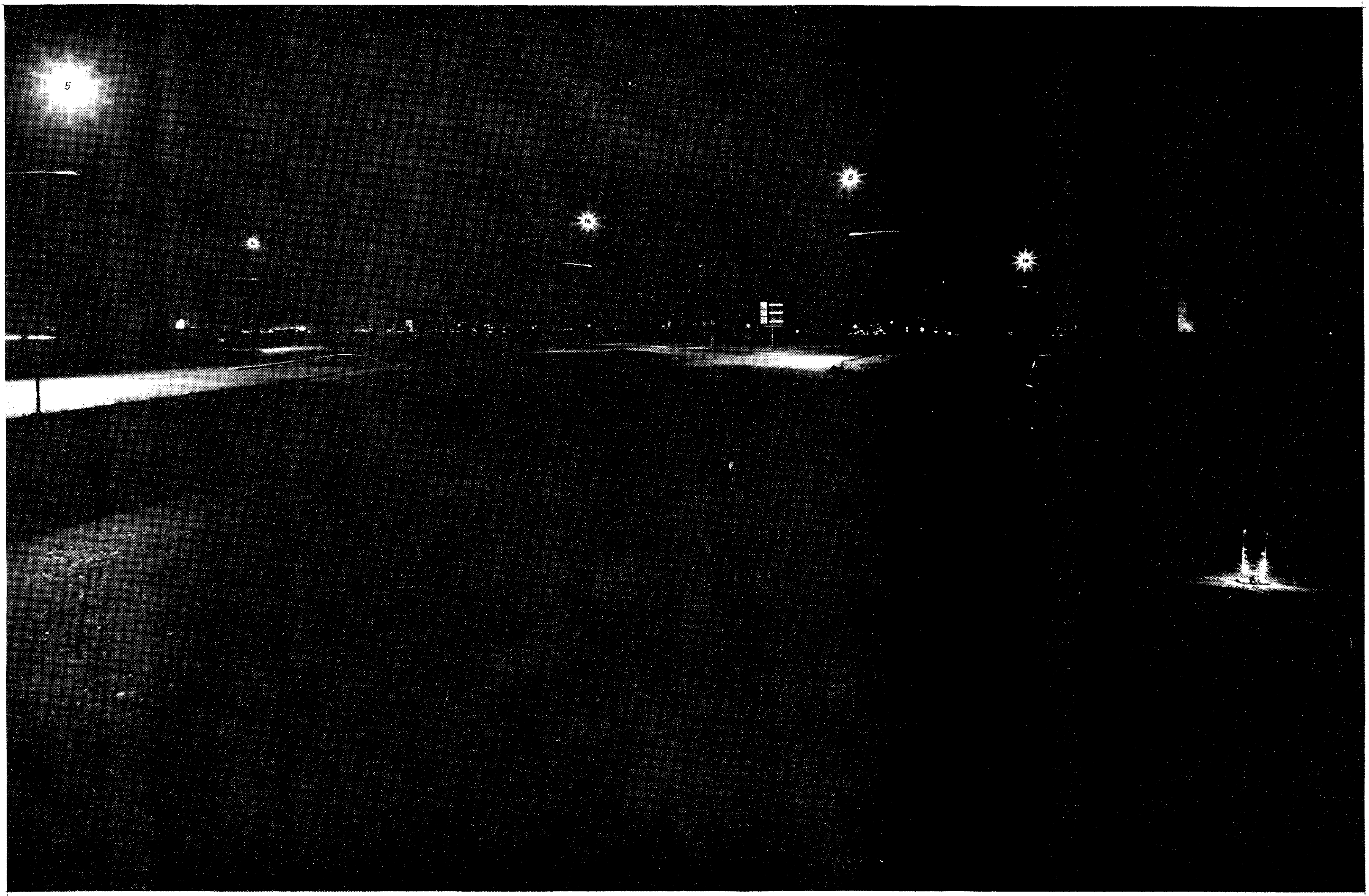


Fig. 9 Galveston Approach 45 ft Minimum System

Fig. 10 Texas City Approach 200 ft Ahead of First Light (#10)

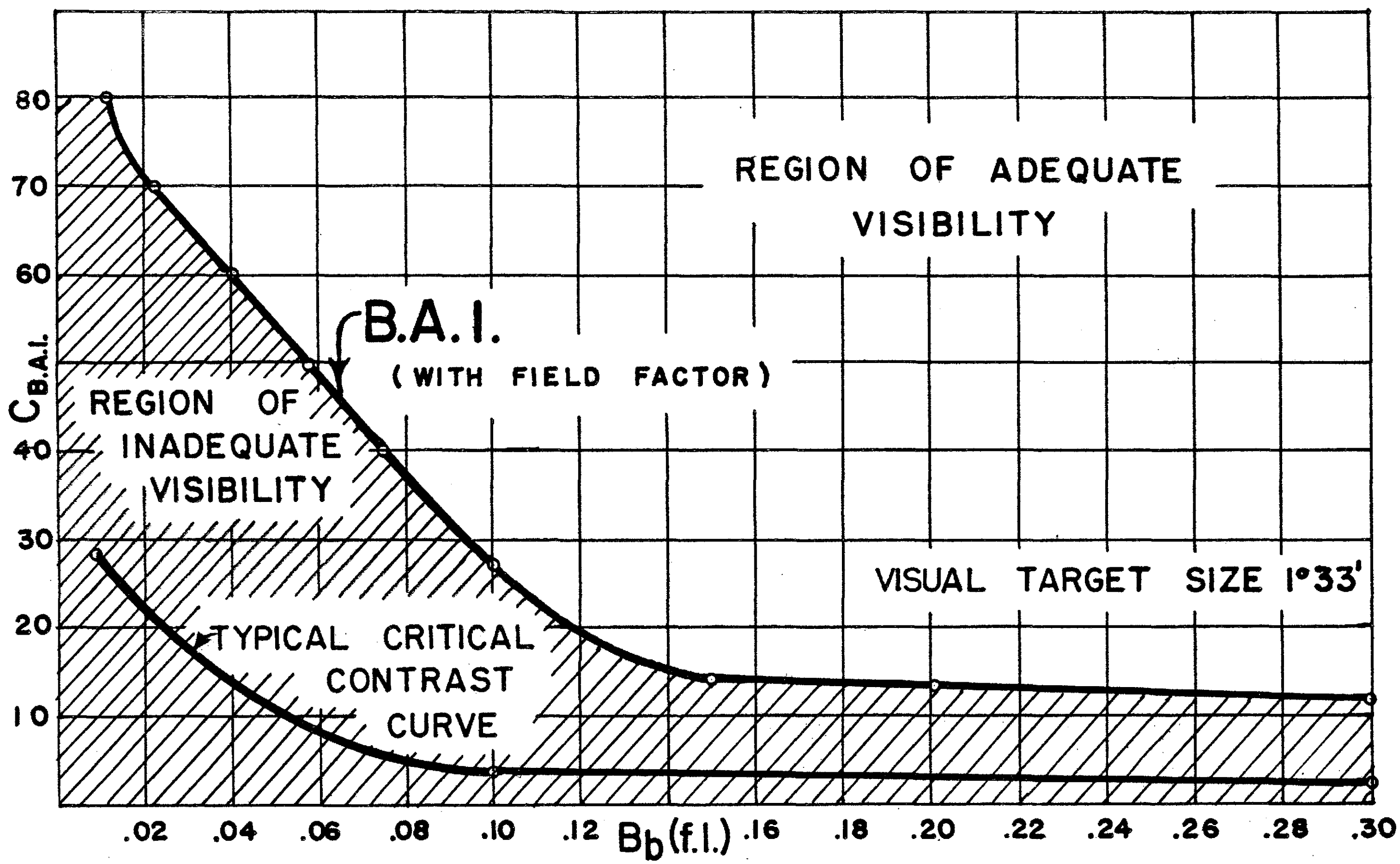
Fig. 11 Texas City Approach 30 ft Continuous System

Fig. 12 Texas City Approach 30 ft Intermediate System

Fig. 13 Texas City Approach 30 ft Minimum System

Fig. 14 Texas City Approach 45 ft Intermediate System

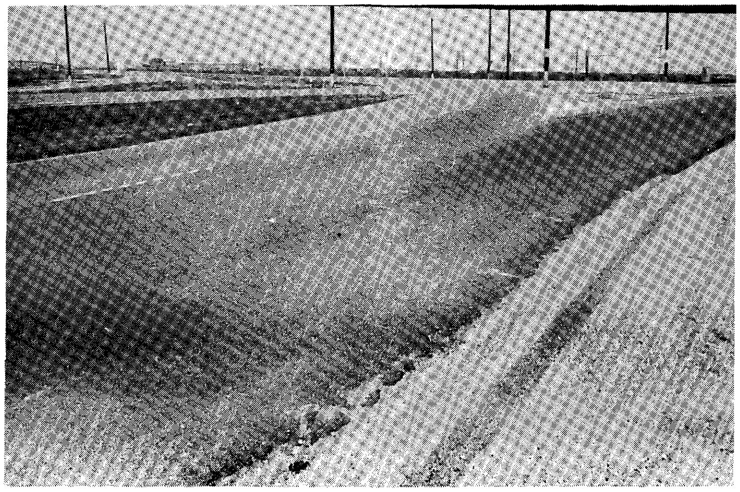
Fig. 15 Texas City Approach 45 ft Minimum System



