AN INTERIM REPORT ON A STUDY OF DISABILITY VEILING BRIGHTNESS

by

Neilon J. Rowan

Hans C. Jensen

and

Ned E. Walton

Research Report Number 75-5

Supplementary Studies in Highway Illumination

Research Study Number 2-8-64-75

Sponsored by

The Texas Highway Department

in Cooperation with the
U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

June, 1967

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University
College Station, Texas

TABLE OF CONTENTS

INTRODUCTION

Vision is the most important sensory process involved in driving. In the daytime and during fair weather, the normal daylight is ample for good visibility of all the tasks encountered in driving. But during the hours of darkness, especially during inclement weather, extra light is needed to improve visibility while driving. Headlights on vehicles contribute some light, but this light is distributed only over a limited area and, for many tasks, it is not sufficient for good visibility. Since thirty percent of automobile traffic occurs at night, good roadway lighting is an important part of a road transportation facility. Good visibility helps traffic safety and also helps traffic operation on the facility.

Good visibility on roadways at night results from lighting which provides adequate pavement brightness with good uniformity and appropriate illumination of adjacent areas. Of importance also is reasonable freedom from glare.

The predominant method of discernment of distant objects on lighted roadways is by silhouette [1]. This occurs when the general level of brightness of an object is higher or lower than the brightness of its background. Another method of discernment is by surface detail. This occurs when the level of illumination on the sides of the object toward the driver is enough to make notable contrasts on the surfaces themselves. Distant objects are usually seen by silhouette and closer objects are seen by surface detail since the ability to discern objects is greatly influenced by the intensity and distribution of light within the visual field.

The ideal seeing conditions exist when the whole field of view is as uniform in brightness as possible, but vision is limited even then. When viewing a bright field some of the light entering the eye is reflected, causing stray light within the eye. The effect of stray light in the eye is to superimpose a veiling brightness upon the object viewed and decreases the brightness contrast needed for discernment. For nonuniform light in the field of view the stray light in the eye increases and the veiling brightness is directly proportional to the intensity of the glare source. The effects of two or more glare sources are strictly additive [1].

For nonuniform fields of view as found in roadway lighting with large glare sources present, the stray light produces disability veiling brightness (hereafter referred to as DVB) which can adversely influence visibility and must be taken into consideration when evaluating roadway lighting systems.

Spacing of the luminaires along the roadway influences the visibility not only by controlling uniformity and magnitude of illumination, but also by changing the frequency of repetitions of the pattern of the DVB along the roadway.

The present study, as part of a project to develop design criteria for economical and functional roadway lighting, is concerned with the effects of system geometry on the DVB produced by various light sources.

OBJECTIVES

Lighting systems are often described by quantitative terms such as footcandles, pavement brightness, average lighting intensity, and ratios of maximum to minimum and average to minimum illumination. Therefore, a lighting system is often judged by the quantity of light on the pavement. However, visibility is the important criterion and to fully evaluate a lighting system, other measures such as the DVB of each system must be measured or calculated and the data analyzed to relate the potential ability of one lighting system with respect to others in revealing the presence of an object on the roadway.

The specific objectives of this research were as follows:

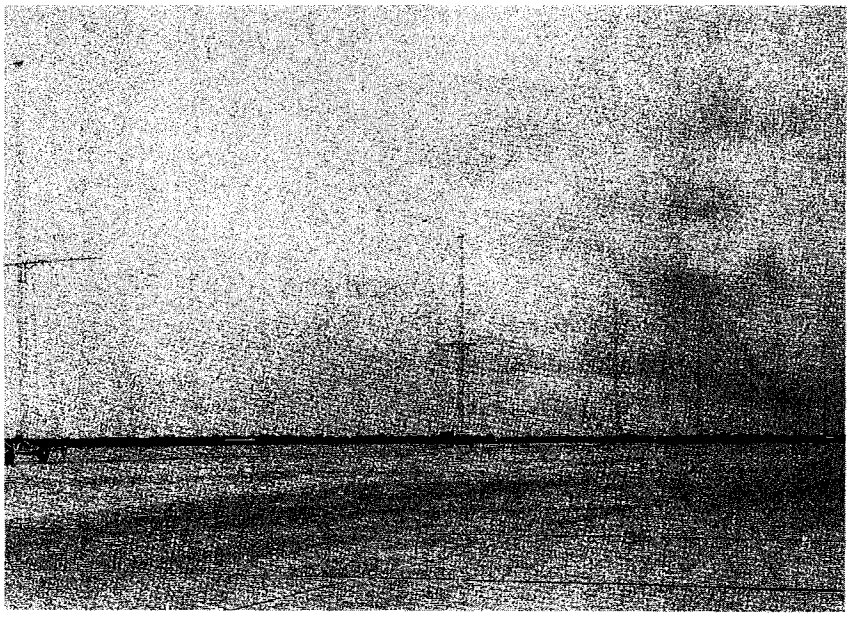
1) To determine the DVB of selected roadway lighting systems of 1000-watt luminaires.

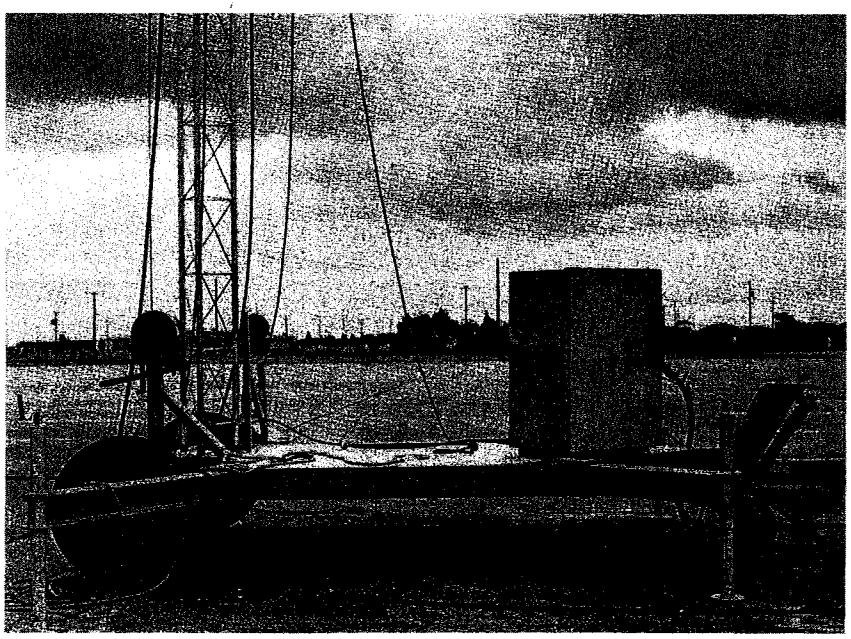
2) To determine the effect of mounting height on DVB for 400- and 1000-watt luminaires.

It is recognized that in a three-dimensional situation such as exists in roadway lighting any change in illumination geometry can alter vision. Therefore, data obtained in this study can only be applied to lighting systems with similar parameters. Comparisons of DVB for different lighting systems must be based on equal illumination levels since DVB is a function of illumination level at the eye and geometry of the system.

THE STUDY

This investigation was conducted at the Highway Illumination Test Facilities at the Texas A&M Research Annex. A 600' by 3000' test section provides for the simulation of any roadway dimensions with as many as 24 lanes of 12.5-foot width. This facility, with 0% grade, has been marked with a grid system of 10-foot longitudinal spacings and 12.5-foot transverse spacings. The grid serves as reference points for various photometric studies. For ready lane reference, the facility has been striped with standard lane lines. Figure 1 shows a view of the test facilities.





HIGHWAY ILLUMINATION TEST
FACILITIES AT TEXAS A&M
UNIVERSITY RESEARCH ANNEX

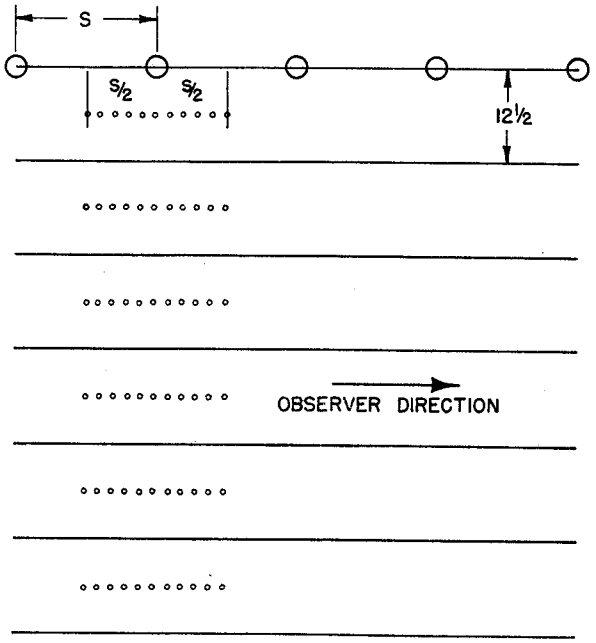
Figure 1

TABLE 1

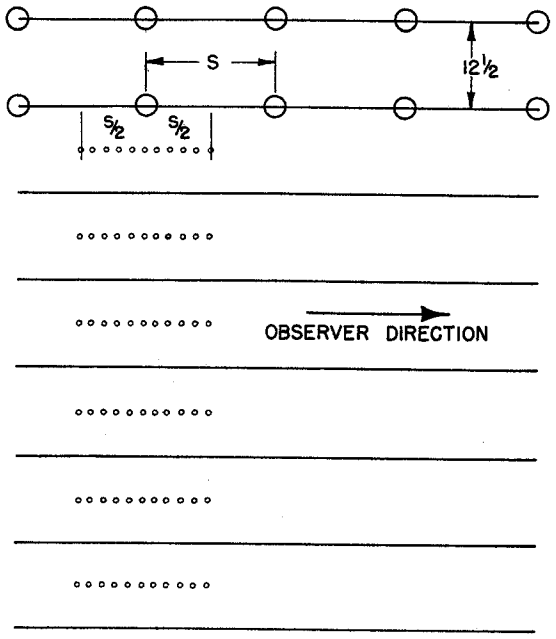
List of Roadway Lighting Systems Tested

Test	Watt	Spacing	Lanes	Mounting Height	Configuration
G-1	400	165	6	30	One-Side
G-2	400	230	6	40	" "
G-3	400	230	6	45	" "
G-4	400	230	6	50	" "
G-5	400	165	6	30	Median
G-6	400	230	6	40	"
G-7	400	230	6	45	"
G-8	400	230	6	50	"
G-9	400	200	6	30	Staggered
G-10	400	200	6	40	"
G-11	400	200	6	45	"
G-12	400	200	6	50	"
G-13	1000	300	6	50	One-Side
G-14	1000	300	6	60	" "
G-15	1000	300	6	50	Median
G-16	1000	300	6	60	"
G-17	1000	250	8	50	Staggered
G-18	1000	250	8	60	"

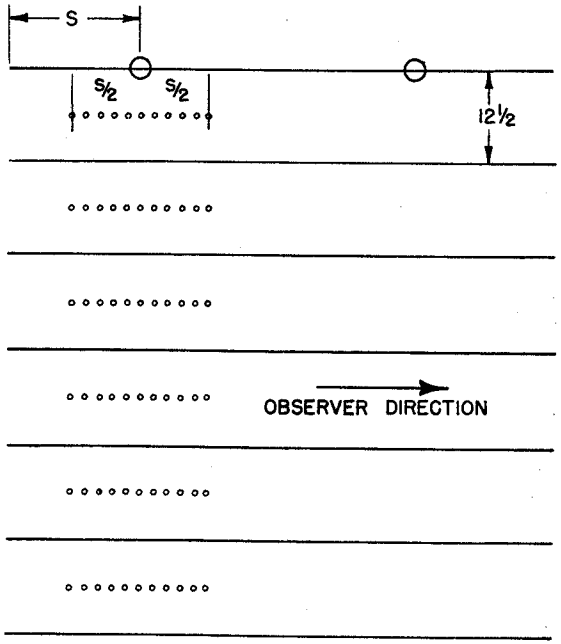
S — LONGITUDINAL SPACING
O — LUMINAIRE POSITIONS
∘ MEASUREMENT POINTS



ONE-SIDE SYSTEMS



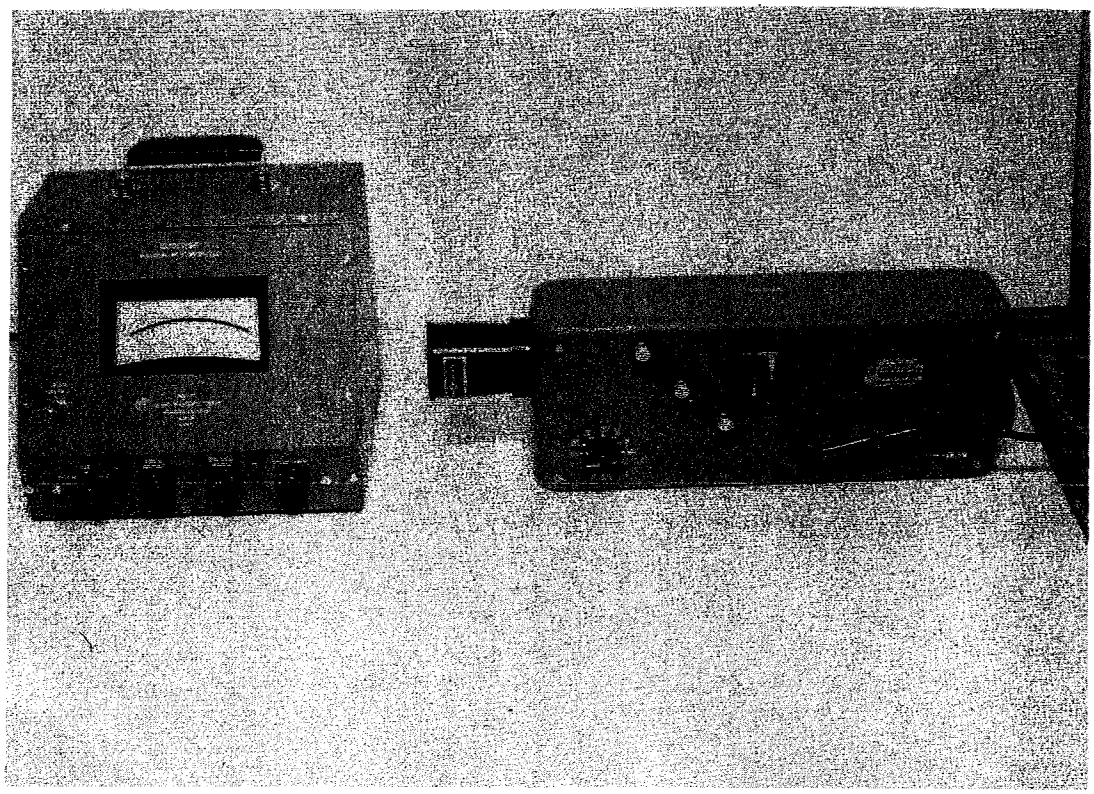
MEDIAN SYSTEMS



STAGGERED SYSTEMS

LAYOUT OF THE TEST SITE

FIGURE 2



SPECTRA PRITCHARD PHOTOMETER

Figure 3

Table 1 shows lighting systems parameters and the layout of the test conditions can be seen in Figure 2. In this figure the luminaires are marked at the side of the roadway. Measuring points are indicated along each lane with the direction of observation marked.

One-Side Lighting Systems. The 400-watt luminaires were mounted on five portable towers on which the mounting height could be varied for any setting up to 60 feet. The towers were at a 165-foot spacing for the 30-foot mounting height and 230-foot spacing for the other mounting heights. The luminaires were positioned at the edge of the left lane and were tilted upward vertically to their maximum adjustment on a horizontal mast arm to provide illumination over the entire roadway of six 12.5-foot lanes.

The 1000-watt luminaires were mounted on the same towers on longer arms, positioning them five feet out over the first lane. The spacing of the 1000-watt luminaires was 300 feet.

Median Lighting Systems. For these systems, two luminaires were mounted back-to-back on a single support with a spacing of 12 feet between the two 400-watt luminaires and 22 feet between the two 1000-watt luminaires. These luminaires were also adjusted for lateral projection of the light as in the one-side system. The longitudinal spacings and mounting heights were the same as in the one-side system.

Staggered Lighting Systems. For these systems five towers were arranged in a staggered pattern along a roadway 75 feet wide for the 400-watt luminaires and 100 feet wide for the 1000-watt luminaires. The longitudinal spacing was 200 feet for the 400-watt luminaires at all mounting heights and 250 feet for the 1000-watt luminaires. Overhang was the same as in the one-side system.

