Surface-Mounted Lights On Roadways–Fog Studies

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● THIS DISCUSSION of surface-mounted lights on roadways is a continuation of the subject previously presented (1). In the previous paper the development of the concept of lines of lights for contour perception was presented. The idea started at the University of California with work on airports which was later continued under the sponsorship of the Federal Aviation Agency to improve the visual aids for pilots in landing and takeoff operations. The roll-out and taxiing maneuvers on the airport surfaces were also found to be in need of improved visual aids. Even under the best of weather conditions, there was still a gap between the visual information required by pilots and that provided by conventional lighting systems.

The visual problems of motorists on the roadway are very similar to those of pilots on the runway after touchdown, or on a taxiway. There is great need for directional guidance information which will enable them to maneuver their vehicles in the desired direction and to avoid conflict with other fixed or moving obstacles on the runway or the roadway. The development of a visual-aid lighting system for both good and bad weather was reviewed in the previous report (1) and is not repeated here.

Since the last report there have been additional developments. First, two additional reports have been presented to the Federal Aviation Agency on the subject of the surface-mounted lights for runway guidance (2, 3). Second, a general discussion of the visibility of a pattern of lights on the runway was presented in an article in "Business and Commercial Aviation," Dec. 1960. The article discusses the general requirements and performance under adverse weather conditions. Also, a report has been prepared on the installation of a centerline taxiway lighting system at the San Francisco International Airport (4). Another report on Airport Lighting Studies has been prepared for the Chief Engineer of the Port of Oakland, who has under development a completely new runway for the Metropolitan Oakland International Airport (5). This report includes a discussion of multiple-line lighting patterns using surface-mounted lights in models studied in the University of California's fog chamber.

THE CONCEPT OF LINEAL PERCEPTION

The visual principle employed in the use of small lights for guidance on the surface of the roadway involves the concept of lineal perception. The application of this principle to the present problem consists of developing contours and borders of the scene to give the driver most of the orientation that he needs regarding his vehicle's position, heading and rate of closure with objects and other areas of the roadway. The logic for such a system is as follows: the visual world of the driver, external to the vehicle, is made up of edges, slopes, surfaces, shapes and interspaces, plus textures and colors. The driver's principal visual problem is one of orientation in such a world, rather than identification of specific objects, places, people, signs or signals. The primary visual elements that furnish most of the information are the edges of the roadway, the lane markers on the roadway, the horizon ahead, and the brightness gradients in the central field. These basic visual elements can be noted in any roadway scene and are included in the various figures of this report. One can note that, even without texture, color, or detail of specific objects, most of the required guidance information is available from the contours. The driver's scene is, of course, dynamic, and the perspective is constantly changing. The flow of information in the peripheral visual field and the rate of change of apparent position of parts of the field with respect to things ahead are extremely important. The peripheral region will be streaming by at a rather fast rate and can never be concentrated on. The driver is therefore forced to look toward an area from 150 to 500 feet ahead, where the rate of change is not too drastic. The axis of his line of sight will depend on his speed and the type of roadway and terrain that he is in at the time.

During the daytime and in clear weather at night, with headlights and/or street lighting on, a steady stream of uninterrupted visual information is available to the driver and is usually interpreted clearly. In areas without proper lighting at night, and in periods of adverse weather, the conditions are vastly different. Only the most meager visual aids are then present. It is therefore desirable to provide a visual environment for these adverse conditions that will resemble the more familiar daytime scene.

Satisfactory lighting patterns for clear weather night conditions may be created quite easily by providing an array of lighting in the general area which will establish reference surfaces in the immediately surrounding terrain, plus a continuously developed pattern for several hundred feet ahead. Many miles of such roadway are used at present, and for the most part, these are negotiated without incident, even though they may not be too pleasant. But there are many points of conflict in such systems that should be more critically analyzed and treated more carefully. The points of conflict are generally known to traffic engineers. Such areas include "on- and off-ramps" at expressways, regions of transition from two to four lanes, or from four lanes to a divided roadway, or at intersections. Even in good weather, such situations need more critical attention from the visual point of view. In periods of very poor visibility, the operating conditions become quite hazardous in these particular zones.