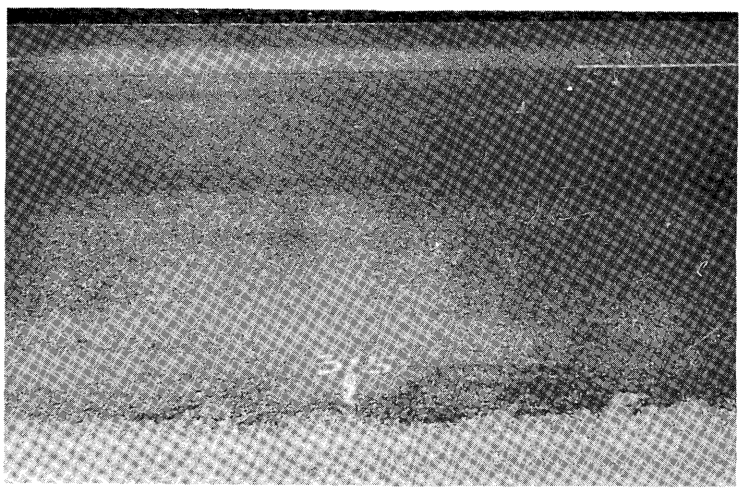
HIGHWAY LIGHTING

BORDERLINE BETWEEN ADEQUATE AND INADEQUATE VISIBILITY

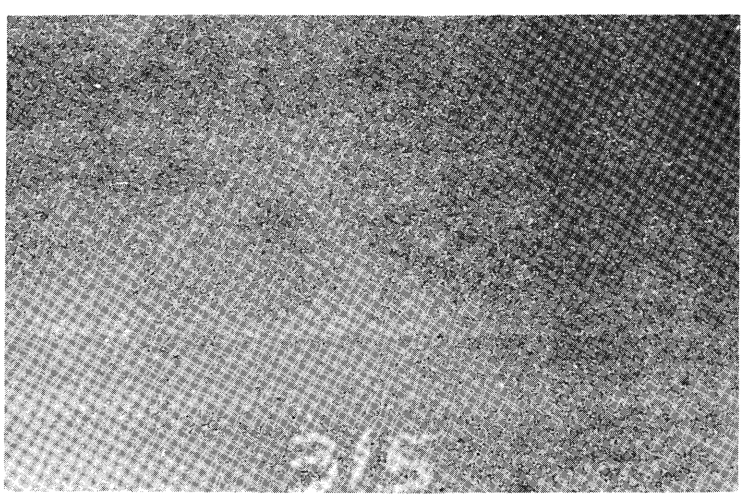
FIGURE 16



Roadway Location for Brightness Factor Measurements on Galveston Approach New-laid Asphaltic Concrete (2-4 months old) Station 315



General View of Measurement Area on Roadway Station 315 Between Light #7 and #8

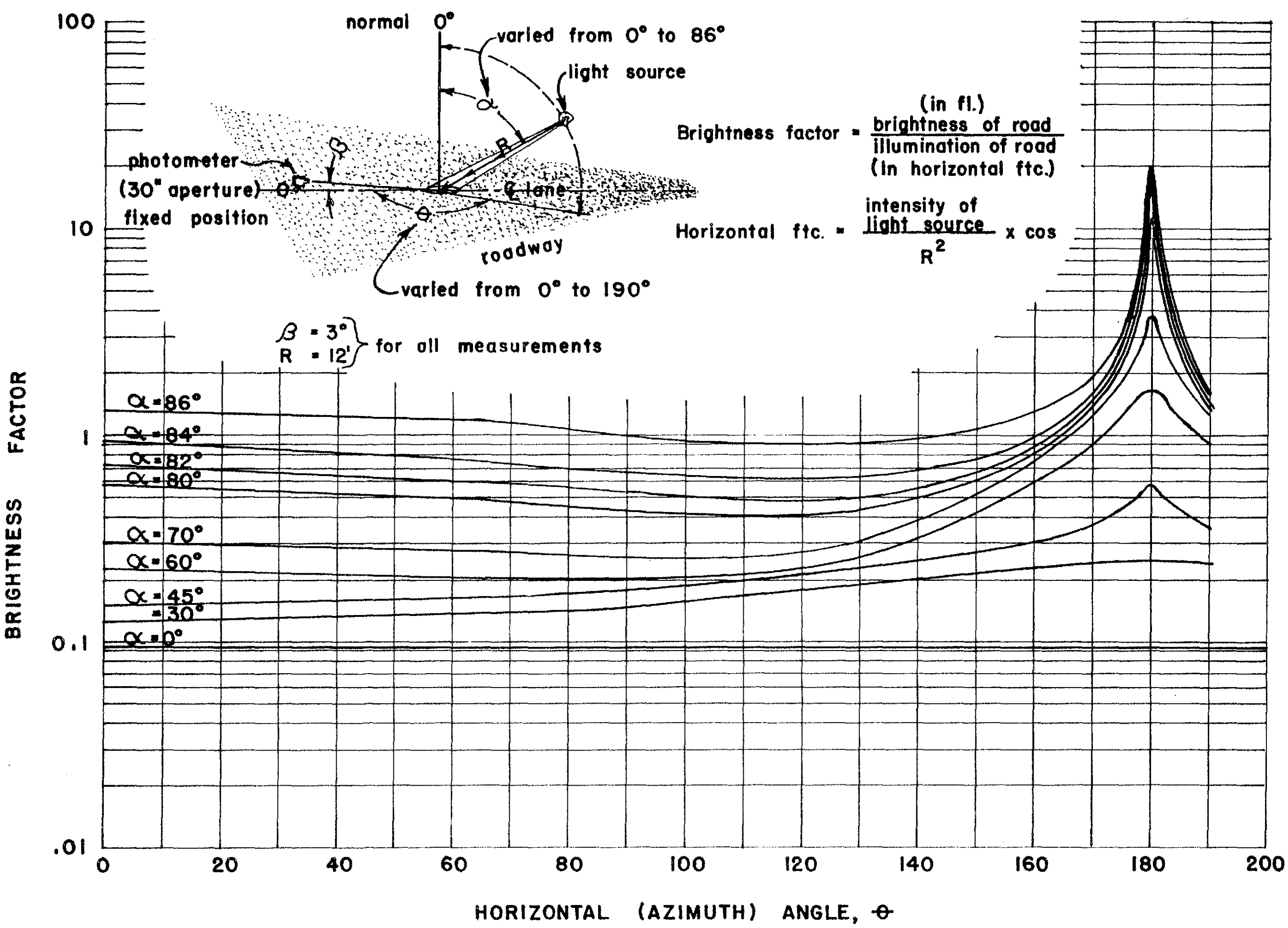


Close-up Detail of Asphaltic Concrete Surface Station 315

Fig. 17 Roadway Surface Galveston Approach

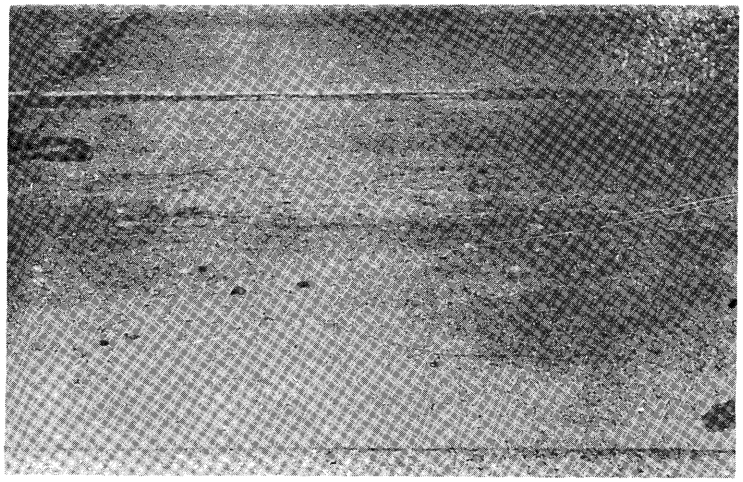
BRIGHTNESS FACTORS FOR ASPHALTIC CONCRETE
(new laid — 3 to 4 months old)

GALVESTON APPROACH AT T.C. – LA MARQUE – GALVESTON INTERCHANGE, TEXAS
MEASURING STATION 100 FEET BEYOND LAMP NO. 7
(STATION 315 ON LAYOUT DRAWING)



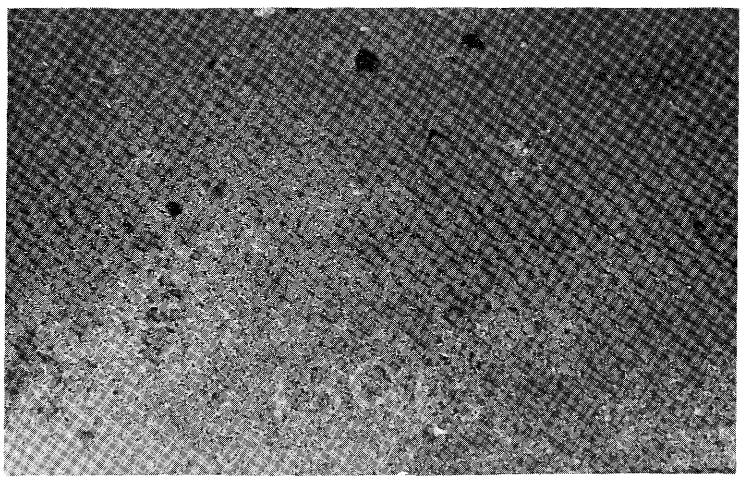
BRIGHTNESS FACTOR vs. HORIZONTAL ANGLE
FOR ASPHALTIC CONCRETE