For each lighting system, readings were taken along each lane at 10-foot intervals starting midway between the first and second luminaires and ending midway between the second and third luminaires as shown in Figure 2. The second luminaire was always at the center of the line of measuring stations and always to the left of the roadway as the instrument was aimed down the roadway. For each system, readings were taken in six lanes, except for systems numbered 17 and 18, when the roadway between the rows of luminaires was divided into eight lanes.

INSTRUMENTATION

A Spectra Pritchard Photometer was used for the brightness and DVB measurements (Figure 3) A disability glare integrator attachment was used for the DVB measurements. The integrator is constructed to conform to the relation:

$$B_V = \frac{10\pi E \cos\theta}{\theta\ (1.5 + \theta)}$$

where B_V = equivalent veiling luminance produced by disability glare, in footlamberts,

E = illumination striking the plane of the pupil of the eye in lumens/ft.^{2}, measured normal to the incoming ray, and

θ = the angle between the line of sight and the source of disability glare.

This glare integrator evaluates the DVB effect from all sources including reflections from the pavement and the effect from the central two degrees of the visual field.

At each measurement station the photometer was aimed at a point 300 feet down the roadway and a reading was taken measuring the pavement brightness. The glare integrator was then placed over the objective lens without moving the photometer and a reading was taken measuring the DVB from the entire visual field. The photometer was mounted at a height of four feet above the pavement on a tripod with wheels. This height and the aiming distance of 300 feet conforms to the normal viewing position of a driver. An aperture of two degrees was used for all measurements, since the disability glare lens was constructed for this size aperture only.

DATA ANALYSIS

Data as read on the photometer were transformed into DVB and brightness values by application of correction coefficients for aperture, neutral filters and glare lens. To obtain the average brightness of the area imaged within the mirror-aperture the following expression was used:

$$B = \frac{M \times N \times K}{R}$$

where B = average brightness in footlamberts

M = microammeter reading;

N = neutral filter factor;

K = combined aperture and sensitivity factor; and

R = microammeter reading for a built-in reference source.

For DVB value, B was multiplied by a correction factor to correct for sensitivity changes in the instrument with the DVB lens attached.

A relative measure of glare due to the non-uniformity of the brightness field was computed using the expression:

$$K = \frac{B_V + B}{B} - 0.07$$

where B_V = DVB as measured by the photometer in footlamberts; and

B = pavement brightness, in footlamberts.

This expression represents the glare due only to the non-uniformity of the field because glare or veiling brightness resulting from a uniform field is removed by the negative constant, 0.07. This computational procedure is based on earlier research by Moon and Spencer [2] in which they computed the DVB produced by a uniform field of brightness and found it to be 1/14th or 7 percent as bright as the field of brightness producing it.

This glare constant, K, being a form of ratio between DVB and pavement brightness indicates the proportion of DVB present in relation to pavement brightness. A completely uniform field of brightness, irregardless of the level of pavement brightness, would have a K-value of 1.00. The K-values of a system do not indicate the loss of visibility due to DVB but rather the reduction in task contrast.

DISCUSSION OF RESULTS

The data for all the systems tested have been summarized by constructing contours based on the K-values for each lighting system. From the patterns formed by the contour lines of the different systems, it can be seen that changes in mounting height do not necessarily change the pattern as to form, but only change the intensity. For a low mounting height the intensity is higher than for a higher mounting height. This is illustrated in Figures 4 to 21, Appendix A. The average K-value for each test is given in Table 2. Tables 3 and 4 show average DVB and pavement brightness values for each system.

The decrease in DVB for increased mounting height follows from the expression for DVB. When the mounting height is increased the angle θ is increased for any glare source and for any position as long as the line of sight is the same. This decrease in DVB for increased mounting height appears for all configurations except test number G-2. Only one measurement was taken at each point for every test and therefore, this condition could not be checked.

It can be seen in Table 2, that the average K-value for any of the luminaires is higher or at least equal to the K-value of the corresponding system with a double line of luminaires (median lighting) for both 400-watt and 1000-watt luminaires. Even though the DVB has increased with the addition of more glare sources, the brightness has increased also because of the backlight from the second row of luminaires. This increased brightness offsets the increased DVB and the loss in visibility from DVB is less.

Table 3 indicates that DVB is greater for 1000-watt systems than for corresponding 400-watt systems. The pavement brightness (Table 4) is also greater for every case. Since the DVB is dependent only on the geometry of the lighting system, the observer position and the illumination at the eye, and since the 1000-watt systems produce greater brightness, the illumination at the eye will be greater and the DVB should be greater. The spacing of the 1000-watt luminaires is greater than for the 400-watt luminaires which extends the lighting system farther, increasing the illuminated area and thereby raising the average pavement brightness.

To get a better picture of the variation of DVB along the roadway, averages of K-values for each station along the roadway were computed and the points plotted. Trend lines were fitted to the points. These trend lines are shown in Appendix A, Figures 22-27. Each figure shows the average K-values for a specific configuration with the different mounting heights in the same figure. Unfortunately, there is no quantitative index available to indicate the amount of extra loss of visibility from DVB fluctuations at different frequencies of fluctuation and different magnitudes of DVB. In general it can be stated that the changes in DVB along the roadway for the 1000-watt systems are smoother and the spacings are longer than for the 400-watt systems. To further show this, Figures 28-30, Appendix A, were prepared. These trend lines represent the average K-values for 400-watt and 1000-watt systems with the same configuration. The 45-foot mounting height for the 400-watt system and the 50-foot mounting height for the 1000-watt systems were selected because of their similar distribution and level of illumination for each configuration.

In Figure 14 (G-11) and Figure 20 (G-17), it can be seen that the uniformity of DVB for the 400-watt system is less for the outside lanes than for the 1000-watt system. Even though the averages of K-values show the systems equal, the 1000-watt staggered system shows up better than the 400-watt staggered system when brightness and uniformity of DVB in the different lanes are considered. These findings indicate the visibility in the 1000-watt system is better than in the 400-watt system.

TABLE 2

Average K-Values

400-Watt Luminaires

MOUNTING HEIGHT (feet)	TEST NO.	ONE-SIDE	TEST NO.	MEDIAN	TEST NO.	STAGGERED
30	G-1	1.25	G-5	1.25	G-9	1.24
40	G-2	1.21	G-6	1.20	G-10	1.24
45	G-3	1.23	G-7	1.19	G-11	1.23
50	G-4	1.23	G-8	1.18	G-12	1.21

1000-Watt Luminaires

50	G-13	1.33	G-15	1.33	G-17	1.23
60	G-14	1.31	G-16	1.29	G-18	1.22

TABLE 3

Average DVB

Foot-lamberts

400-Watt Luminaires

MOUNTING HEIGHT (feet)	ONE-SIDE	MEDIAN	STAGGERED
30	0.22	0.23	0.19
40	0.13	0.14	0.17
45	0.16	0.14	0.16
50	0.15	0.14	0.15

1000-Watt Luminaires

MOUNTING HEIGHT (feet)	ONE-SIDE	MEDIAN	STAGGERED
50	0.34	0.38	0.25
60	0.28	0.31	0.22

TABLE 4

Average Pavement Brightness

Foot-lamberts

400-Watt Luminaires

MOUNTING HEIGHT (feet)	ONE-SIDE	MEDIAN	STAGGERED
30	0.75	0.80	0.62
40	0.49	0.58	0.59
45	0.56	0.57	0.57
50	0.54	0.60	0.54

1000-Watt Luminaires

MOUNTING HEIGHT (feet)	ONE-SIDE	MEDIAN	STAGGERED
50	0.86	1.02	0.88
60	0.77	0.90	0.79

For the systems shown in Figure 28 (one-side) and the ones shown in Figure 29 (median) it is difficult to say whether the 400-watt or the 1000-watt systems are more influenced by DVB. The averages of K-values for the 1000-watt systems are greater than for the corresponding 400-watt systems. But the brightness for the 1000-watt systems is also greater than for the 400-watt systems.

SUMMARY OF FINDINGS

The findings of this study of DVB in selected roadway lighting systems are as follows:

(1) Systems with luminaires in one-side mounting configurations and median mounting configurations produce approximately the same patterns of DVB. The intensities of DVB are smaller for the median configuration than for the one-side configuration.

(2) Distributions of DVB for different mounting heights within the same configuration are similar, only intensities of DVB vary with the greater intensities found for the lower mounting heights.

(3) Intensity of DVB and pavement brightness is greater for 1000-watt luminaire systems than for corresponding 400-watt luminaire systems.

(4) Fluctuation of DVB is greater for the 400-watt systems than for the 1000-watt systems.

(5) For a staggered system, a 1000-watt system with 50-foot mounting height provides better conditions for vision than a 400-watt system with 45-foot mounting height.

(6) For any of the 1000-watt systems the level of DVB appears to be low enough not to be a critical factor in view of the high pavement brightness produced by the systems.

Further studies should include measurements of representative tasks, including measurements of task brightness, pavement brightness, and DVB to determine task contrasts and loss of visibility caused by DVB. This would give an indication of the influence DVB has on visibility for the systems under consideration.

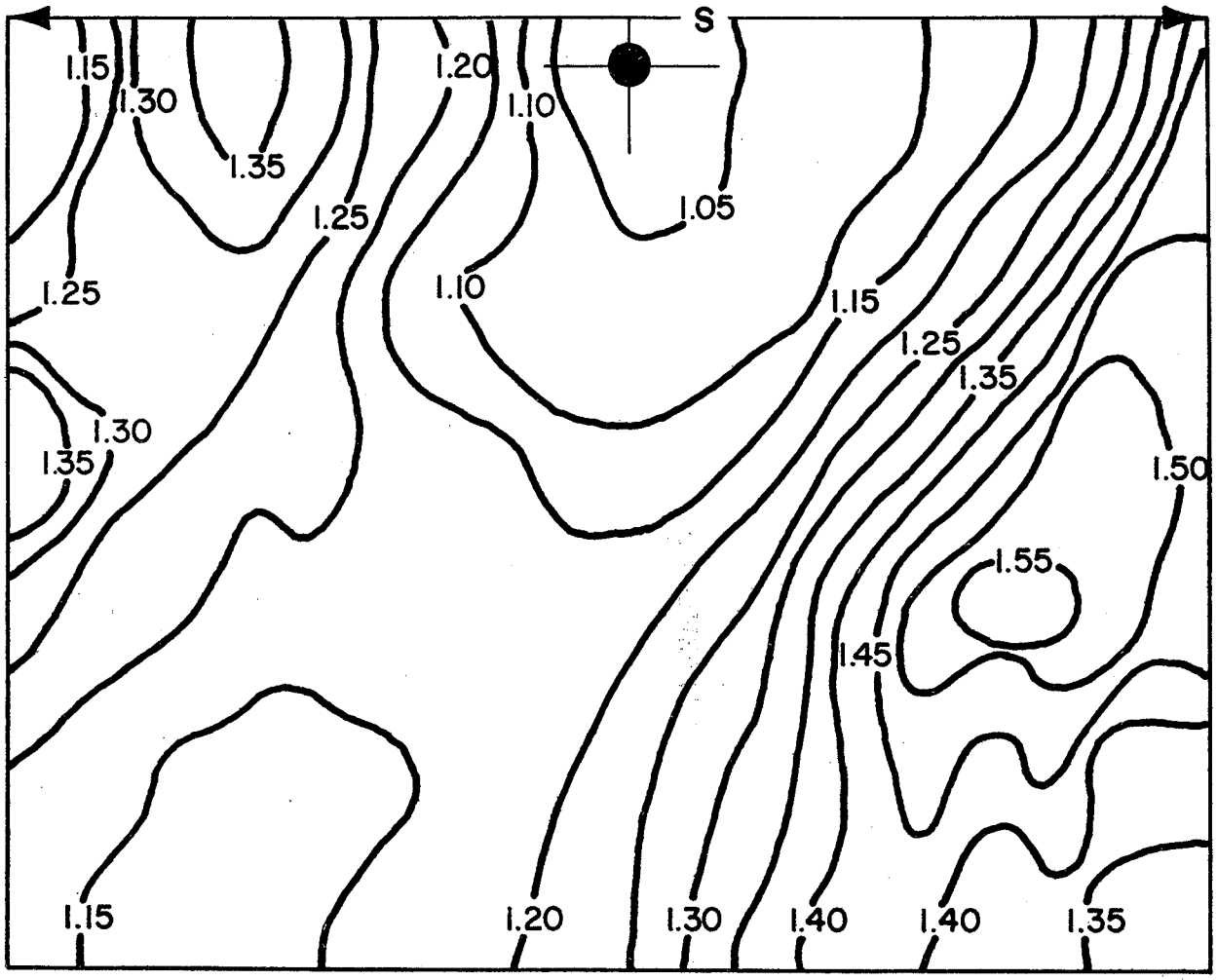
It is evident that ratings for the effectiveness of roadway lighting in producing good seeing conditions are needed. Relative visibility ratings based on the requirement of the visual tasks must be developed to aid in the evaluation of lighting systems.

REFERENCES

1. IES Lighting Handbook, 3rd. ed., Illumination Engineering Society, New York, N.Y., 1959, Chapter 20, p. 2.

2. IES Lighting Handbook, 3rd. ed., Illumination Engineering Society, New York, N.Y., 1959, Chapter 2, p. 14.

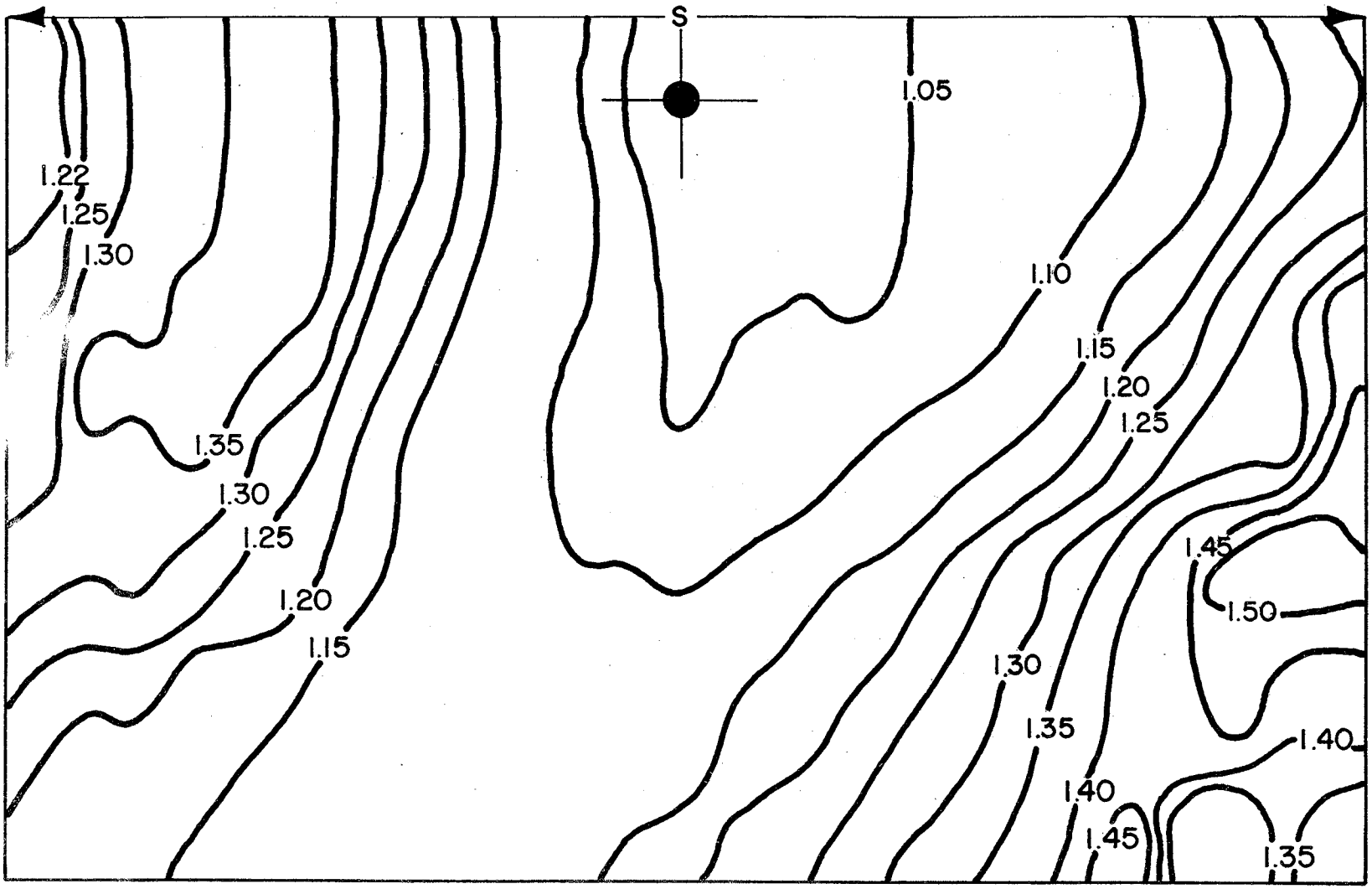
APPENDIX A



ONE-SIDE LIGHTING
LUMINAIRES: 400-WATT

SPACING: 165'
MOUNTING HEIGHT: 30'