Experience to date with the surface-mounted lineal lighting system at airports indicates that very precise directional information can be achieved. It has been found that a single centerline is a great help to a pilot in taxiing. A centerline plus rows of edge lights along the border has been found to be considerably superior to edge lights alone in the landing operation. It has been observed in other tests (6) that a two-line pattern on the runway, called a "narrow-gage system," provides more information than a single centerline. Tentative data show that a multiple-line pattern of lights on the runway in the threshold region is considerably superior to a two-line pattern plus edge lights. Therefore the principle of multiple lines of lights on a runway for guidance has been reasonably well demonstrated and accepted. A photograph of the five-line multiple-lane system proposed for use on airports is shown in Figure 1. The photograph shows the visibility achieved on a model in a very dense fog in the fog chamber at the University of California's Richmond Field Station. This could be a roadway just as readily as an airport runway.

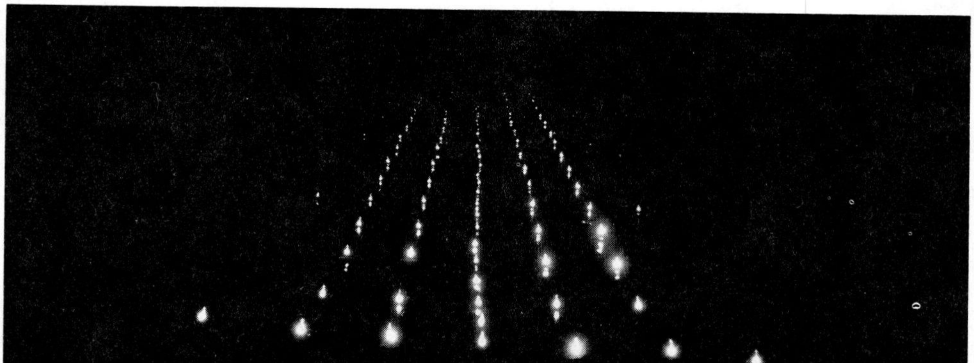

Figure 1. Multi-lane system of lights mounted in the surface of a runway—5-watt lights in a heavy fog. Centerline on 10-ft centers, parallel lines on 25-ft centers, edge lights on 100-ft centers.

NEW HARDWARE DEVELOPED SINCE THE 1959 REPORT

There has been considerable activity in the field of hardware development since the last report was presented. The Federal Aviation Agency (7) and the U.S. Air Force (8) have both issued specifications for lighting devices to be used in connection with patterns on the runways and taxiways. These specifications have been drawn up around a small, high-brightness, relatively high-wattage light source known as a 45-watt quartz, iodine cycle, tungsten bulb. This lighting unit can be operated in the open without damage by moisture, rain, snow or other weather conditions. The quartz bulb insures freedom from thermal shock, and the general construction of the unit is reported to be rugged. This light bulb is incorporated in several designs manufactured by different commercial organizations. The FAA and USAF specifications call for a flat, circular casting of suitable material, such as steel or ductile iron, approximately 6 to 8 in. in diameter and $\frac{1}{2}$- to 1-in. thick. The disc-type units are known as "button lights" or "pancake" lights. These units are installed by cutting recesses in the surface of the runway or roadway and embedding the housing in an epoxy resin adhesive in a semi-flush position so that only $\frac{1}{8}$ to $\frac{1}{2}$ in. of the housing projects above the runway's surface. The bulb is protected by a cover strap which is removable to permit both replacement and servicing. The electrical conductors are placed in slots cut in the surface of the pavement and resealed with a suitable epoxy resin or pavement joint compound. The electrical service is provided by wires in direct burial trenches along the side of the pavement. Transformers supply the low voltage required by the lamps from a high voltage primary. Details of the lighting units and specifications for their installation are available elsewhere (9). The Government services have not investigated units with less than 45-watt sources so far, but they do have under consideration two other designs calling for 100- and 200-watt quartz lamps (10).