FIGURE 18

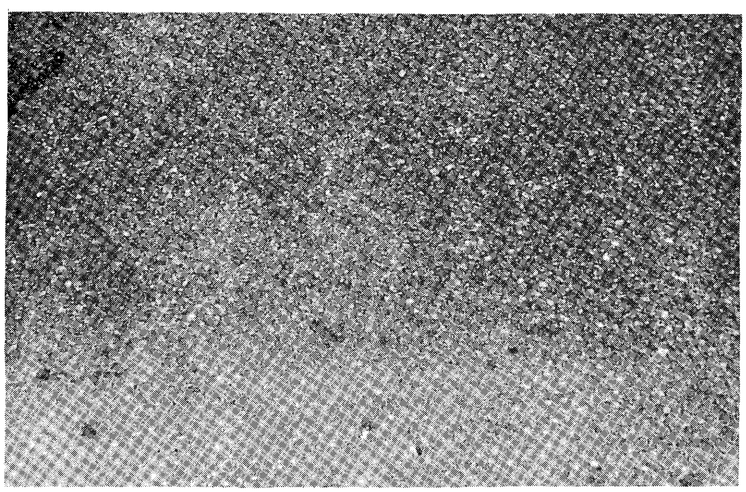


Roadway Location
for Brightness Factor
Measurements on
Texas City Approach

Traffic Worn Concrete
approximately
20 years old
Station 1301



General View of
Measurement Area
on Roadway
Station 1301
180 ft Ahead of
First Light (#10)

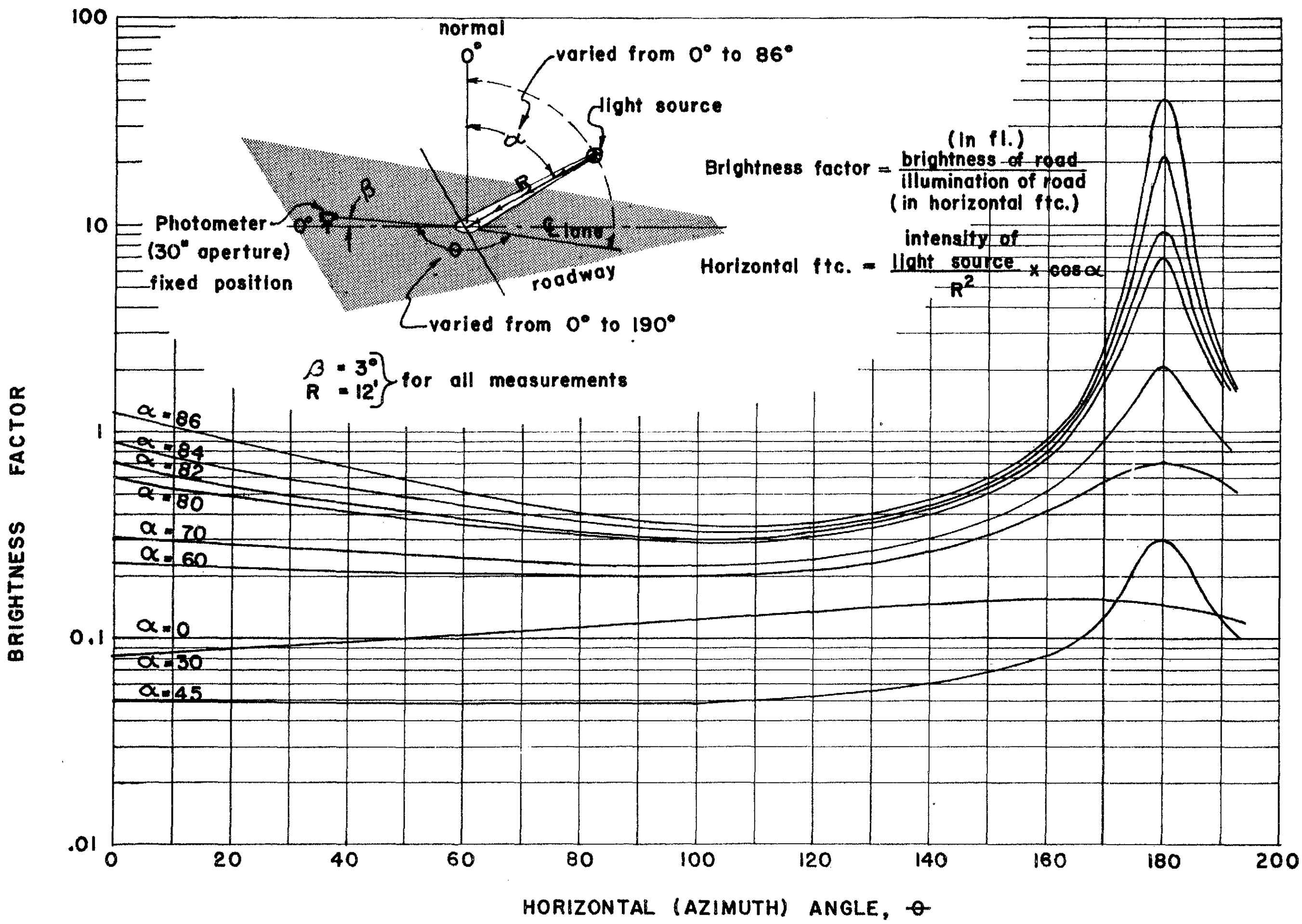


Close-up Detail
of Concrete Surface
Station 1301

Fig. 19 Roadway Surface Texas City Approach

BRIGHTNESS FACTORS FOR TRAFFIC WORN CONCRETE
(approx. 20 years old)

TEXAS CITY APPROACH AT T. C.– LA MARQUE – GALVESTON INTERCHANGE, TEXAS
MEASURING STATION IN RIGHT LANE, 100 FT. AHEAD OF LAMP NO. 10
(STATION 1305 ON LAYOUT DRAWING)



BRIGHTNESS FACTOR vs. HORIZONTAL ANGLE
FOR TRAFFIC WORN CONCRETE

FIGURE 20

Fig. 21 Texas City Approach 30 ft Minimum System <u>Light Fog</u>

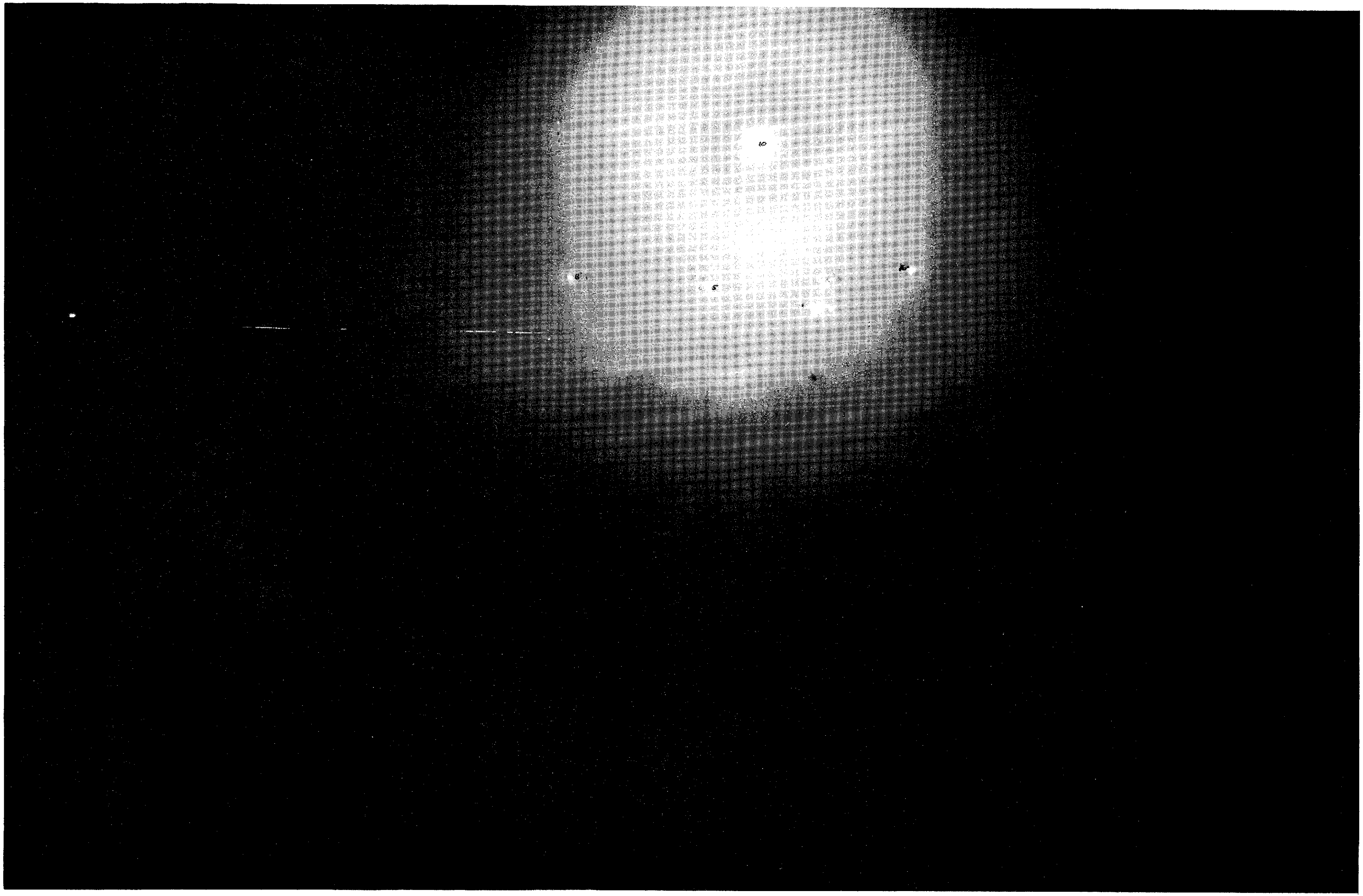


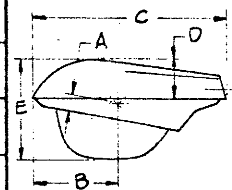
Fig. 22 Texas City Approach 30 ft Minimum System <u>Medium Fog</u>