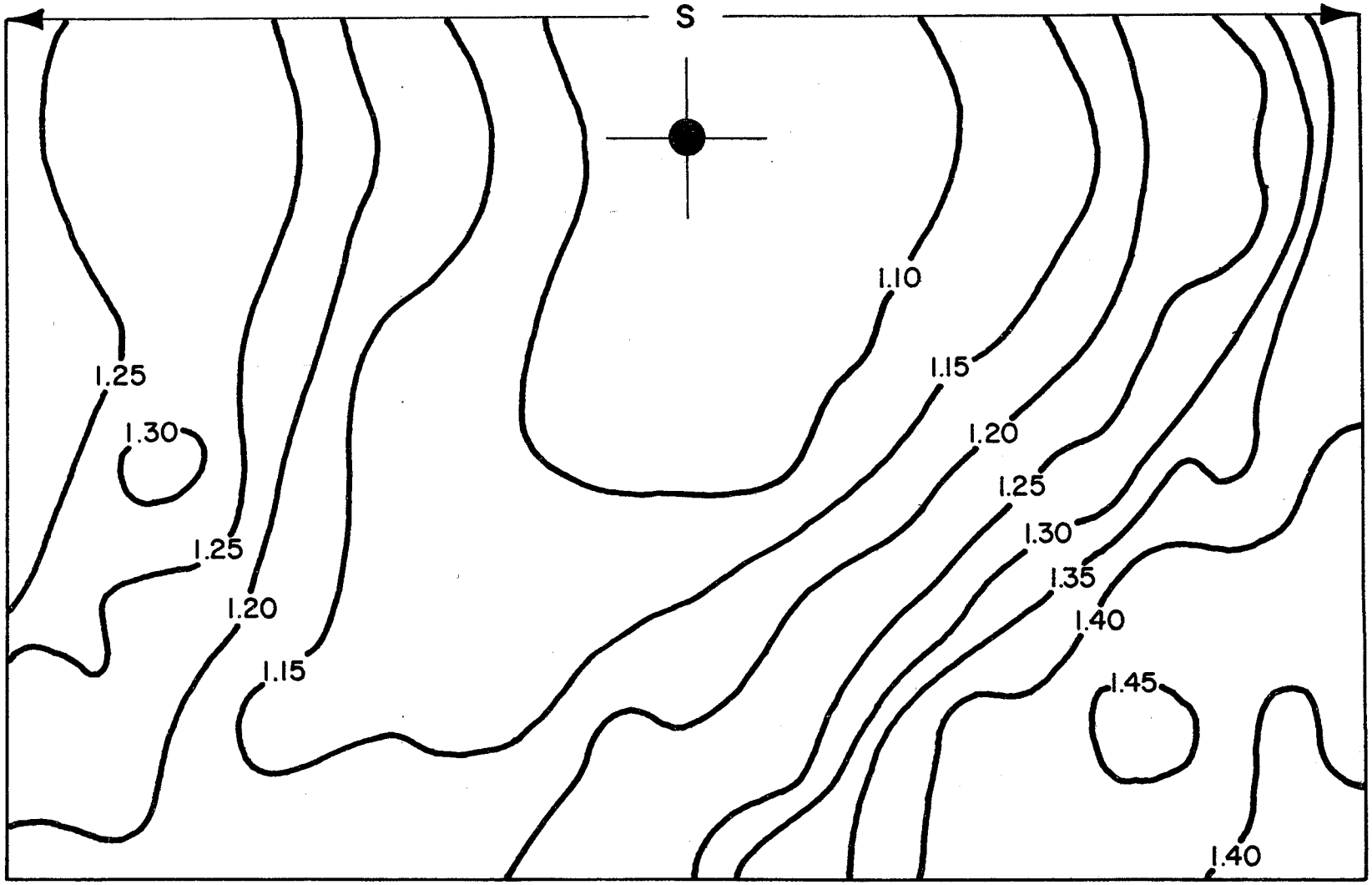
FIGURE 4



ONE-SIDE LIGHTING
LUMINARES: 400 WATT

SPACING: 230'
MOUNTING HEIGHT: 40'

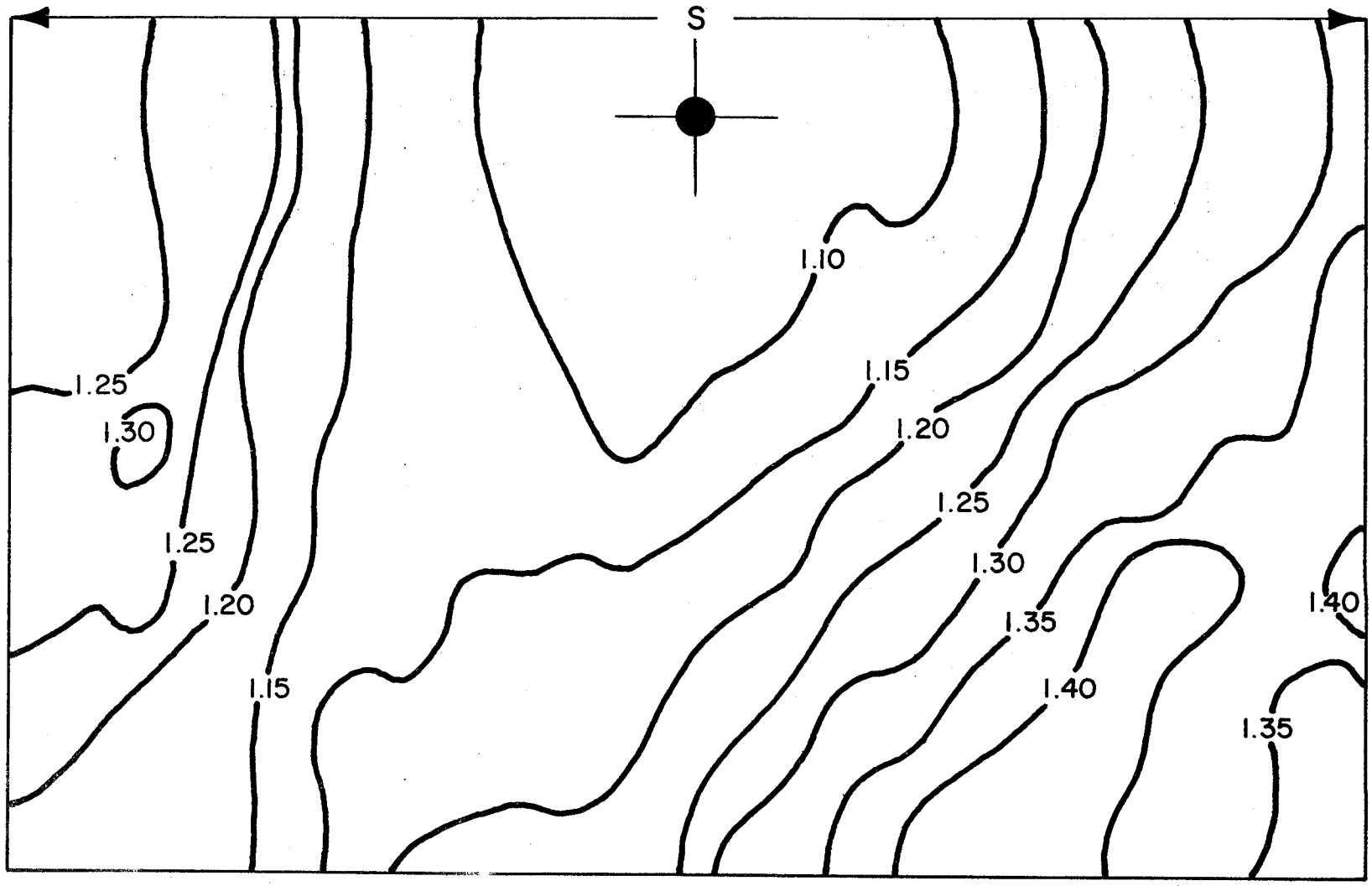
FIGURE 5



ONE-SIDE LIGHTING
LUMINAIRES: 400 WATT

SPACING : 230'
MOUNTING HEIGHT : 45'

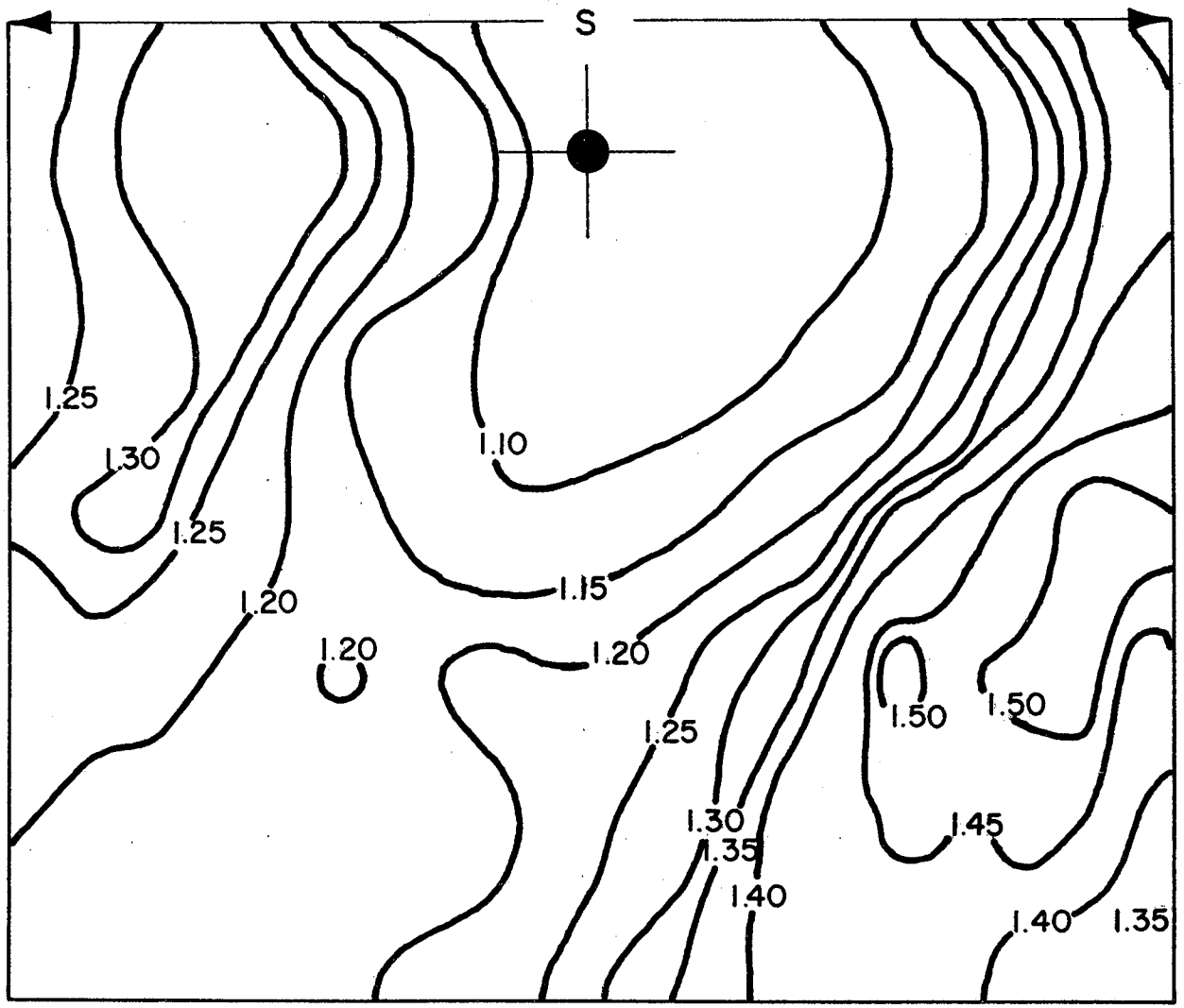
FIGURE 6



ONE-SIDE LIGHTING
LUMINAIRES : 400 WATT

SPACING : 230'
MOUNTING HEIGHT : 50'

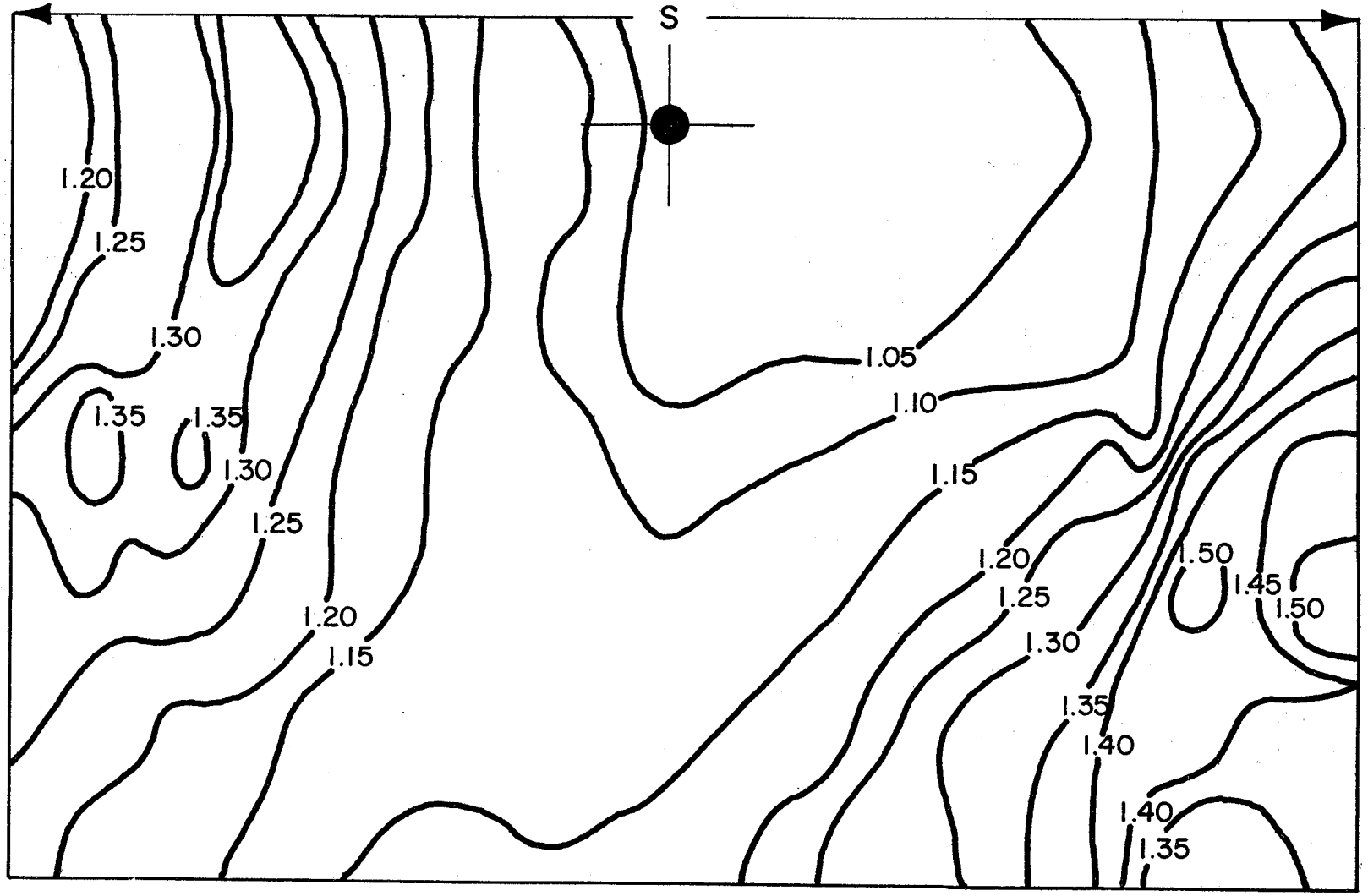
FIGURE 7



MEDIAN LIGHTING
LUMINAIRES : 400 WATT

SPACING : 165'
MOUNTING HEIGHT : 30'

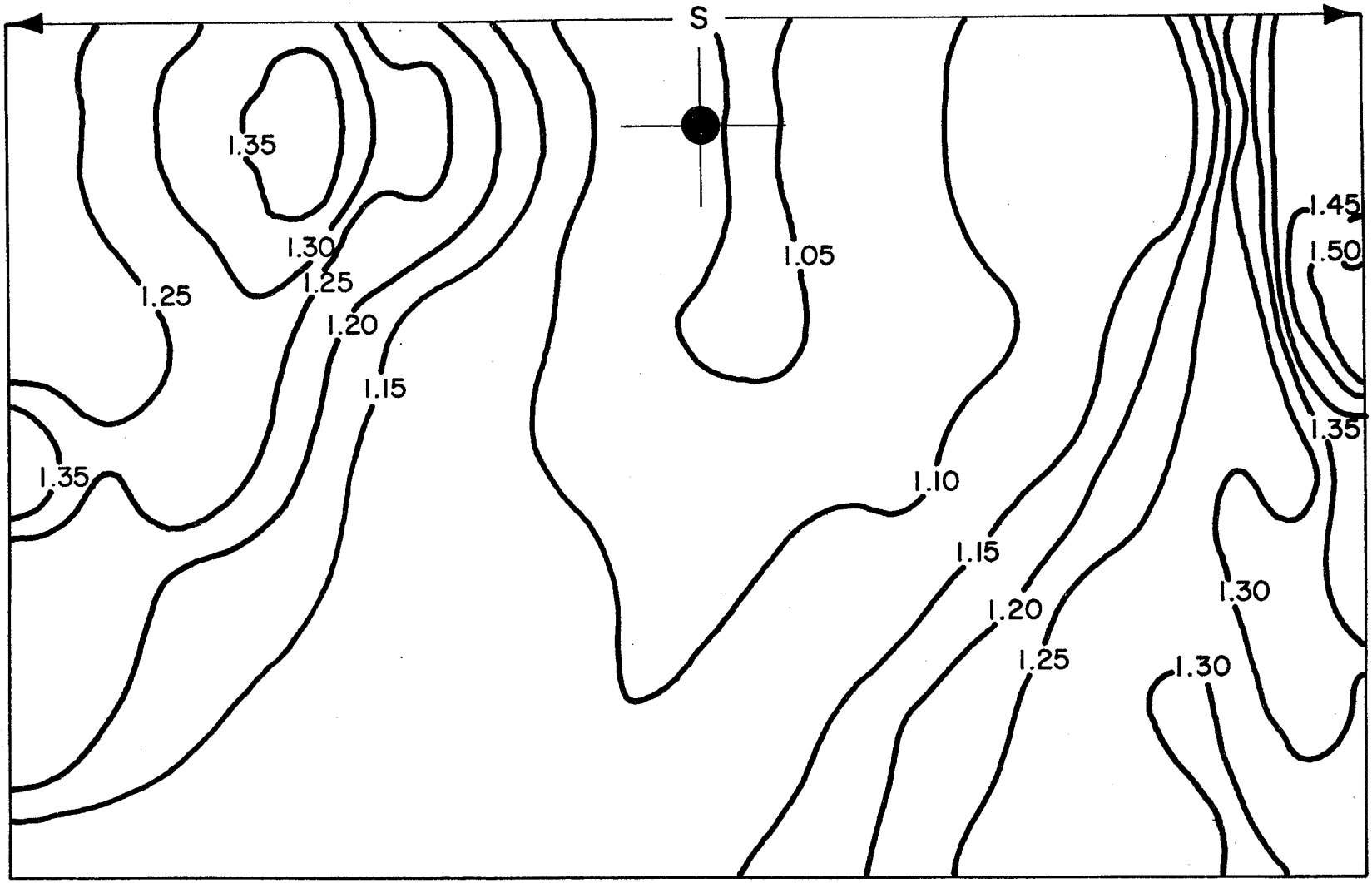
FIGURE 8



MEDIAN LIGHTING
LUMINAIRES : 400 WATT

SPACING : 230'
MOUNTING HEIGHT : 40'

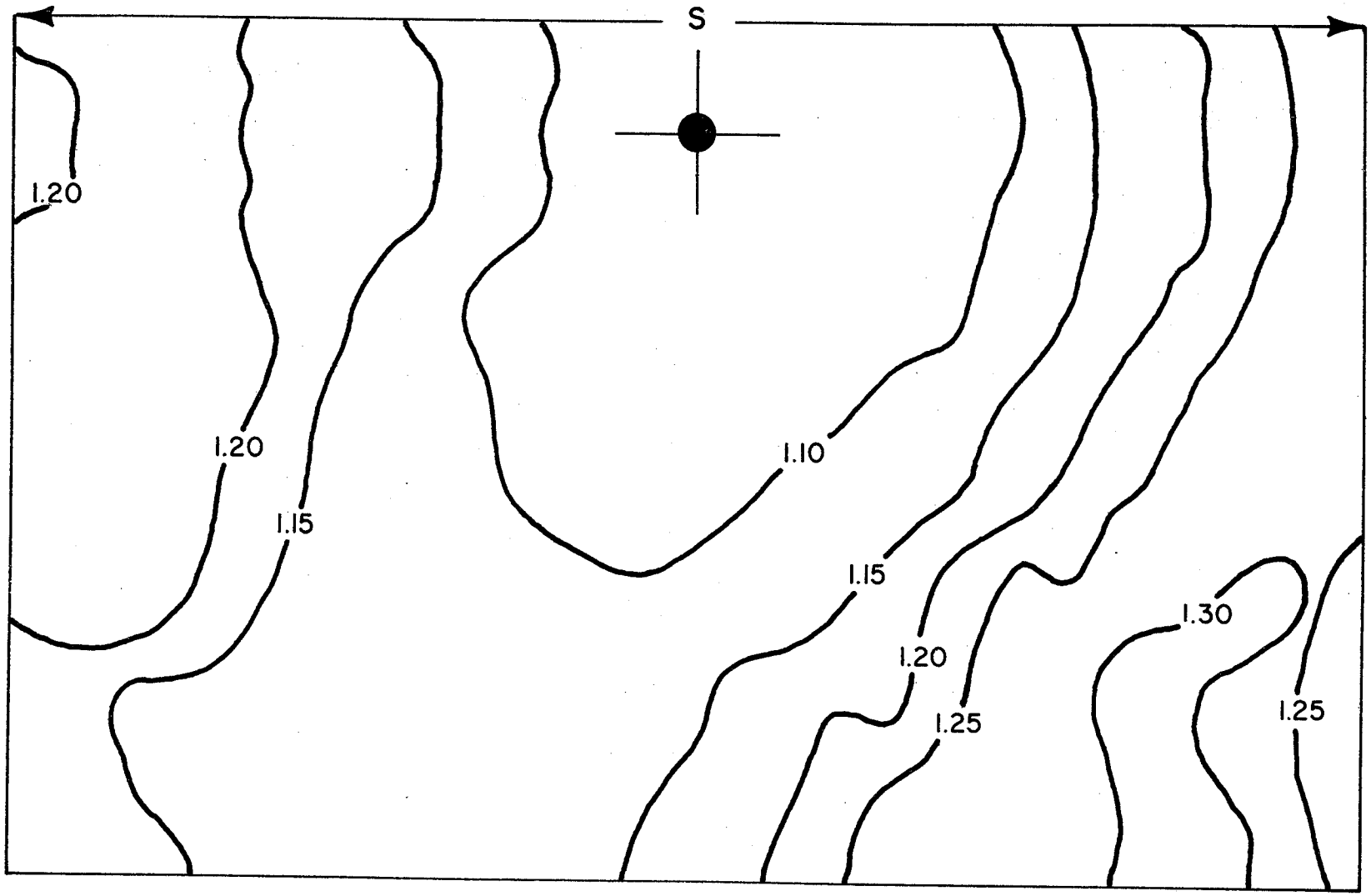
FIGURE 9



MEDIAN LIGHTING
LUMINAIRES : 400 WATT

SPACING : 230'
MOUNTING HEIGHT : 45'

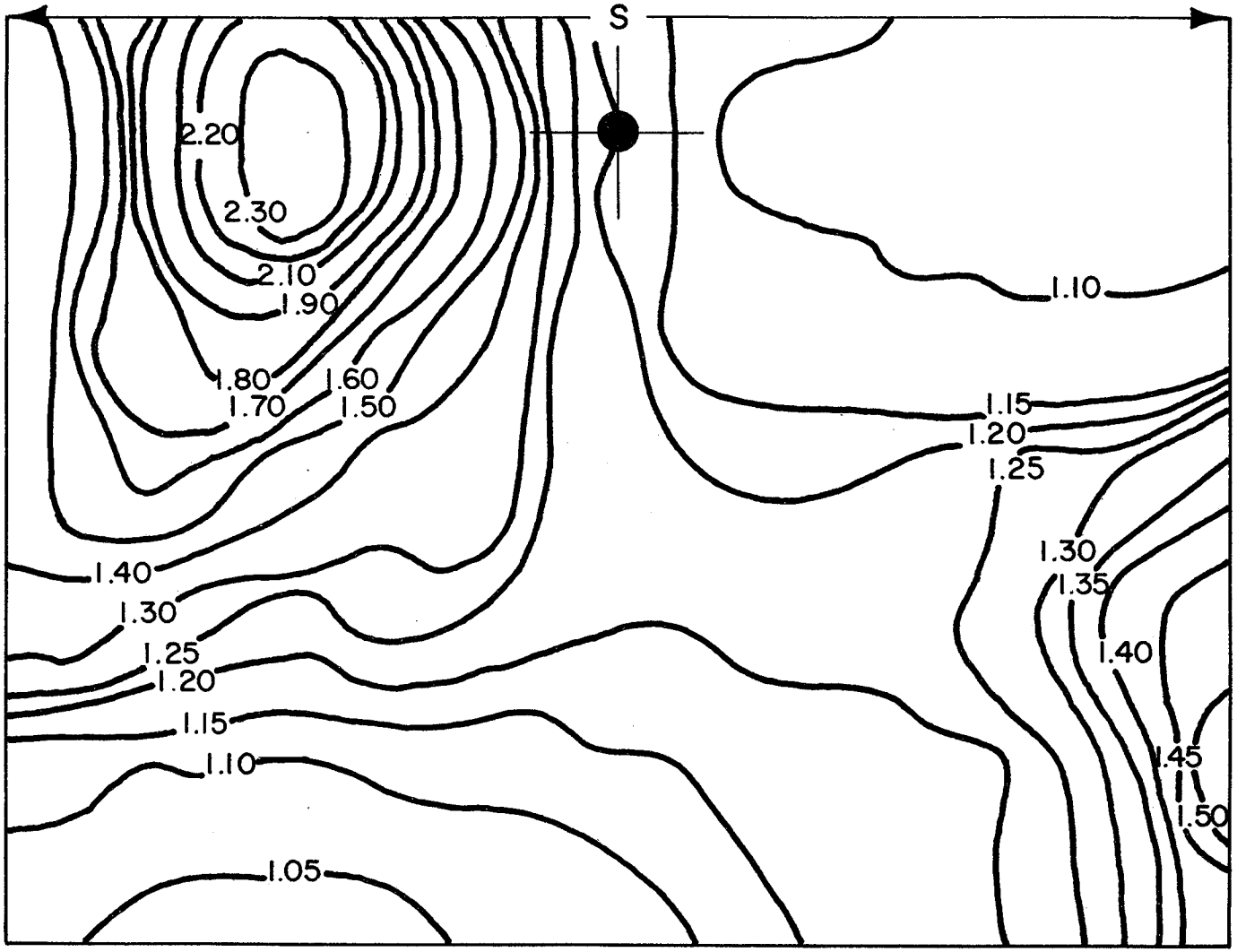
FIGURE 10



MEDIAN LIGHTING
LUMINAIRES: 400 WATT

SPACING 230'
MOUNTING HEIGHT 50'

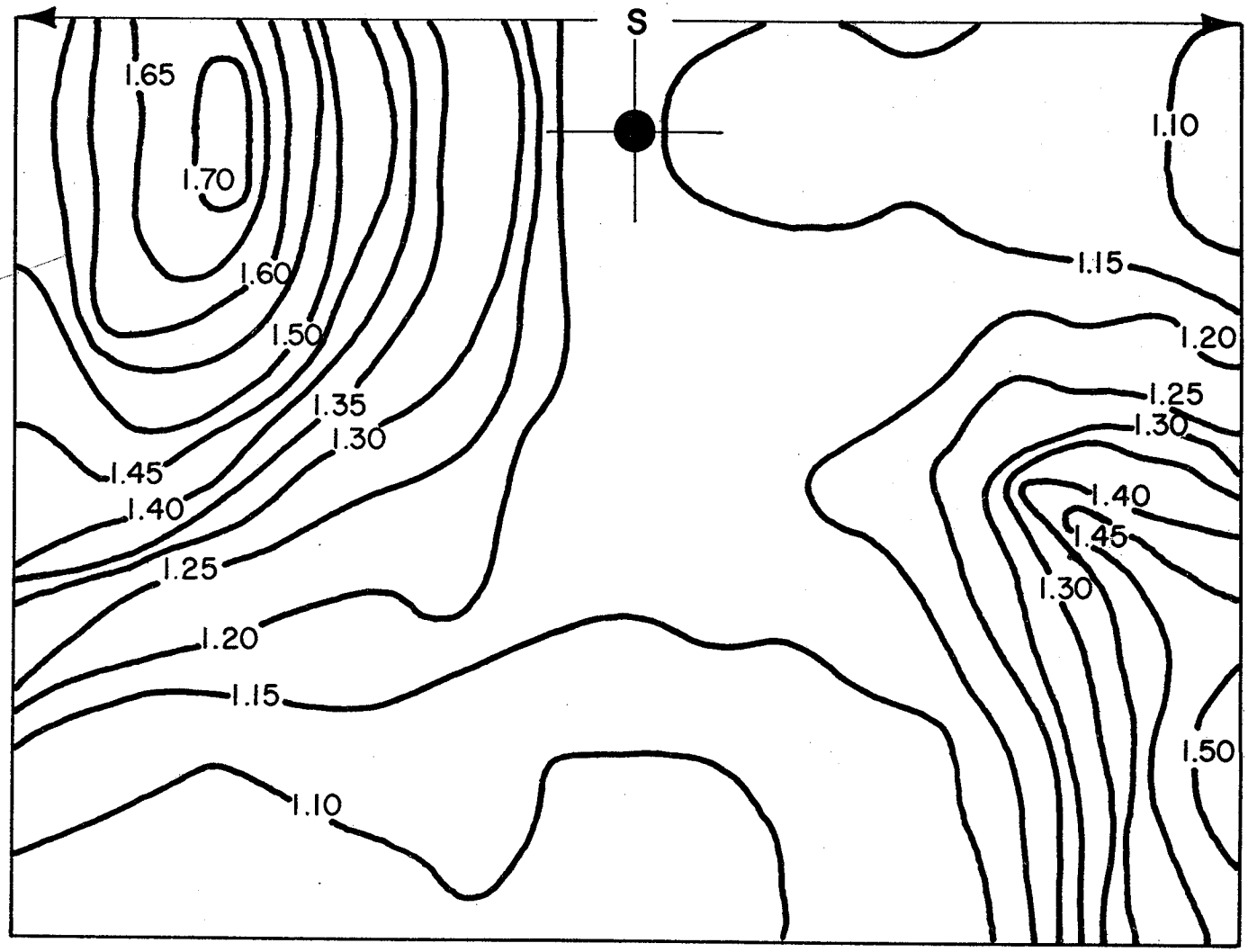
FIGURE 11



STAGGERED LIGHTING
LUMINAIRES : 400 WATT

SPACING : 200'
MOUNTING HEIGHT : 30'