FE 315 C

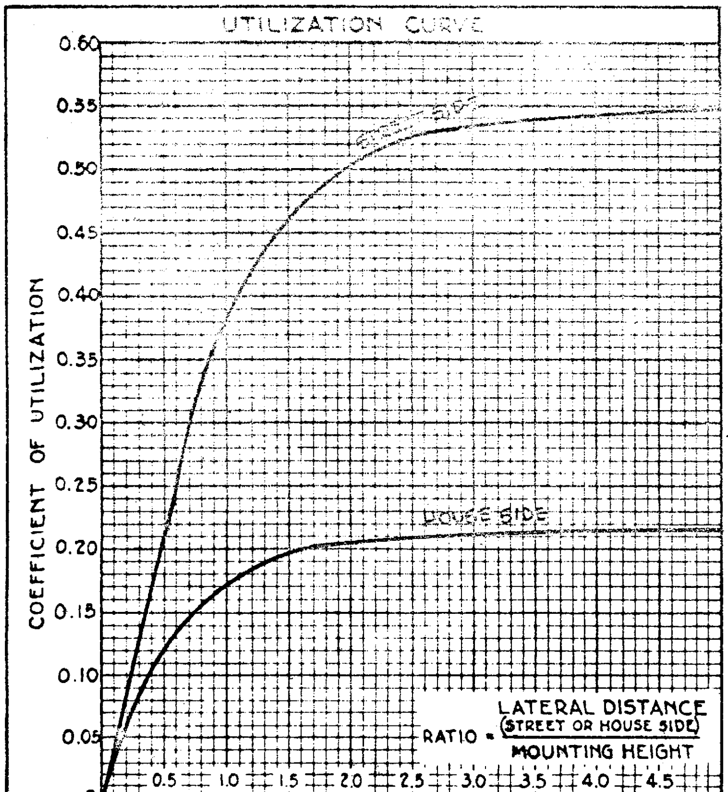
PHOTOMETRIC DATA

LAMP DATA
SERVICE MULTIPLE
LUMENS BARE LAMP 21,000
AMPS.
WATTS 400 (NOMINAL)
VOLTS
BULB BT-37 CLEAR
BASE MOGUL SCREW
FILAMENT E-HI MERCURY
FILAMENT LENGTH
FILAMENT WIDTH
LIGHT CENTER LENGTH 7"
BURNING POSITION 10° ABOVE HORIZONTAL

LIGHT FLUX VALUES	LUMENS	PERCENT OF LAMP
DOWNWARD STREET SIDE	11750	56.0
UPWARD STREET SIDE	448	2.1
DOWNWARD HOUSE SIDE	4640	22.1
UPWARD HOUSE SIDE	318	1.5
TOTAL	17156	81.7



A	2 5/32
B	7 1/2
C	26 3/4
D	5 5/8
E	13 5/16
F	
G	



EFFECTIVE LUMENS = COEFFICIENT OF UTILIZATION X BARE LAMP LUMENS

AVERAGE HORIZONTAL FOOT CANDLES ON STREET = EFFECTIVE LUMENS / SPACING X WIDTH OF STREET

TEST DISTANCE — 25 FT.

REFLECTOR — SPECULAR ALZAK ALUMINUM

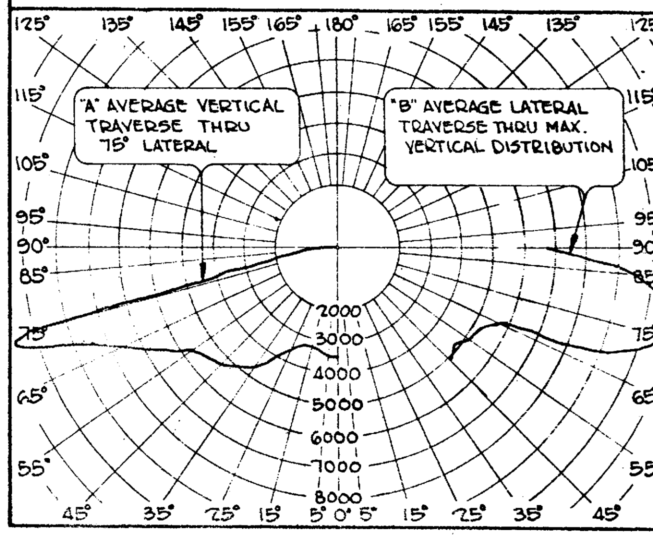
TEST CONDITIONS — LAMP STATIONARY TITLED 10° ABOVE HORIZONTAL

WESTINGHOUSE TYPE OV-25 LUMINAIRE
"SILVERLINER"
TYPE II DISTRIBUTION
WITH HOLOPHANE REFRACTOR # 4027

IES TYPE II

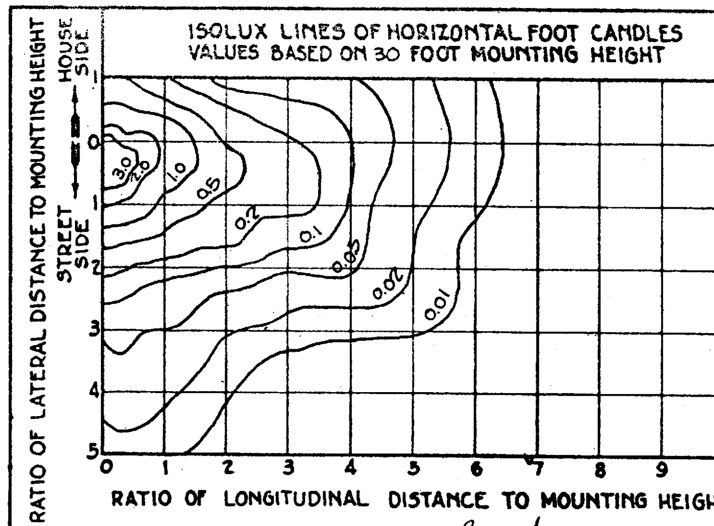
TESTED IN ACCORDANCE WITH I.E.S. GUIDE FOR PHOTOMETRIC TESTING OF STREET LIGHTING LUMINAIRES.

CANDLE POWER DISTRIBUTION



ANGLE	CANDLE POWER A	CANDLE POWER B
180°		
175°		
165°		
155°		
145°	-	
135°	57	
125°	90	
115°	147	
105°	226	
95°	362	
90°	475	6717
85°	746	9326
75°	9105	10,880
74°	10,880	—
65°	7510	5863
55°	5598	5149
45°	5248	5135
35°	4739	
25°	3506	
15°	3201	
5°	3597	
0°	3551	

ISOLUX LINES OF HORIZONTAL FOOT CANDLES
VALUES BASED ON 30 FOOT MOUNTING HEIGHT



MOUNTING HEIGHT	CORRECTION FACTOR
22	1.86
23	1.70
24	1.56
25	1.44
26	1.33
27	1.24
28	1.15
29	1.07
30	1.00
31	0.936
32	0.878
33	0.826
34	0.779
35	0.735

TEST NO. K974084 APPROVED *[signature]*

TEST BY *[signature]* DATE 8-22-58 CURVE NO. 433959

WESTINGHOUSE ELECTRIC CORPORATION — CLEVELAND, OHIO

APPENDIX I

APPENDIX II

ILLUMINATION MEASUREMENTS

(in foot candles)