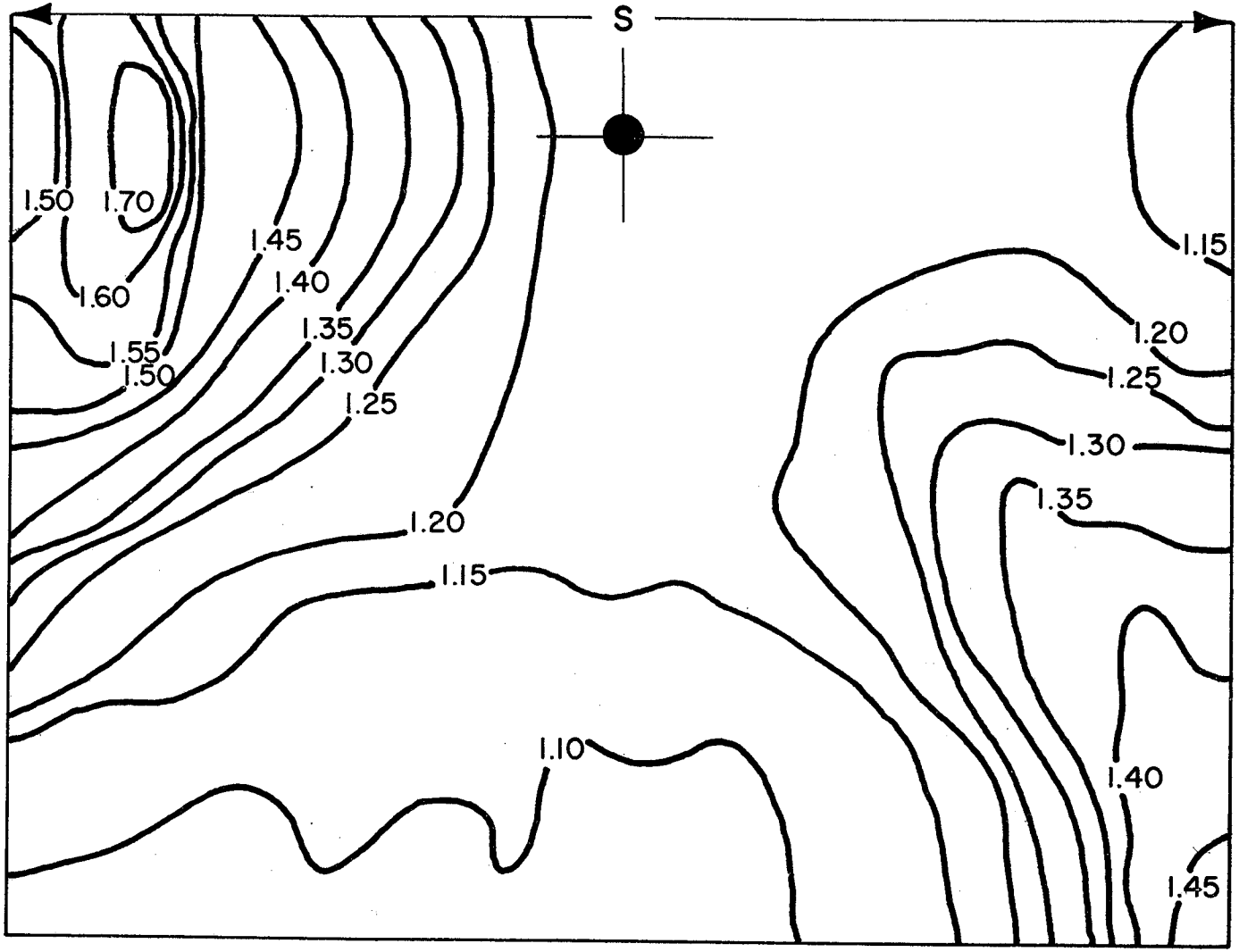
FIGURE 12



STAGGERED LIGHTING
LUMINAIRES : 400 WATT

SPACING : 200'
MOUNTING HEIGHT : 40'

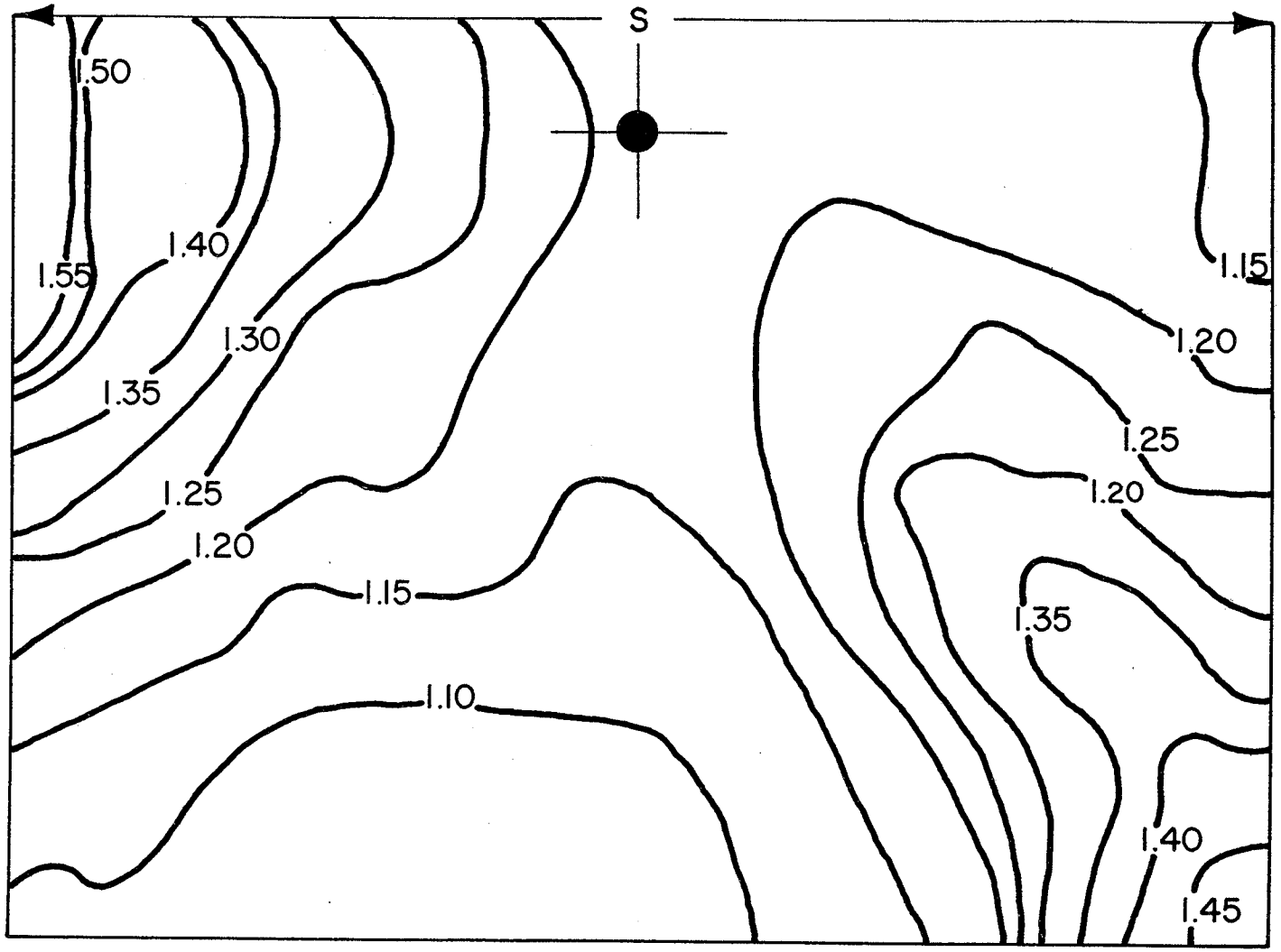
FIGURE 13



STAGGERED LIGHTING
LUMINAIRES : 400 WATT

SPACING : 200'
NTING HEIGHT : 45'

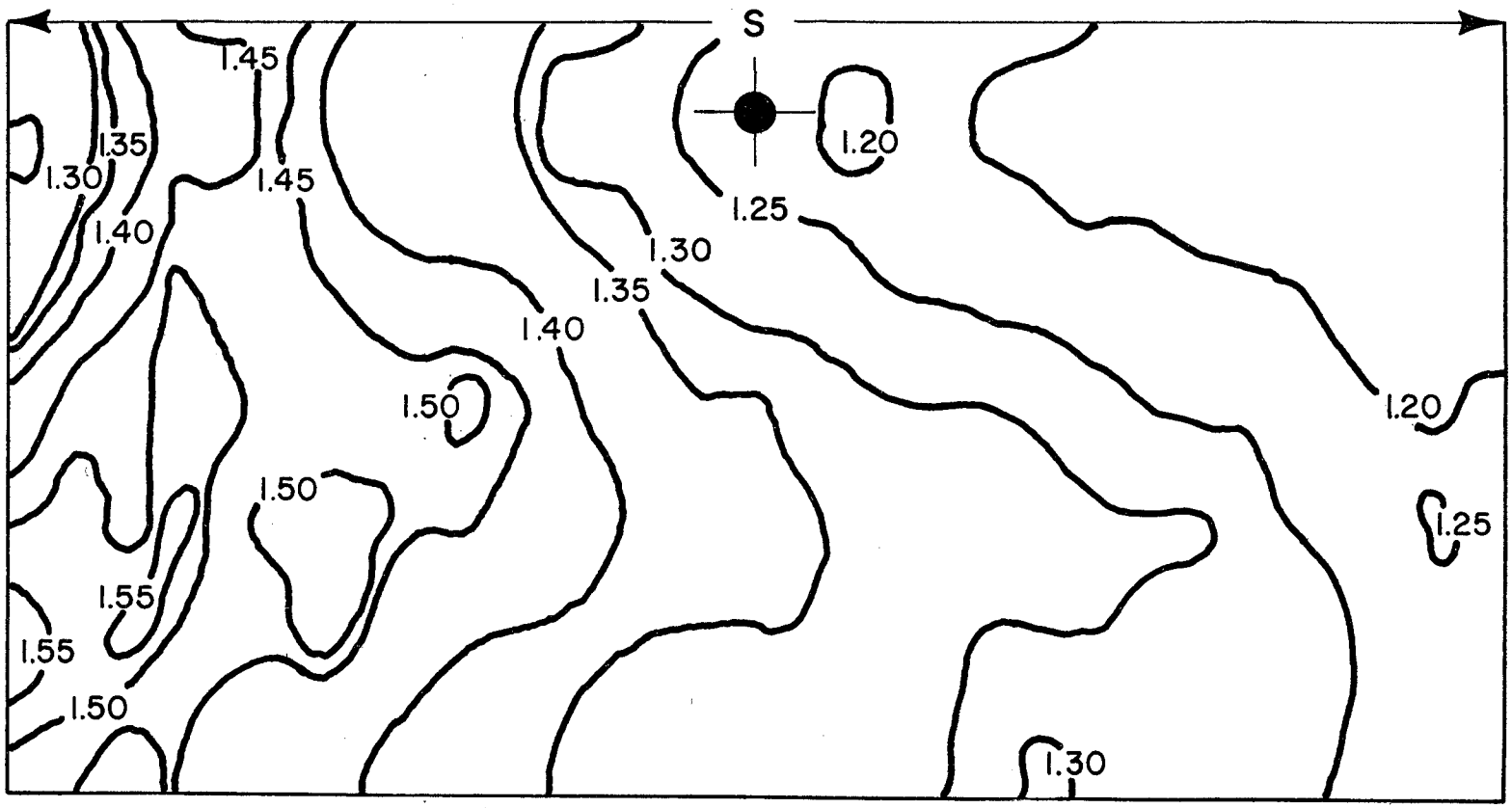
FIGURE 14



STAGGERED LIGHTING
LUMINAIRES : 400 WATT

SPACING : 200'
MOUNTING HEIGHT : 50'

FIGURE 15



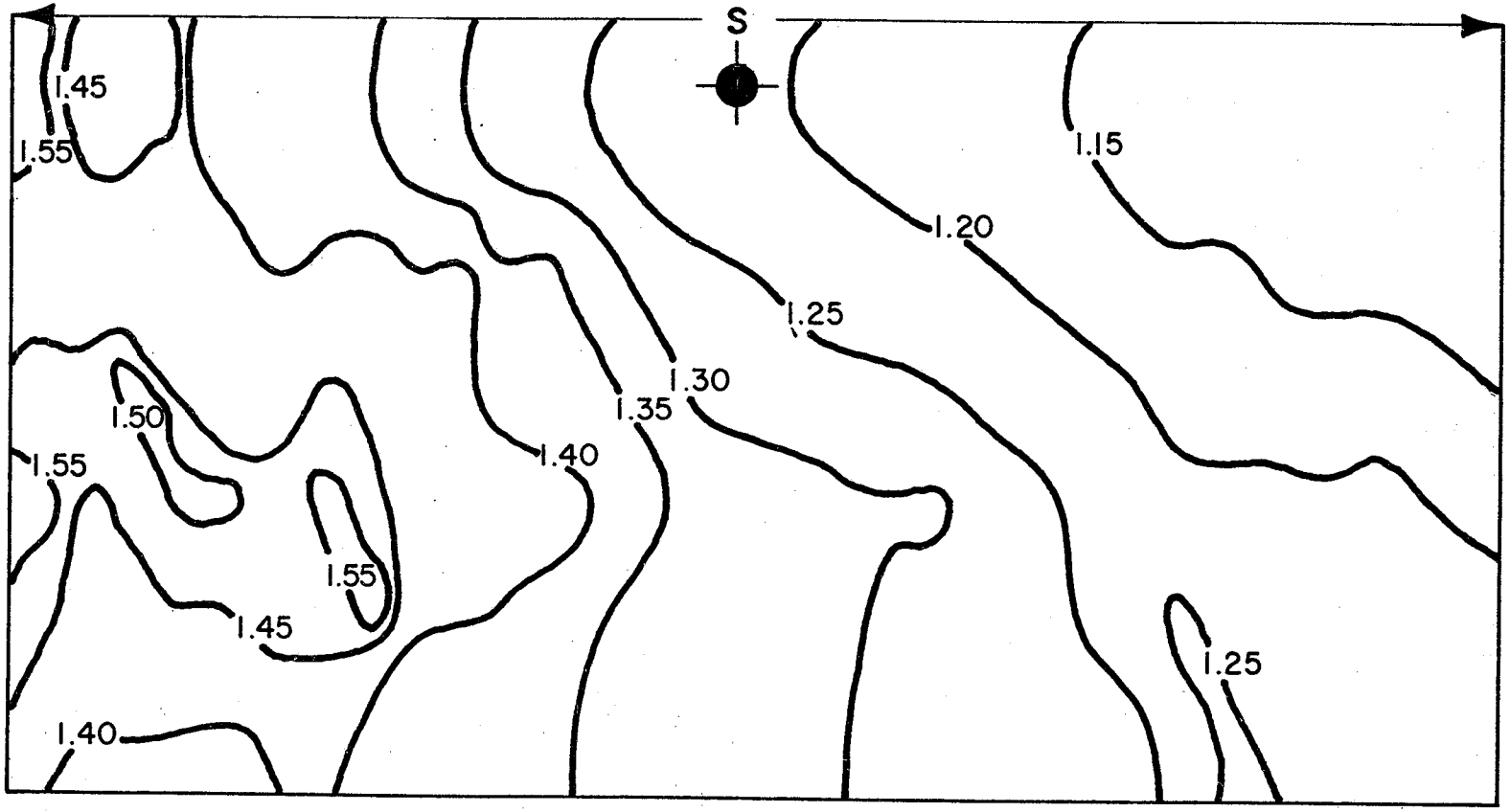
ONE SIDE LIGHTING

LUMINAIRES : 1000 WATT

SPACING 300'

MOUNTING HEIGHT 50'

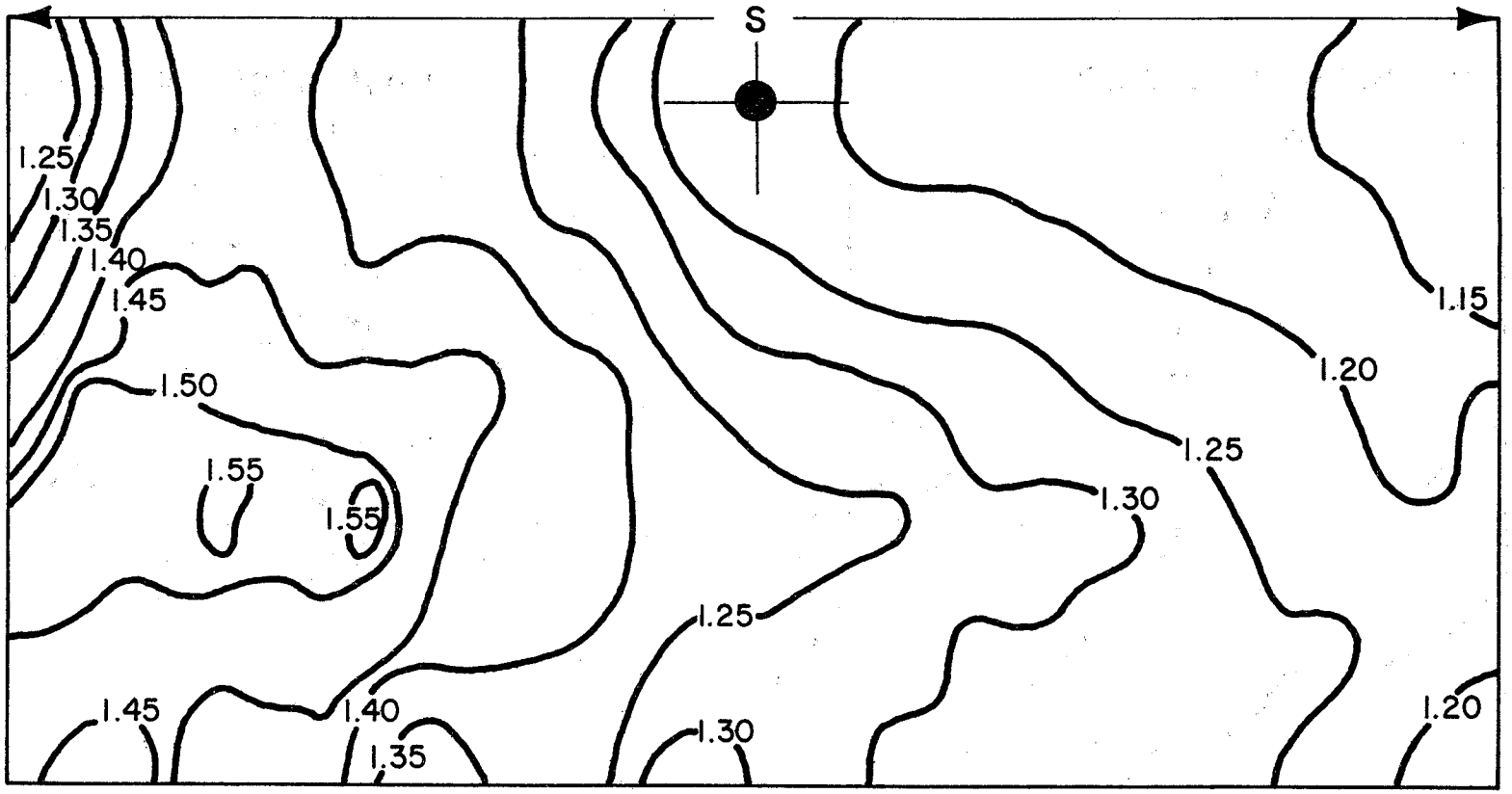
FIGURE 16



ONE-SIDE LIGHTING
LUMINAIRE : 1000 WATT

SPACING : 300'
MOUNTING HEIGHT : 60'

FIGURE 17



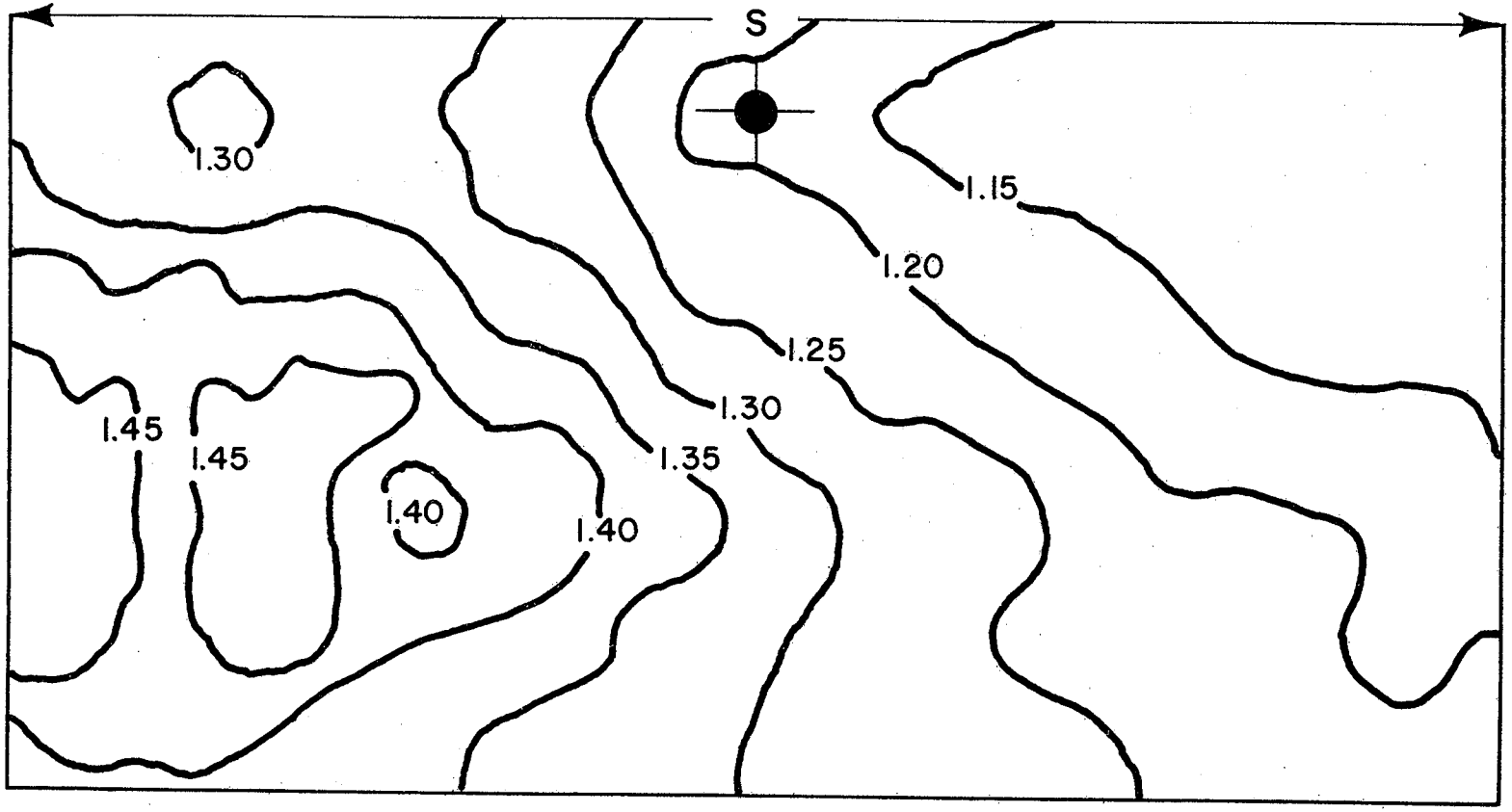
MEDIAN LIGHTING

LUMINAIRES : 1000 WATT

SPACING : 300'

MOUNTING HEIGHT : 50'

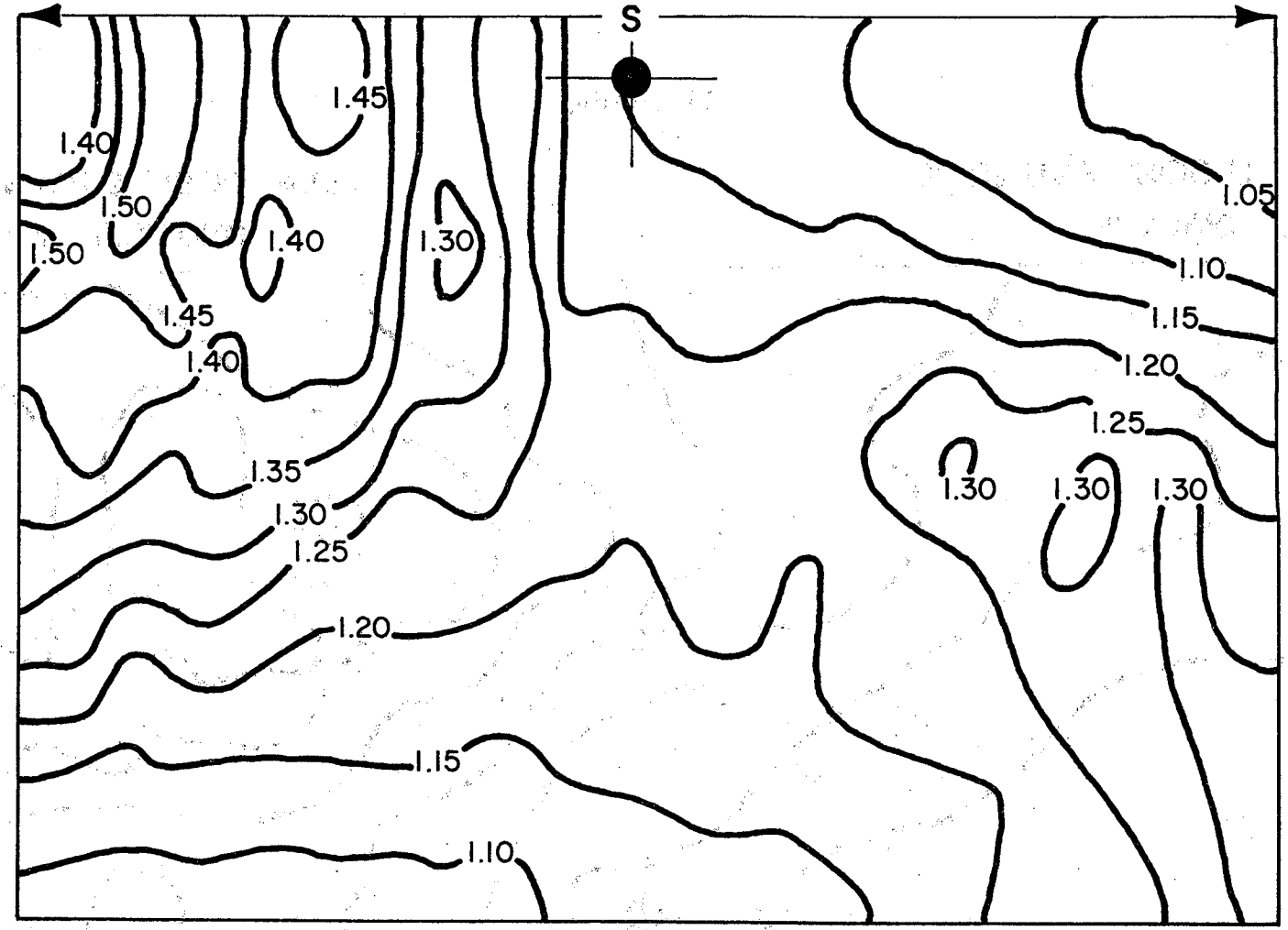
FIGURE 18



MEDIAN LIGHTING
LUMINAIRES : 1000 WATT

SPACING 300'
MOUNTING HEIGHT 60'

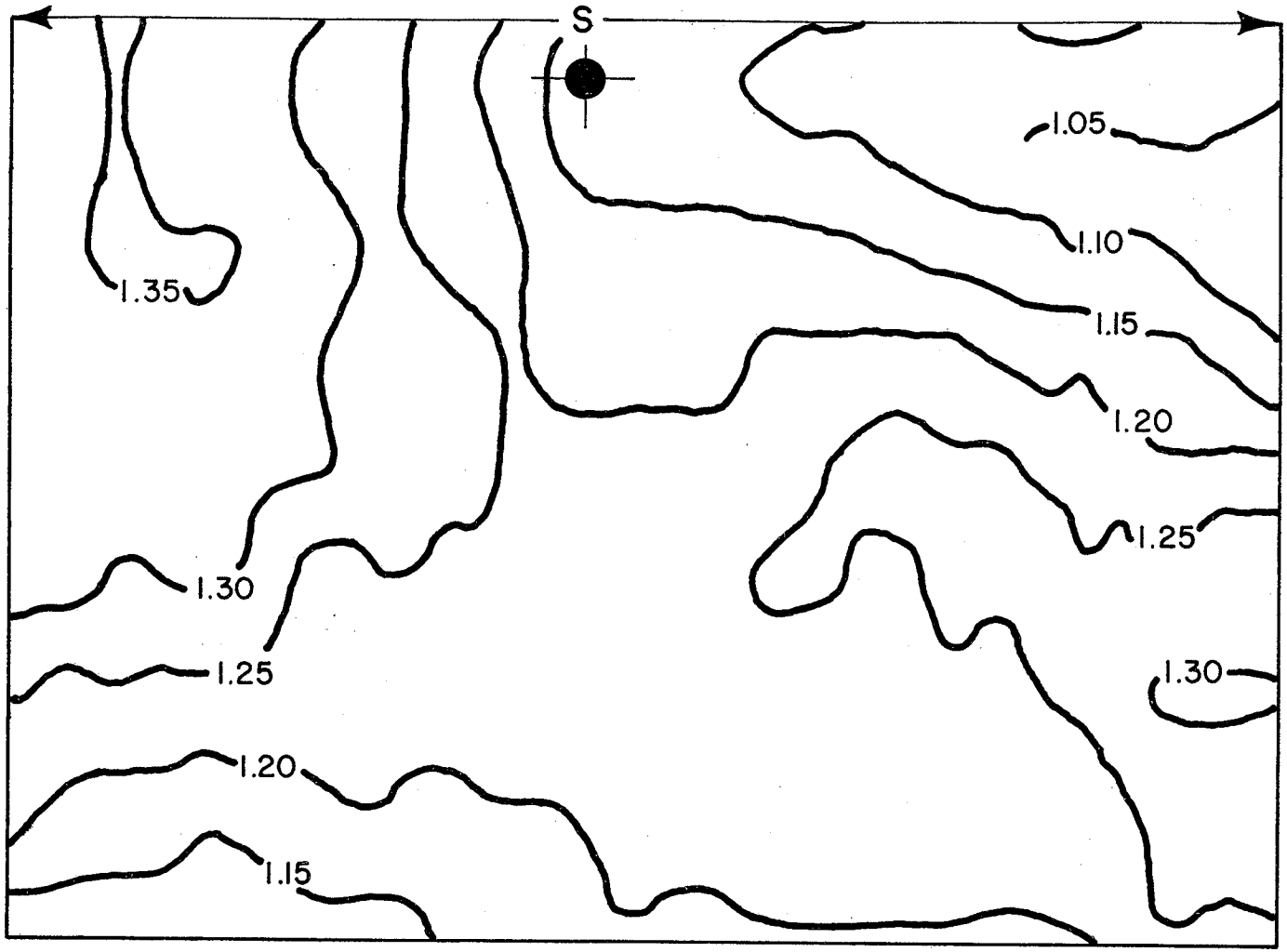
FIGURE 19



STAGGERED LIGHTING
LUMINAIRES : 1000 WATT

SPACING : 250'
MOUNTING HEIGHT : 50'