GALVESTON APPROACH

Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}
101	.02	.01	.02	.06	201	.03	.01	.01	.06	301	.02	.01	.02	.05
2	.06	.02	.02	.15	2				.12	2	.04	.01	.02	.11
3	.10	.02	.02	.24	3	.05			.19	3	.04	.01	.02	.15
4	.09	.02	.02	.21	4	.05	.02	.01	.17	4	.04	.01	.01	.11
5	.10	.03	.04	.19	5	.07	.01	.01	.13	5	.05	.01	.03	.11
6	.15	.06	.09	.20	6	.08	.06	.06	.15	6	.08	.01	.03	.10
7	.24	.16	.09	.17	7	.20	.08	.07	.14	7	.16	.02	.06	.13
8	.31	.26	.07	.10	8	.39	.23	.06	.10	8	.45	.04	.05	.10
9	.57	.54	.05	.09	9	.58	.23	.05	.09	9	.44	.10	.04	.08
110	.13	.12	.09	.13	210	1.91	.84	.11	.17	310	1.15	.09	.07	.19
1	.22	.21	.13	.21	1	2.86	1.29	.19	.19	1	1.58	.13	.12	.17
2	.09	.96	.09	.15	2	.15	.71	.12	.15	2	.77	.07	.62	.11
3	.42	.42	.07	.13	3	.58	.22	.26	.13	3	.33	.04	.57	.11
4	.31	.24	.08	.13	4	.32	.17	.76	.12	4	.32	.04	.76	.09
5	.35	.34	.09	.14	5	.33	.18	.73	.11	5	.24	.03	.46	.09
6	.31	.37	.40	.11	6	.41	.24	.34	.11	6	.28	.03	.22	.07
7	.31	.40	.27	.08	7	.63	.65	.22	.08	7	.37	.03	.13	.11
8	.34	.46	.16	.08	8	.75	.72	.15	.08	8	.65	.05	.11	.17
9	.41	.68	.13	.10	9	1.39	1.56	.14	.11	9	1.27	.09	.11	.22
120	.31	.41	.22	.10	220	1.05	1.23	.58	.11	320	1.47	.13	.65	.37
1	.23	.32	.28	.09	1	.63	.70	.81	.10	1	.89	.07	1.00	.16
2	.15	.20	.27	.10	2	.27	.24	.38	.09	2	.39	.05	.74	.26
3	.10	.12	.14	.10	3	.15	.16	.21	.11	3	.21	.04	.40	.15
4	.13	.09	.12	.06	4	.17	.12	.18	.13	4	.29	.06	.32	.20
5	.22	.11	.12	.09	5	.27	.12	.15	.17	5	.38	.06	.32	.20
6	.71	.26	.12	.10	6	.70	.25	.14	.39	6	.77	.05	.18	.44
7	.22	.84	.14	.38	7	1.84	.44	.15	.90	7	1.57	.10	.13	.34
8	4.79	1.92	.23	.90	8	4.21	1.71	.52	.20	8	2.08	.13	.15	.26
9	4.32	1.17	2.50	.76	9	3.83	1.19	2.24	.16	9	1.43	.11	.11	.34
130	1.94	.51	2.54	.51	230	1.58	2.10	1.05	.28	330	.64	.05	1.11	.09
1	.93	.28	.19	.32	1	.32	3.99	.76	.14					
2	.46	.39	.12	.23	2									
3	.31	.78	.71	.10	3	.35	.98	.55	.20					
					4	.27	.81	.36	.34					

30 FT CONTINUOUS SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}
901	1.84	.95	.16	.17
2	2.43	1.42	.34	.19
3	1.59	1.14	.14	.23
4	.77	.63	.11	.21
5	.36	.22	.85	.19
6	.25	.18	.56	.20
7	.22	.13	.29	.20
8	.37	.18	.90	.46
9	.92	.25	1.25	.60
910	2.09	.72	2.37	1.21
925	.40	.32	.95	.18
6	.33	.28	.72	.29
7	.31	.29	.59	.32
8	.26	.26	.30	.42
9	.43	.39	1.82	.35
935	.45	.68	1.05	.10
6	.40	.47	.87	.33
7	.43	.40	.67	.25
8	.58	.53	.36	.20
9	.86	.89	.22	.22
940	1.90	1.70	.23	.38
1	2.47	1.97	.75	.61
2	1.15	.87	1.69	.89
3	1.03	.73	1.68	.74

E_h = horizontal illumination
E_{ve} = vertical illumination, photocell facing east
E_{vt} = vertical illumination, photocell facing traffic
E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX II

ILLUMINATION MEASUREMENTS *
(in foot candles)

GALVESTON APPROACH — 30 FT INTERMEDIATE SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}
101					201					301				
2					2					2				
3					3					3				
4					4					4				
5					5					5				
6					6					6				
7					7					7				
8					8					8				
9					9					9				
110	.02	.01		.06	210	.01	.01	.01	.06	310				
1	.03	.01	.01	.12	1	.02	.01	.01	.08	1				
2	.03	.01	.01	.09	2	.03	.01	.01	.08	2	.01	.01	.01	.07
3	.04	.02	.02	.11	3	.03	.01	.01	.08	3	.03	.01		.07
4	.06	.04	.02	.11	4	.05	.03	.02	.08	4	.04	.01	.03	.07
5	.16	.17	.04	.12	5	.13	.06	.02	.08	5	.05	.02	.02	.06
6	.23	.31	.04	.09	6	.33	.29	.04	.08	6	.30	.02	.02	.06
7	.24	.36	.03	.05	7	.58	.06	.04	.07	7	.29	.03	.03	.07
8	.28	.40	.04	.07	8	.69	.08	.04	.08	8	.66	.04	.04	.15
9	.38	.66	.04	.10	9	.14	.16	.07	.09	9	1.25	.08	.05	.17
120	.26	.40	.16	.11	220	.10	.12	.07	.09	320	1.56	.11	.06	.20
1	.22	.32	.31	.09	1	.06	.06	.07	.10	1	.89	.06	.10	.12
2	.13	.17	.21	.08	2	.20	.15	.35	.09	2	.38	.08	.08	.19
3	.77	.06	.10	.07	3	.12	.08	.18	.10	3	.17	.03	.04	.15
4	1.05	.03	.09	.08	4	.15	.05	.15	.13	4	.11	.04	.04	.12
5	1.89	.04	.08	.06	5	.23	.04	.12	.13	5				
6	.59	.05	.09	.22	6	.45	.04	.11	.39	6				
7	1.52	.11	.10	.43	7	1.21	.06	.12	.84	7				
8	3.31	.10	.11	.92	8	2.29	.07	.13	1.61	8				
9	3.49	.17	.16	.73	9	2.45	.05	.08	1.83	9				
130	1.63	.08	.20	.26	230	.92	.05	.10	.78	330				

E_h = horizontal illumination
E_{ve} = vertical illumination, photocell facing east
E_{vt} = vertical illumination, photocell facing traffic
E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX II

ILLUMINATION MEASUREMENTS*
(in foot candles)

GALVESTON APPROACH

30 FT MINIMUM SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}
101					201					301				
2					2					2				
3					3					3				
4					4					4				
5					5					5				
6					6					6				
7					7					7				
8					8					8				
9					9					9				
110	.02	.01	.01	.05	210	.02	.01	.01	.06	310				
1				.11	1					1				
2	.03	.01	.01	.09	2	.02	.01	.01	.07	2	.02	.01	.01	.05
3				.08	3					3	.03	.01	.01	.05
4	.05	.04	.02	.07	4	.04	.03	.02	.06	4	.03	.01	.01	.05
5	.12	.16	.05	.08	5	.13	.13	.03	.06	5	.12	.01	.02	.04
6	.20	.31	.05	.07	6	.31	.35	.05	.07	6	.26	.02	.02	.03
7	.23	.38	.04	.02	7	.46	.07	.04	.06	7	.31	.02	.03	.06
8	.27	.46	.04	.04	8	.66	.08	.05	.05	8	.68	.04	.04	.05
9	.39	.07	.05	.04	9	.14	.16	.07	.07	9	1.31	.07	.05	.27
120	.28	.41	.15	.03	220	.10	.12	.03	.06	320	1.43	.10	.06	.18
1	.12	.29	.30	.03	1	.06	.05	.07	.04	1	.88	.07	.10	.11
2	.12	.14	.19	.03	2	.19	.11	.34	.08	2				
3	.72	.05	.11	.02	3	.08	.07	.18	.11	3				
4	1.01	.05	.08	.07	4	.14	.05	.14	.11	4				
5	1.79	.03	.07	.01	5	.24	.04	.12	.11	5				
6	.59	.05	.08	.09	6	.46	.04	.11	.35	6				
7	1.53	.09	.09	.20	7	1.21	.07	.11	.79	7				
8	3.42	.12	.12	.64	8	2.24	.08	.13	1.59	8				
9	3.51	.16	.17	.89	9	2.55	.06	.08	1.80	9				
130	1.59	.08	.20	.34	230	.89	.05	.10	.65	330				

E_h = horizontal illumination
E_{ve} = vertical illumination, photocell facing east
E_{vt} = vertical illumination, photocell facing traffic
E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX II

ILLUMINATION MEASUREMENTS*
(in foot candles)

GALVESTON APPROACH — 45 FT INTERMEDIATE SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}
101					201					301				
2					2					2				
3					3					3				
4					4					4				
5					5					5	.02	.01	.20	.04
6					6					6	.02	.01	.20	.04
7					7					7	.02	.01	.11	.05
8					8					8	.02	.01	.10	.04
9					9					9				
110	.05	.01	.01	.14	210	.04	.01	.11	.11	310	.04	.01	.19	.25
1	.06	.01	.01	.14	1	.04	.01	.10	.15	1	.05	.01	.21	.14
2	.07	.02	.01	.14	2	.05	.01	.12	.13	2	.05	.01	.34	.12
3	.10	.04	.02	.15	3	.08	.01	.15	.13	3	.08	.01	.26	.11
4	.19	.07	.03	.15	4	.16	.07	.35	.13	4	.13	.02	.41	.17
5	.24	.17	.04	.15	5	.22	.18	.41	.11	5	.15	.02	.37	.16
6	.34	.24	.06	.14	6	.36	.20	.48	.13	6	.24	.02	.43	.10
7	.36	.32	.05	.14	7	.44	.28	.43	.12	7	.39	.03	.47	.23
8	.42	.42	.04	.12	8	.78	.28	.46	.11	8	.73	.04	.47	.16
9	.75	.72	.05	.16	9	1.00	.72	.50	.13	9	.82	.05	.53	.21
120	.48	.46	.19	.13	220	.94	.69	.16	.14	320	.95	.08	.23	.20
1	.37	.33	.27	.11	1	.73	.56	.43	.13	1	.78	.04	.60	.12
2	.25	.17	.25	.10	2	.34	.20	.33	.15	2	.36	.03	.39	.24
3	.20	.08	.18	.11	3	.23	.06	.23	.12	3	.39	.03	.33	.37
4	.18	.06	.15	.11	4	.20	.06	.18	.12	4	.24	.03	.29	.31
5	.22	.06	.11	.08	5	.24	.06	.14	.11	5	.16	.03	.22	.23
6	.36	.11	.09	.11	6	.39	.08	.11	.11	6	.13	.02	.21	.19
7	.83	.26	.10	.15	7	.86	.15	.11	.29	7	.12	.02	.19	.17
8	1.59	.06	.19	.19	8	1.87	.42	.21	.39	8	.14	.03	.22	.26
9	1.53	.04	.07	.25	9	2.27	.36	.09	.70	9	.15			
130	1.17	.03	.03	.17	230	1.63	.25	.13	.62	330				