FIGURE 20



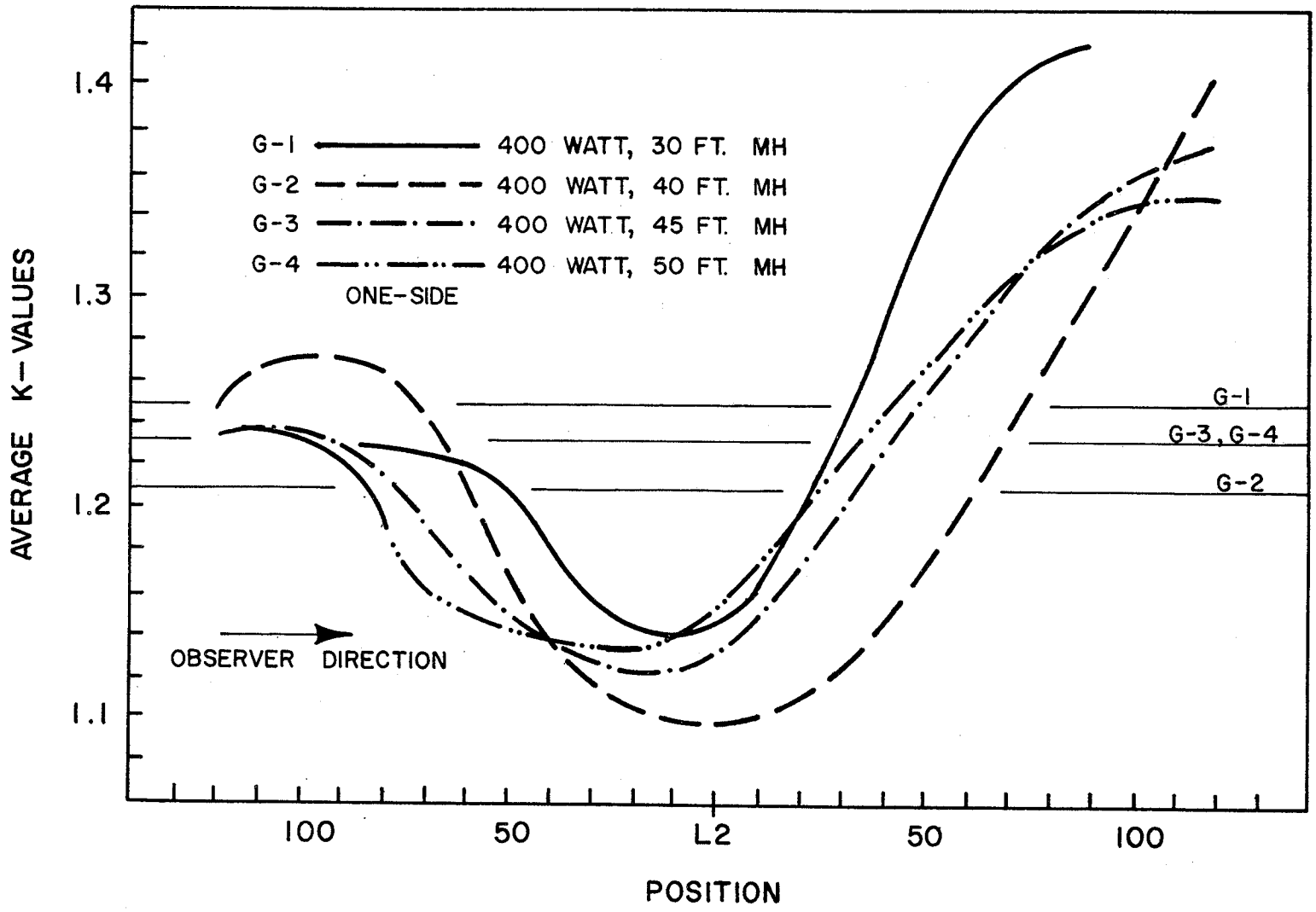
STAGGERED LIGHTING

LUMINAIRES : 1000 WATT

SPACING 250'

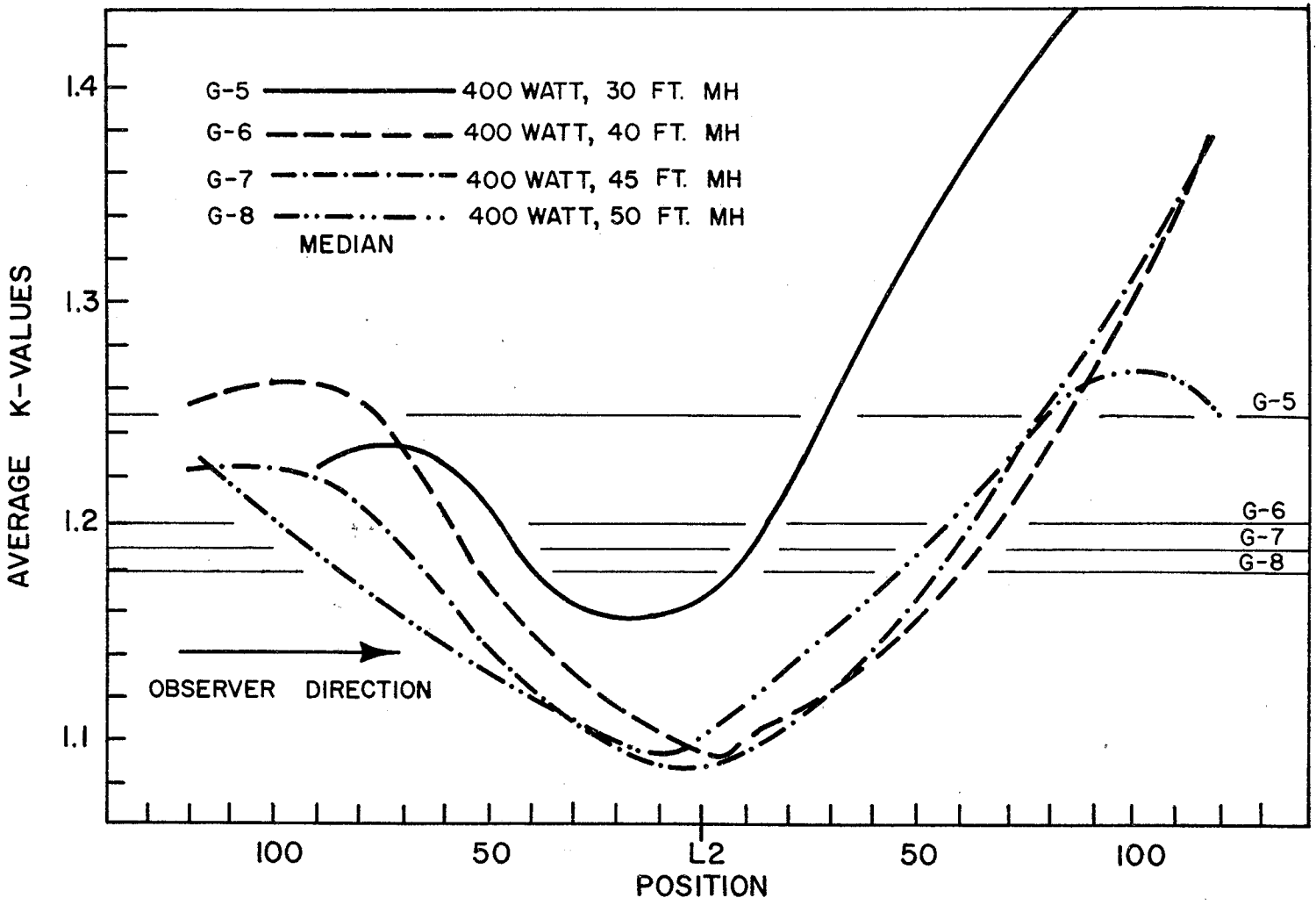
MOUNTING HEIGHT 60'

FIGURE 21



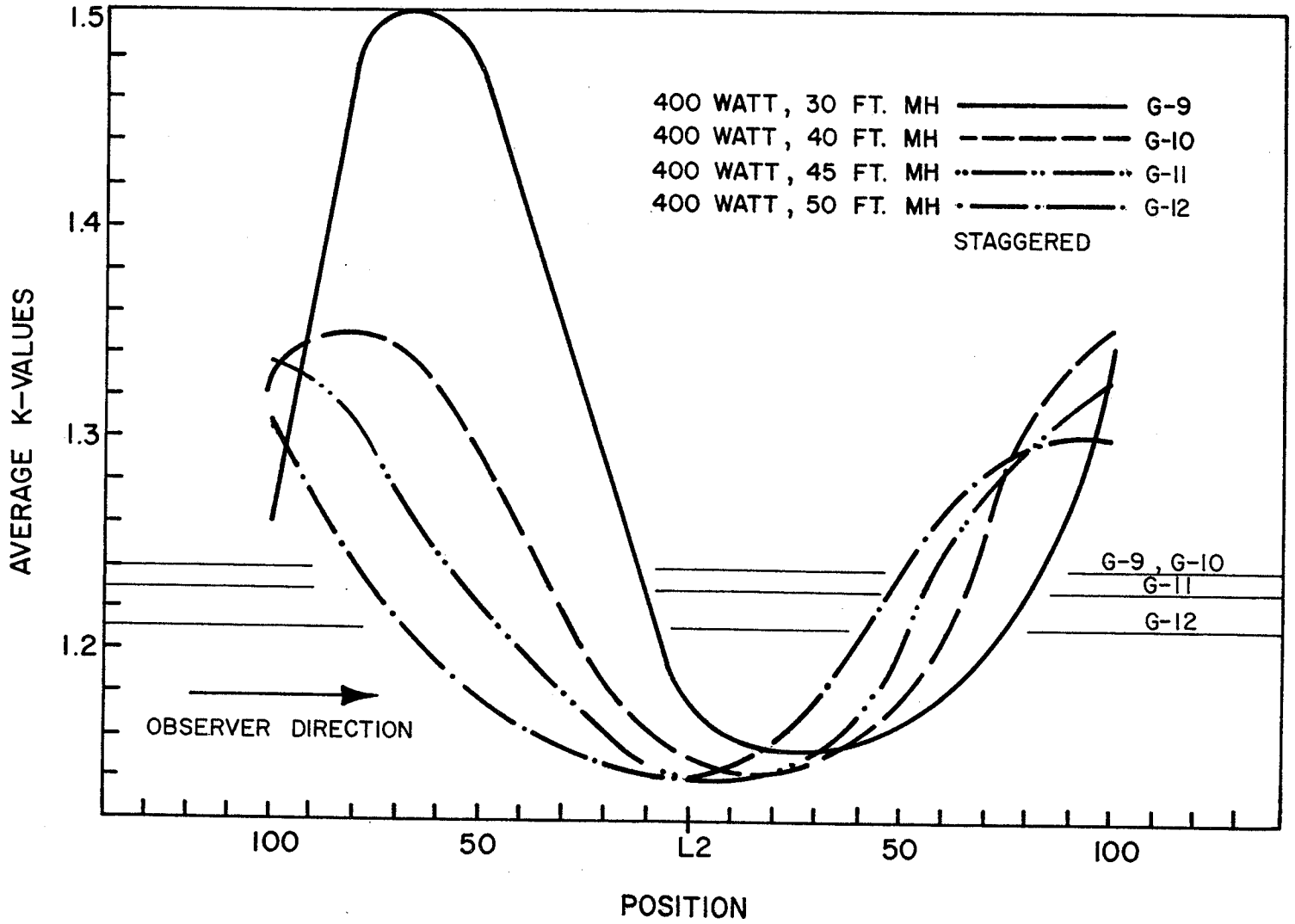
AVERAGE K-VALUES AS A FUNCTION OF POSITION

FIGURE 22



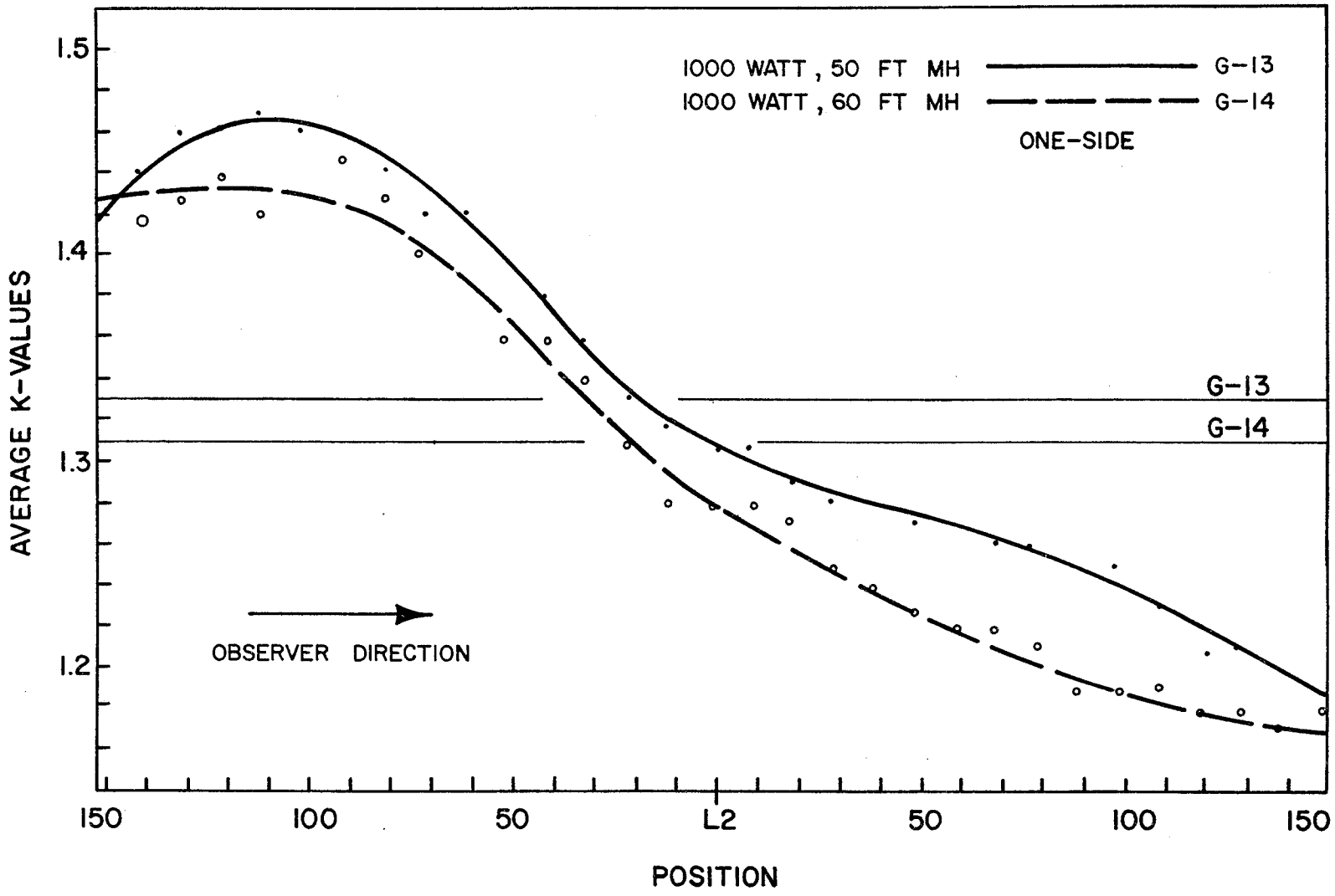
AVERAGE K-VALUES AS A FUNCTION OF POSITION

FIGURE 23



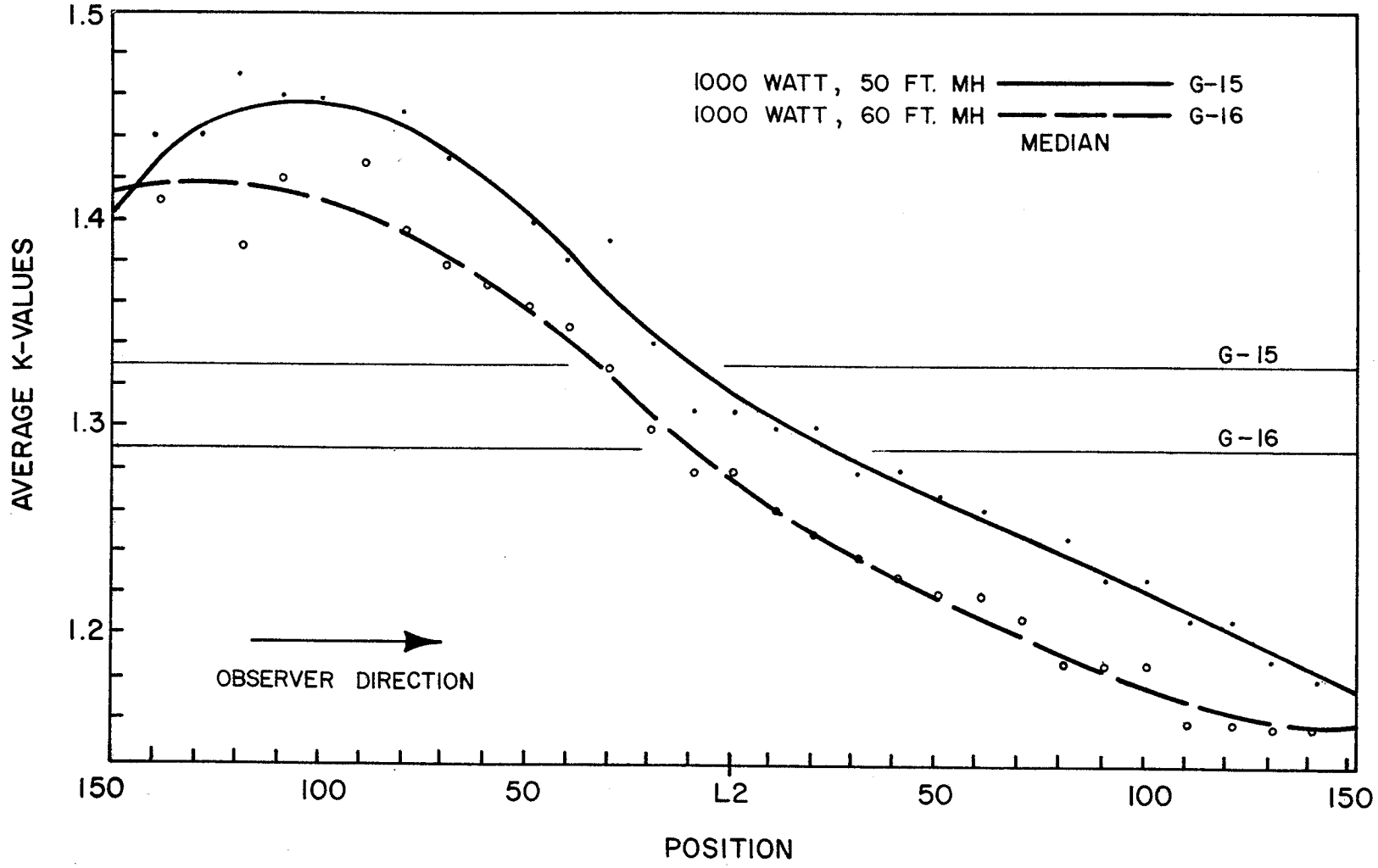
AVERAGE K-VALUES AS A FUNCTION OF POSITION

FIGURE 24



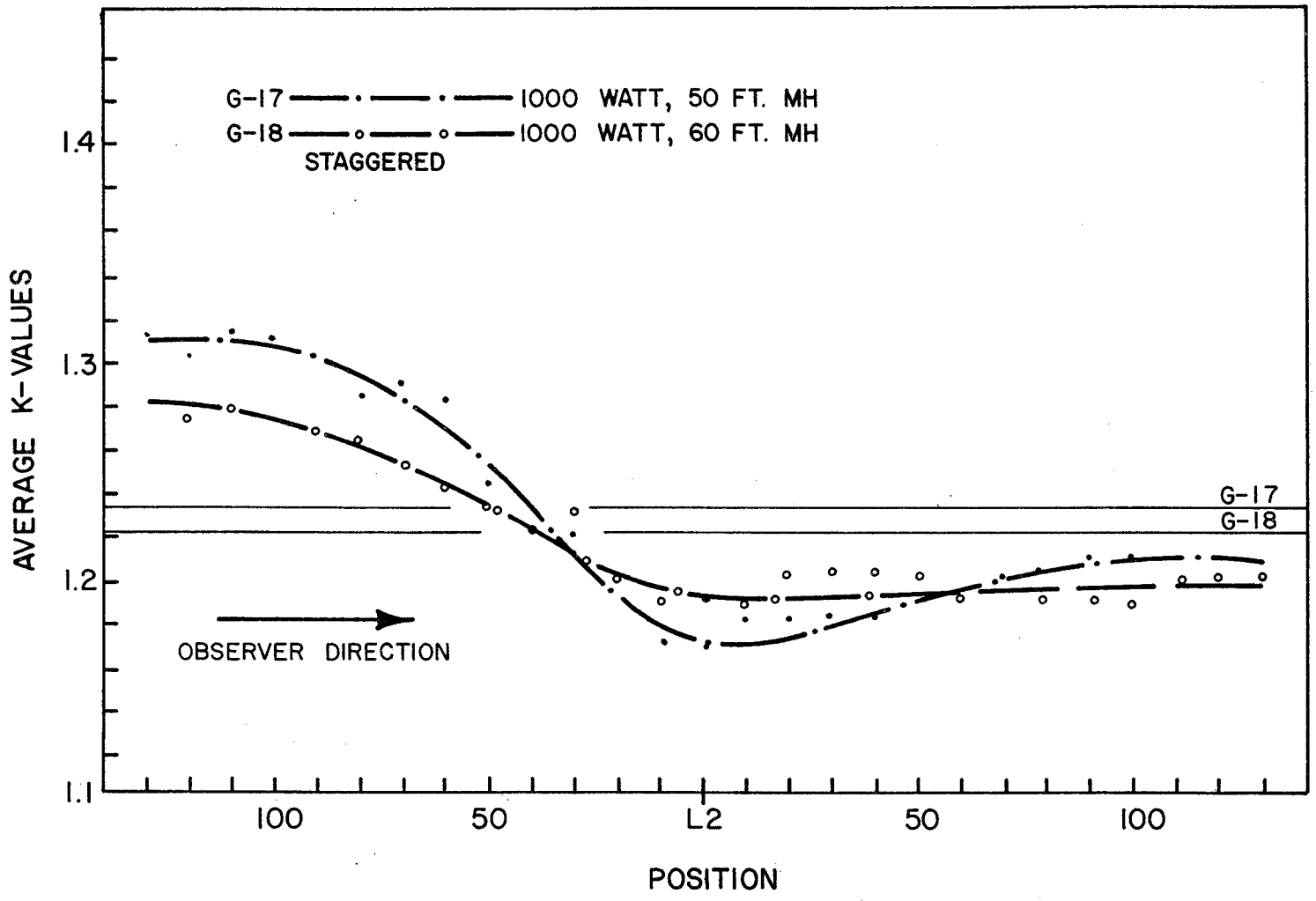
AVERAGE K-VALUES AS A FUNCTION OF POSITION

FIGURE 25



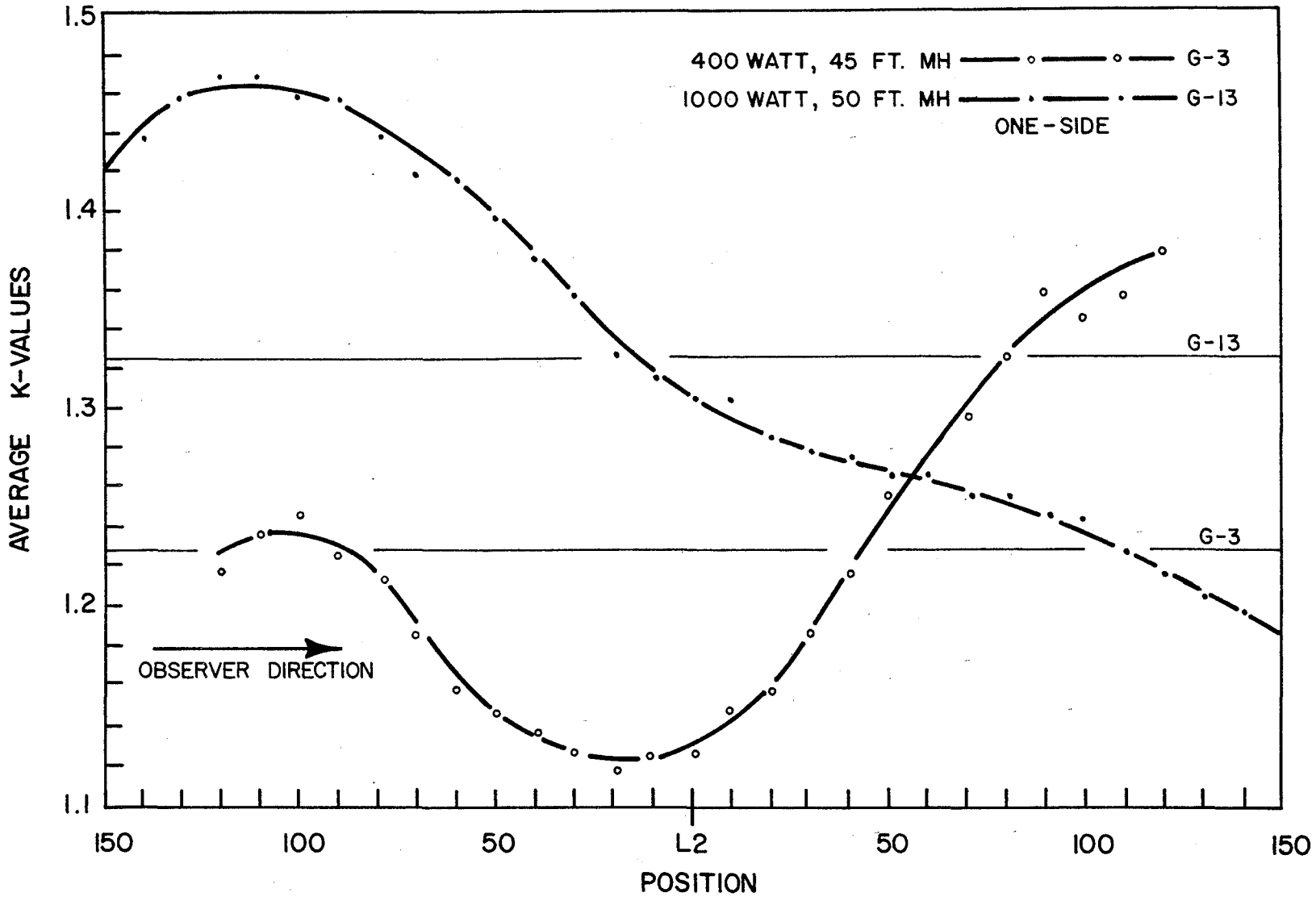
AVERAGE K-VALUES AS A FUNCTION OF POSITION

FIGURE 26



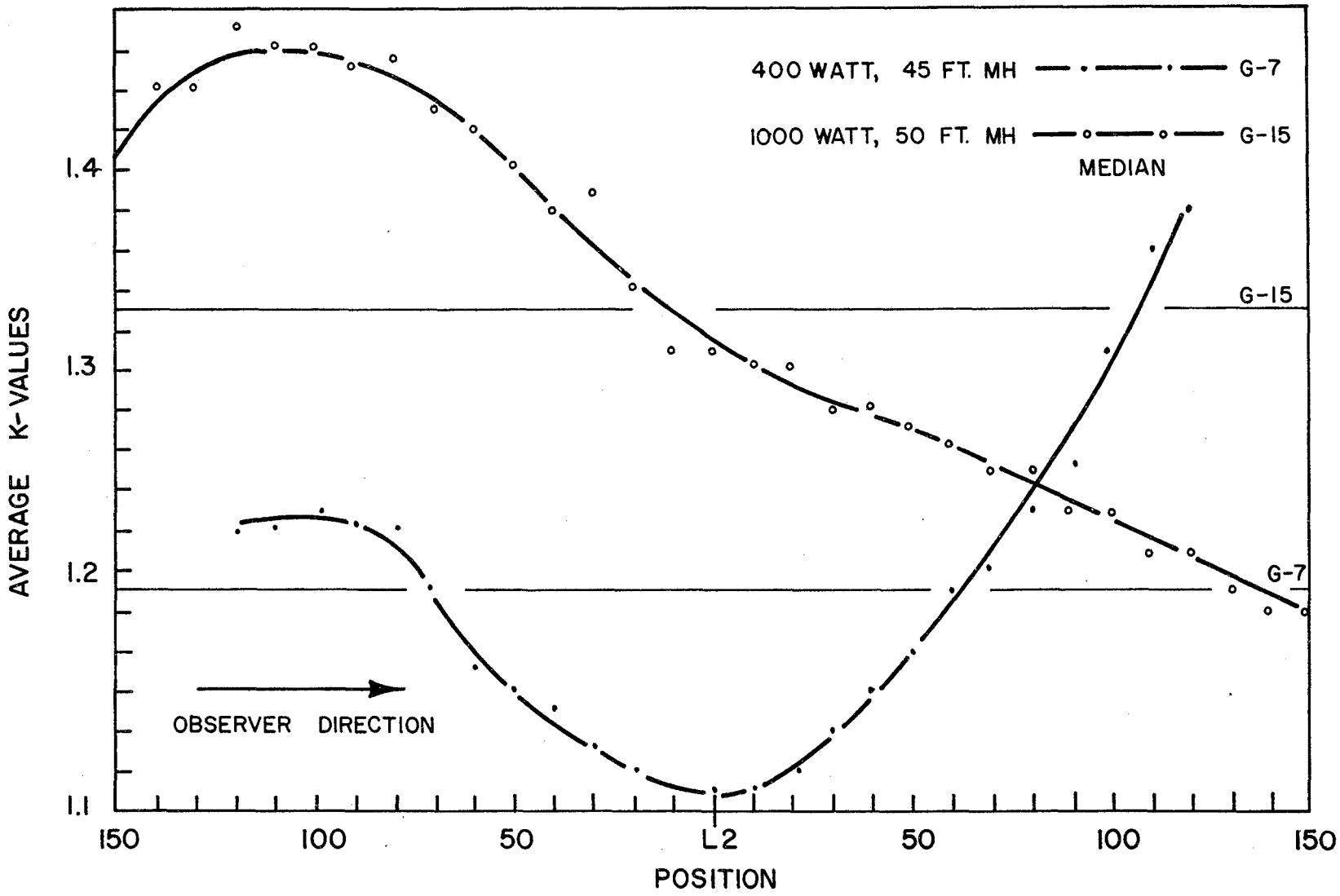
AVERAGE K-VALUES AS A FUNCTION OF POSITION

FIGURE 27



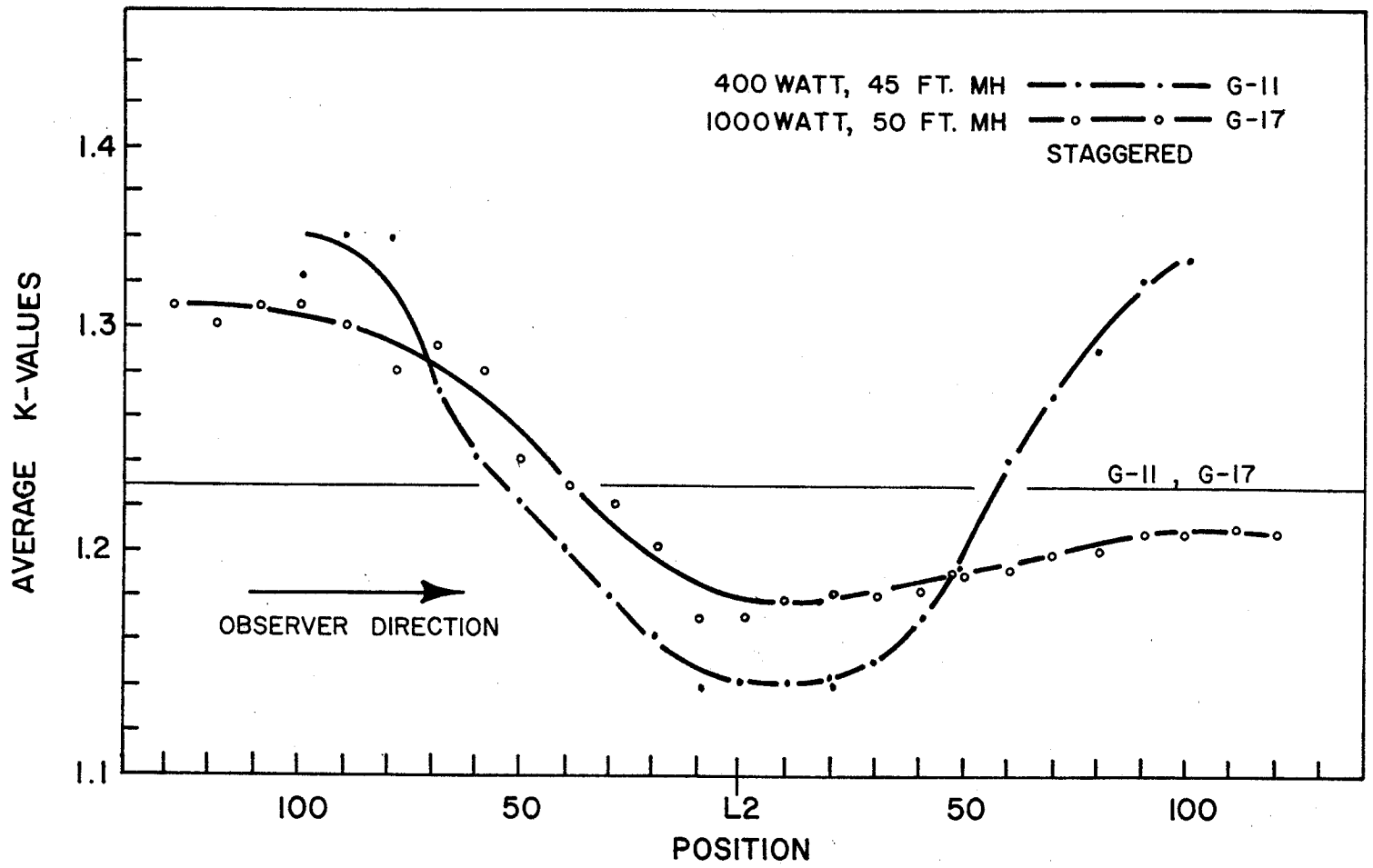
AVERAGE K-VALUES AS A FUNCTION OF POSITION

FIGURE 28



AVERAGE K-VALUES AS A FUNCTION OF POSITION

FIGURE 29



AVERAGE K-VALUES AS A FUNCTION OF POSITION

FIGURE 30