E_h = horizontal illumination
E_{ve} = vertical illumination, photocell facing east
E_{vt} = vertical illumination, photocell facing traffic
E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX II

ILLUMINATION MEASUREMENTS *

(in foot candles)

GALVESTON APPROACH

45 FT MINIMUM SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}
101					201					301					901	.13	.25	.62	.01
2					2					2					2	.14	.62	.92	.01
3					3					3					3	.13	.76	.45	.02
4					4					4					4	.45	.23	.43	.02
5					5					5	.01	.01	.05	.03	5	.35	.10	.43	.02
6					6					6					6	.26	.04	.33	.14
7					7					7	.01	.01	.06	.03	7	.24	.04	.26	.20
8					8					8					8	.30	.04	.22	.12
9					9					9	.02	.01	.05	.04	9	.65	.09	.20	.56
110	.05			.11	210	.02	.01	.07	.06	310	.03	.01	.07	.06	910	.67	.07	.17	.57
1	.06			.13	1	.03	.01	.06	.09	1	.03	.01	.09	.08	1				
2	.07	.02	.01	.11	2	.05	.01	.12	.08	2	.04	.01	.10	.07	2				
3	.09	.06	.01	.10	3	.05	.04	.24	.06	3	.06	.01	.18	.05	3				
4	.18	.17	.03	.10	4	.16	.07	.22	.07	4	.12	.01	.28	.05	4				
5	.25	.26	.06	.11	5	.23	.08	.32	.06	5	.14	.01	.24	.07	5				
6	.33	.28	.07	.09	6	.38	.18	.48	.08	6	.23	.02	.34	.11	6				
7	.34	.39	.06	.07	7	.42	.33	.43	.06	7	.39	.03	.41	.10	7				
8	.39	.46	.05	.05	8	.78	.57	.48	.05	8	.75	.04	.43	.18	8				
9	.71	.77	.06	.05	9	.97	.72	.53	.05	9	.85	.04	.49		9				
120	.45	.56	.19	.05	220	.92	.75	.21	.05	320	.96	.05	.22	.14	920				
1	.36	.36	.35	.04	1	.70	.42	.46	.05	1	.76	.03	.47	.06	1				
2	.24	.20	.25	.06	2	.32	.22	.32	.08	2	.35	.03	.36	.19	2				
3	.17	.09	.18	.06	3	.20	.09	.20	.07	3	.26	.02	.30	.31	3				
4	.15	.06	.13	.06	4	.16	.06	.15	.08	4	.20	.02	.28	.26	4				
5	.16	.04	.08	.04	5	.15	.04	.10	.08	5	.12	.02	.20	.16	5	.40	.16	.44	.02
6	.25	.04	.07	.05	6	.24	.03	.09	.12	6	.09	.02	.18	.10	6	.31	.16	.39	.04
7	.43	.05	.07	.09	7	.47	.05	.08	.21	7	.05	.01	.15	.05	7	.25	.05	.33	.03
8	.83	.06	.07	.14	8	.98	.06	.09	.41	8					8	.21	.10	.28	.03
9	.92	.07	.02	.17	9	1.39	.07	.03	.63	9	.04	.01	.14	.07	9	.23	.10	.29	.03
130	.86	.07	.07	.19	230	1.07	.06	.07	.47	330	.04				930				
															1				
															2				
															3				
															4				
															5	.47	.31	.06	.03
															6	.31	.23	.43	.03
															7	.27	.16	.36	.03
															8	.16	.07	.31	.02
															9	.14	.07	.26	.02
															940	.12	.05	.21	.02

E_h = horizontal illumination
E_{ve} = vertical illumination, photocell facing east
E_{vt} = vertical illumination, photocell facing traffic
E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX II

ILLUMINATION MEASUREMENTS*

(in foot candles)

TEXAS CITY APPROACH — 30 FT CONTINUOUS SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}
1101	.04	.04	.04	.04	1201	.05				1301	.11	.02	.02	.01
2	.03	.04	.04	.05	2					2				
3	.04	.04	.04	.07	3	.06				3	.14	.09	.09	.01
4	.06	.04	.05	.01	4					4				
5	.09	.04	.05	.12	5	.14	.06	.09	.14	5	.24	.09	.10	.13
6	.29	.08	.07	.53	6					6	.24	.10	.10	.14
7	.19	.04	.24	.22	7	.17	.02	.19	.89	7	.70	.11	.10	.15
8	.54	.06	.36	.57	8	.32	.05	.34	1.60	8	1.67	.39	.19	.39
9	.78	.07	.48	.79	9	.73	.10	.62	3.28	9	4.74	.48	.34	.06
1110	1.17	.08	.68	1.13	1210	1.77	.14	1.39	.81	1310	1.15	.12	.77	.13
1	2.08	.14	1.43	2.05	1	3.20	.20	2.80	1.77	1	1.94	.19	1.67	.19
2	1.55	.11	1.07	1.57	2	2.39	.19	1.81	1.30	2	1.89	.19	1.37	.19
3	.46	.05	.72	.57	3	1.19	.10	1.57	.60	3	.97	.09	1.29	.12
4	.27	.03	.57	.37	4	.43	.06	.98	.27	4	.56	.09	.91	.09
5	.24	.03	.36	.35	5	.47	.08	.79	.36	5	.48	.10	.65	.07
6	.24	.02	.30	.35	6	.72	.01	.62	.65	6	.58	.07	.44	.08
7	.24	.02	.22	.40	7	1.19	.01	.58	1.03	7	1.01	.13	.35	.19
8	.34	.03	.18	.74	8	2.15	.01	.67	2.02	8	2.21	.16	.36	.41
9	.28	.02	.21	.61	9	2.81	.02	1.31	2.69	9	2.25	.19	.73	.42
1120	.27	.03	.32	.72	1220	1.20	.01	1.51	1.20	1320	1.49	.24	1.58	.34
1	.26	.03	.28	.90	1	.96	.02	1.27	1.07	1	.86	.34	.86	.26
2	.25	.03	1.63	.95	2	1.05	.04	1.26	1.67	2	1.38	.27	.43	.34
3	.17	.04	1.47	.45	3	1.16	.04	1.08	1.64	3	1.99	.22	.28	.52
4					4	.88	.03	1.08	1.29	4	1.30	.19	.90	.34
5					5	.34	.03	.62	.40	5	.68	.31	.86	.19
6					6	.35	.03	.34	.23	6	.30	.14	.33	.11
7					7	.77	.04	.27	.25	7	.45	.10	.19	.01
8					8	.22	.09	.36	.40	8	.68	.10	.14	.01
9					9					9	1.35	.11	.15	.02
1130					1230					1330				

E_h = horizontal illumination
E_{ve} = vertical illumination, photocell facing east
E_{vt} = vertical illumination, photocell facing traffic
E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX II

Appendi

ILLUMINATION MEASUREMENTS *

(in foot candles)

TEXAS CITY APPROACH

Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}
1101					1201	.02		.05	.03
2					2				
3					3	.01		.05	.02
4					4				
5	.01	.01	.10	.26	5	.11	.01	.09	.11
6	.03	.01	.11	.38	6	.29	.01	.10	.20
7	.16	.03	.24	.16	7	.13	.02	.22	.11
8	.40	.05	.44	.40	8	.34	.05	.34	.14
9	.72	.07	.50	.66	9	.76	.09	.60	.38
1110	1.13	.08	.74	1.05	1210	1.85	.15	1.25	.11
1	2.06	.14	1.58	1.92	1	3.11	.24	3.20	1.71
2	1.55	.10	1.15	1.63	2	2.28	.12	1.72	1.29
3	.43	.04	.75	.42	3	.95	.08	1.52	.60
4	.20	.03	.45	.21	4	.34	.05	.96	.26
5	.10	.02	.36	.13	5	.21	.04	.75	.13
6	.08	.01	.30	.15	6	.10	.02	.57	.08
7	.04	.01	.21	.05	7	.07	.02	.39	.05
8	.03	.01	.16	.03	8	.05	.02	.28	.04
9	.02	.01	.12	.02	9	.03	.02	.22	.03
1120	.02	.01	.09	.02	1220	.02	.01	.15	.03

30 FT INTERMEDIATE SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}
1301				
2	.01	.01	.02	.05
3				
4				
5				
6	.29	.01	.09	.06
7	.78	.01	.10	.14
8	1.82	.02	.10	.22
9	4.55	1.04	.31	.05
1310	1.29	.10	.58	.10
1	1.95	.15	1.39	.19
2	1.84	.29	1.39	.15
3	.91	.07	1.25	.08
4	.48	.08	.86	.05
5	.18	.03	.61	.01
6				
7	.08	.04	.34	.02
8				
9				
1320	.03	.02	.13	.01
1				
2				
3	.09	.03	.19	.02
4				
5	.60	.03	.12	.04
6	1.27	.02	.19	.05
7	2.77	.04	.29	.07
8	6.71	.03	.34	.07
9	1.40	.06	.62	.14
1330	2.34 2.37	.13 .23	.59 .68	.21 .30
1	1.62 1.57	1.10 1.67	1.55 1.63	.13 .19
2	.72 .72	.53 .96	1.20 1.23	.10 .13
3	.45 .48	.34 .61	1.15 1.15	.08 .12
4	.24	.48	.73	.10
5	.08 .11	.38 .48	.32 .34	.03 .10

E_h = horizontal illumination

E_{ve} = vertical illumination, photocell facing east

E_{vt} = vertical illumination, photocell facing traffic

E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX II

ILLUMINATION MEASUREMENTS *

(in foot candles)

TEXAS CITY APPROACH

30 FT MINIMUM SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}	Station	E_h	E_{ve}	E_{vt}	E_{vw}
1101					1201	.02		.05	.03	1301				
2					2					2	.01	.01	.02	.05
3					3	.01		.05	.02	3				
4					4					4				
5	.01	.01	.10	.26	5	.11	.01	.09	.11	5				
6	.03	.01	.11	.38	6	.29	.01	.10	.20	6	.29	.01	.09	.06
7	.16		.24	.16	7	.13		.22	.11	7	.78		.10	.14
8	.40	.01	.44	.40	8	.34	.01	.34	.14	8	1.82		.10	.22
9	.72	.01	.50	.66	9	.76	.01	.60	.38	9	4.55		.31	.05
1110	1.13	.01	.74	1.05	1210	1.85	.01	1.25	.11	1310	1.29	.10	.58	.10
1	2.06	.01	1.58	1.92	1	3.11	.02	3.20	1.71	1	1.95	.02	1.39	.19
2	1.55	.01	1.15	1.63	2	2.28	.01	1.72	1.29	2	1.84	.03	1.39	.15
3	.43	.01	.75	.42	3	.95	.01	1.52	.60	3	.91	.01	1.25	.08
4	.20	.03	.45	.21	4	.34	.01	.96	.26	4	.48	.01	.86	.05
5	.10	.02	.36	.13	5	.21	.04	.75	.13	5	.18	.03	.61	.01
6	.08	.01	.30	.15	6	.10	.02	.57	.08	6				
7	.04	.01	.21	.05	7	.07	.02	.39	.05	7	.08	.04	.34	.02
8	.03	.01	.16	.03	8	.05	.02	.29	.04	8				
9	.02	.01	.12	.02	9	.03	.02	.22	.03	9				
1120	.01	.01	.09	.01	1220	.02	.01	.15	.02	1320	.03	.02	.13	.01
1					1					1				
2					2					2				
3					3					3	.09	.03	.19	.02
4					4					4				
5					5					5				
6					6					6				
7					7					7				
8					8					8				
9					9					9				
1130					1230					1330				

E_h = horizontal illumination
E_{ve} = vertical illumination, photocell facing east
E_{vt} = vertical illumination, photocell facing traffic
E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX II
ILLUMINATION MEASUREMENTS *
(in foot candles)

TEXAS CITY APPROACH

45 FT INTERMEDIATE SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}
1101				
2				
3				
4				
5	.08	.02	.14	.63
6	.06	.02	.17	.74
7	.18	.03	.20	1.00
8	.30	.04	.31	1.83
9	.67	.06	.44	3.85
1110	.87	.06	.62	.66
1	1.03	.09	1.52	.81
2	.90	.06	.43	.63
3	.44	.04	.42	3.53
4	.23	.03	.36	1.60
5	1.67	.02	.33	1.34
6	.10	.01	.26	.97
7	.07	.01	.22	.61
8	.05	.01	.19	.58
9	.04	.01	.16	.41
1120	.04	.01	.14	.60
1	.03			
2				
3				

Station	E_h	E_{ve}	E_{vt}	E_{vw}
1201				
2				
3				
4				
5	.05	.01	.10	.37
6	.07	.01	.13	.46
7	.15	.02	.18	.79
8	.27	.04	.26	1.25
9	.41	.04	.48	1.87
1210	.95	.08	.85	3.66
1	1.10	.10	1.22	3.91
2	.99	.09	.62	3.53
3	.71	.06	.70	2.53
4	.38	.04	.66	1.34
5	.19	.03	.39	.68
6	.10	.02	.30	.70
7	.08	.02	.25	.54
8	.06	.02	.23	.34
9	.04	.01	.19	.60
1220	.04	.02	.15	.47
1				
2				
3				

Station	E_h	E_{ve}	E_{vt}	E_{vw}
1301	.01	.02	.02	.01
2				
3	.02	.02	.02	.01
4				
5	.01	.02	.10	.01
6	.06	.03	.10	.01
7	.14	.03	.17	.02
8	.24	.03	.19	.03
9	.41	.04	.35	.04
1310	.48	.05	.28	.04
1	.73	.07	.57	.07
2	.64	.07	.35	.07
3	.52	.06	.50	.06
4	.29	.05	.41	.05
5	.19	.03	.30	.07
6	.12	.03	.26	.03
7				
8	.07	.03	.18	.02
9				
1320				
1	.05	.04	.11	.04
2				
3				
4	.09	.15	.05	.10
5	.15	.21	.09	.07
6	.20	.20	.14	.03
7	.25	.14	1.19	.03
8	.43	.15	1.25	.04
9	.70	.17	1.29	.04
1330	.83	.14	.21	.06
1	.76	.13	.06	.06
2	.47	.08	.05	.06
3				
4				
5	1.48	.05	.05	.03

E_h = horizontal illumination
E_{ve} = vertical illumination, photocell facing east
E_{vt} = vertical illumination, photocell facing traffic
E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX II

ILLUMINATION MEASUREMENTS *
(in foot candles)

TEXAS CITY APPROACH

45 FT MINIMUM SYSTEM

Station	E_h	E_{ve}	E_{vt}	E_{vw}
1101				
2				
3				
4				
5	.08	.02	.03	.06
6	.10	.02	.14	.07
7	.08	.07	.05	.06
8	.30			
9	.67			
1110	.87			
1	1.03			
2	.84	.07	.46	.64
3	.50	.38	.54	3.45
4	.24	.02	.40	1.72
5	.17 .21	.02	.39	1.34 1.53
6	.10			.73
7	.07 .08	.01	.20	.54 .58
8	.05			.29
9	.04			.29
1120	.03			.29

Station	E_h	E_{ve}	E_{vt}	E_{vw}
1201				
2				
3				
4				
5	.05	.01	.10	.37
6	.07	.01	.13	.46
7	.15	.02	.18	.79
8	.27	.04	.26	1.25
9	.41	.04	.48	1.87
1210	.95	.08	.85	3.66
1	1.10	.10	1.22	3.91
2	.99	.09	.62	3.53
3	.71	.06	.70	2.53
4	.38	.04	.66	1.34
5	.20 .19	.03	.39	1.01
6	.11 .10	.02	.30	.43
7	.09 .08	.02	.25	.53
8	.07 .06	.02	.23	.38
9	.05 .04	.01	.19	.31
1220	.04 .04	.02	.15	.37

Station	E_h	E_{ve}	E_{vt}	E_{vw}
1301				
2	.02	.01	.01	.01
3				
4	.03	.01	.09	.01
5				
6	.06	.01	.10	.01
7	.15	.02	.10	.03
8	.22	.03	.19	.04
9	.40	.04	.29	.05
1310	.45	.04	.33	.04
1	.73	.06	.59	.06
2	.65	.06	.34	.06
3	.54	.05	.50	.06
4	.29	.04	.46	.06
5	.19	.03	.31	.04
6				
7	.09	.02	.20	.02
8				
9				
1320	.05	.02	.14	.02
1				
2				
3	.04	.09	.05	.06
4				
5				
6	.06	.17	.11	.02
7				
8				
9	.03	.09	.81	.01
1330				
1	.03	.07	.06	.01
2				
3				
4	.02	.04	.04	.01

E_h = horizontal illumination
E_{ve} = vertical illumination, photocell facing east
E_{vt} = vertical illumination, photocell facing traffic
E_{vw} = vertical illumination, photocell facing west

* Values rounded off to the nearest hundredth foot candle.

APPENDIX III

BRIGHTNESS READINGS ON THE ROADWAY

GALVESTON APPROACH

30 FT MOUNTING HEIGHT CONTINUOUS SYSTEM

Brightness meter 200 ft ahead of light no. 7 in center of outside lane--48 in high--6 minute aperture--Pritchard Spectra Brightness Meter.

Brightness in foot-lamberts

Distance	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor for Avg. Br.
50 ft	---	.04	.36	.03	100
100	---	.10	.88	.23	30
150	---	.56	2.56	.54	10
200	---	.44	.16	.30	5
250	---	.26	.67	.31	3
300	---	.18	1.31	.43	2
400 on La Marque turn	---	.21	.15	.33	1
500 on La Marque turn	---	.20	.72	.20	---

Around the center island:

At nose (on roadway)	.76
Island curb-center right	.41
Island curb-far right	.28
Island curb-center left	.24
Island curb-far left	.37
Sign on island	.58

Average Brightness of Roadway (wtd. avg., 50 to 400 ft) — 0.18 fl

Adaptation Brightness of Driver (avg. over 30° cone angle) — ≈3.1 fl

APPENDIX III

BRIGHTNESS READINGS ON THE ROADWAY

GALVESTON APPROACH

30 FT MOUNTING HEIGHT INTERMEDIATE SYSTEM

Brightness meter 200 ft ahead of light no. 7 in center of outside lane--48 in high--Pritchard Spectra Brightness Meter--6 minute aperture.

Brightness in foot-lamberts

Distance	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor For Avg. Br.
50 ft	---	---	---	---	100
100	---	---	---	---	30
150	---	.01	.02	.02	10
200	---	.02	.05	.02	5
250	---	.05	.35	.20	3
300	---	.14	1.31	.33	2
400	---	.07	.16	.24	1
500	---	.19	.02	---	

Around the center island

At nose (on roadway)	.54
Island curb-center right	.23
Island curb-center left	.09
Island curb-far left	.28
Sign on island	.56

Average Brightness of Roadway (wtd. avg. 50 to 400 ft.) — 0.02 fl

Adaptation Brightness of Driver (avg. over 30° cone angle) — 1.5 fl

APPENDIX III

BRIGHTNESS READINGS ON THE ROADWAY

GALVESTON APPROACH

30 FT MOUNTING HEIGHT MINIMUM SYSTEM

Brightness meter 200 ft ahead of light no. 7 in center of outside lane--48 in high--Pritchard Spectra Brightness Meter--6 minute aperture.

Brightness in fl

Distance	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor for Avg. Br.
50 ft	---	---	---	---	100
100	---	---	---	---	30
150	---	---	---	---	10
200	---	.02	.05	.02	5
250	---	.05	.35	---	3
300	---	.14	1.31	.33	2
400	---	.07	.06	.24	1
500	---	.23	.02	---	---

Around the center island

At nose (on roadway)	.54
Island curb-center right	.23
Island curb-center left	.12
Island curb-far right	.08
Sign on Island	.56

Average Brightness on Roadway (wtd. avg., 50 to 400 ft) — 0 .01 fl

Adaptation Brightness of Driver (avg. over 30° cone angle) — 1.2 fl

APPENDIX III

BRIGHTNESS READINGS ON THE ROADWAY

GALVESTON APPROACH

45 FT MOUNTING HEIGHT INTERMEDIATE SYSTEM

Brightness meter 200 ft ahead of light no. 7 in center of outside lane--48 in high--Pritchard Spectra Brightness Meter--6 minute aperture.

Brightness in foot-lamberts

Distance	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor for Avg. Br.
50 ft	---	.02	.01	.01	100
100	---	.02	.02	.02	30
150	---	.03	.02	---	10
200	---	.05	.12	.06	5
250	---	.09	.09	.17	3
300	---	.29	.70	.21	2
400	---	.21	.07	.12	1
500	---	.15	.05	.08	---

Around the center island

At nose (on roadway)	.40
Island curb-center right	.14
Island curb-center left	.17
Island curb-far left	.25
Sign on island	.54

Average Brightness on Roadway (wtd. avg. 50 to 400 ft) — 0.03 fl

Adaptation Brightness of Driver (avg. over 30° cone angle — 2.1 fl

APPENDIX III

BRIGHTNESS READINGS ON THE ROADWAY

GALVESTON APPROACH

45 FT MOUNTING HEIGHT MINIMUM SYSTEM

Brightness meter 200 ft ahead of light no. 7 in center of outside lane--48 in high--Pritchard Spectra Brightness Meter--6 minute aperture.

Brightness in foot-lamberts

Distance	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor for Avg. Br.
50 ft	---	---	---	---	100
100	---	.01	.01	.01	30
150	---	---	---	---	10
200	---	.03	.08	.06	5
250	---	.17	.10	.18	3
300	---	.25	.52	.21	2
400	---	.15	.08	.14	1
500	---	.20	.04	.08	---

Around the center island

At nose (on roadway)	.35
Island curb-center right	.14
Island curb-center left	.16
Island curb-far left	.15

Sign on island .54

Average Brightness on Roadway (wtd. avg. 50 to 400 ft) 0.02 fl

Adaptation Brightness of Driver (avg. over 30° cone angle) 1.5 fl

APPENDIX III

BRIGHTNESS READINGS ON THE ROADWAY

TEXAS CITY APPROACH

30 FT MOUNTING HEIGHT CONTINUOUS SYSTEM

Brightness meter 200 ft ahead of light no. 10 in center of outside lane--48 in high--6 minute aperture--Prichard Spectra Brightness Meter.

Brightness in foot-lamberts

Distance	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor for Avg. Br.
50 ft	---	.02	.02	---	100
100	.05	.02	.05	---	30
150	.21	---	.28	---	10
200	.43	.46	1.18	---	5
250	---	---	.61	---	3
300	.42	---	.63	---	2
400	.67	---	---	---	1
500	---	---	---	---	---

Around the center island:

At nose (on roadway	.61
Island curb (300 ft)	.67
Island curb (400 ft)	.45

Sign on island 1.1

Average Brightness of Roadway (wtd. avg. 50 to 400 ft) 0.08 fl

Adaptation Brightness of Driver (avg. over 30° cone angle) 2.3 fl

APPENDIX III

BRIGHTNESS READINGS ON THE ROADWAY

TEXAS CITY APPROACH

30 FT MOUNTING HEIGHT INTERMEDIATE SYSTEM

Brightness meter 200 ft ahead of light no. 10 in center of outside lane--48 in high--6 minute aperture--Pritchard Spectra Brightness Meter.

Brightness in foot-lamberts

Distance	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor for Avg. Br.
50 ft	---	.01	---	---	100
100	.05	.03	.03	---	30
150	---	---	.59	---	10
200	.25	.20	.56	---	5
250	---	.72	.54	---	3
300	.04	---	.48	---	2
400	---	---	.06	---	1
500	---	---	.05	---	---

Around the center island:

At nose (on roadway)	.72
Island curb (300 ft)	.10
Island curb (400 ft)	.02

Sign on island 1.1

Average Brightness of Roadway (wtd. avg. 50 to 400 ft) 0.06 fl

Adaptation Brightness of Driver (avg. over 30° cone angle) 1.5 fl

APPENDIX III

BRIGHTNESS READINGS ON THE ROADWAY

TEXAS CITY APPROACH

30 FT MOUNTING HEIGHT MINIMUM SYSTEM

Brightness meter 200 ft ahead of light no. 10 in center of outside lane--48 in high--6 minute aperture--Pritchard Spectra Brightness Meter.

Brightness in foot-lamberts

Distance	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor for Avg. Br.
50 ft	---	.01	---	---	100
100	.05	.03	.03	---	30
150	---	---	.59	---	10
200	.25	.20	.56	---	5
250	---	.72	.54	---	3
300	.04	---	.48	---	2
400	---	---	.06	---	1
500	---	---	.05	---	---

Around the center island:

At nose (on roadway	.72
Island curb (300 ft)	.10
Island curb (400 ft)	.02

Sign on island 1.1

Average Brightness of Roadway
(wtd. avg. 50 to 400 ft) 0.05 fl

Adaptation Brightness of Driver 1.3 fl
(avg. over 30° cone angle)

APPENDIX III

BREAKDOWN
BRIGHTNESS READINGS ON THE ROADWAY

TEXAS CITY APPROACH

45 FT MOUNTING HEIGHT INTERMEDIATE SYSTEM

Brightness meter 200 ft ahead of light no. 10 in center of outside lane--48 in high--6 minute aperture--Pritchard Spectra Brightness Meter.

Brightness in foot-lamberts

Direction	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor for Avg. Br.
50 ft	.02	.02	.04	---	100
100	.08	.10	.07	---	30
150	.16	.17	.63	---	10
200	.30	.36	.35	---	5
250	.26	.40	---	---	3
300	.04	---	.20	---	2
400	.03	---	.05	---	1
500	---	---	---	---	---

Around the center island:

At nose (on roadway) .40
Island curb (300 ft) .11

Sign on island .63

Average Brightness of Roadway (wtd. avg. 50 to 400 ft) 0.08

Adaptation Brightness of Driver (avg. over 30° cone angle) 2.2 fl

APPENDIX III

BRIGHTNESS READINGS ON THE ROADWAY

TEXAS CITY APPROACH

45 FT MOUNTING HEIGHT MINIMUM SYSTEM

Brightness meter 200 ft ahead of light no. 10 in center of outside lane--48 in high--6 minute aperture--Pritchard Spectra Brightness Meter.

Brightness in foot-lamberts

Distance	Location				
	Along ℄ Left Lane	Along ℄ Roadway	Along ℄ Right Lane	Along Right Shoulder	Weighting Factor for Avg. Br.
50 ft	.03	---	.03	---	100
100	.09	.10	.06	---	30
150	.17	.10	.10	---	10
200	.31	.36	.19	---	5
250	.20	.37	.49	---	3
300	.05	---	.17	---	2
400	---	---	.04	---	1
500	---	---	---	---	---

Around the center island:

At nose (on roadway)	.37
Island curb (300 ft)	.09
Sign on island	.55

<u>Average Brightness of Roadway</u> (wtd. avg. 50 to 400 ft) 0.06

<u>Adaptation Brightness of Driver</u> (avg. over 30° cone angle) 1.8 fl