Further work on hardware has been proceeding at the University of California on a limited scale. A 1,000-ft long roadway has been provided with a centerline using units removed from the San Francisco Airport installation and modified for insetting in the roadway surface so that only $\frac{3}{8}$ in. of the fixture extends above the roadway. The light bulbs used in these units are 5-watt, tubular shape, of the same general construction as described for the San Francisco Airport installation (2).

NEW INSTALLATION SINCE THE 1959 REPORT

A new taxiway centerline has been installed at San Francisco International Airport, in which 1,880 ft of taxiway are lighted with a centerline using button lights on 25-ft centers (4). The lights are a new design developed at the University of California and manufactured locally in California for the San Francisco Airport installation. Details of the lighting units and the electrical installation are shown in Figures 2a, 2b and 2c.

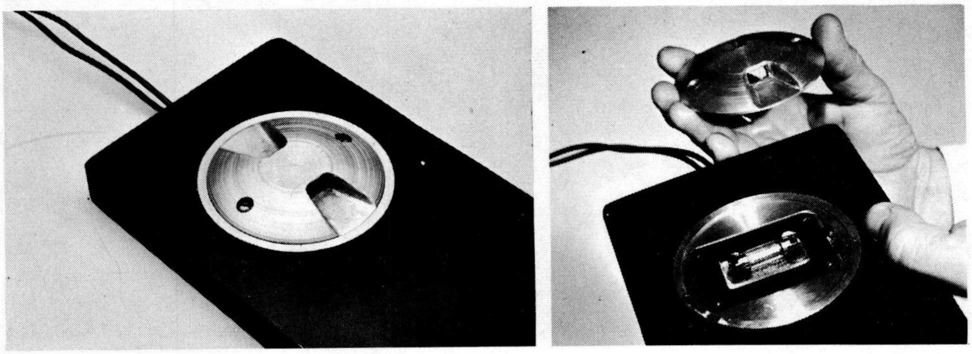

Figure 2a and 2b. Five-watt surface-mounted lighting unit as used at San Francisco International Airport.

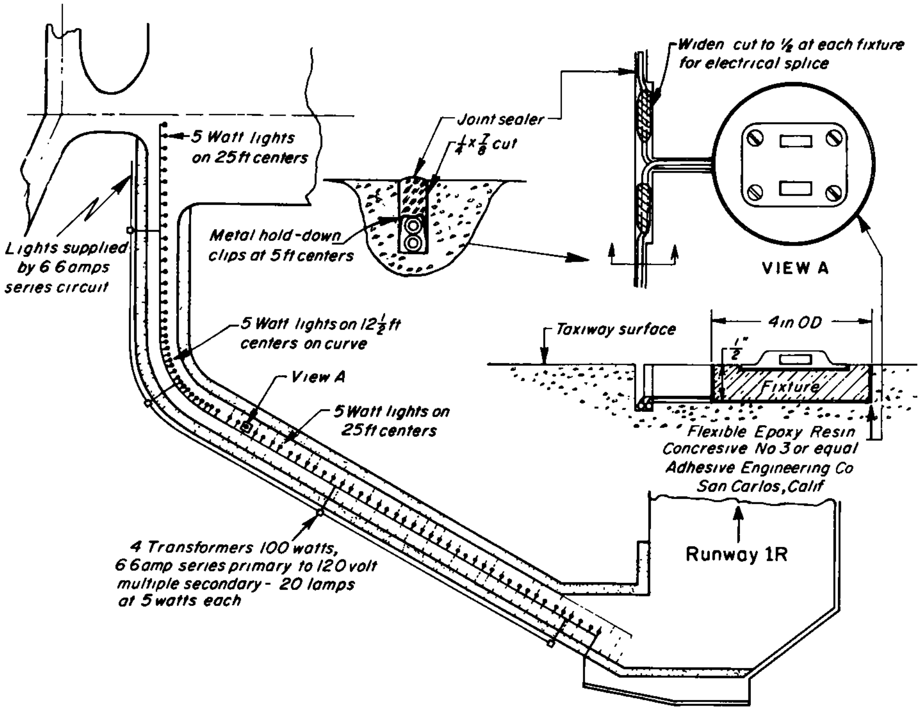

Figure 2c. Details of installation, San Francisco International Airport.

This installation uses 5-watt bulbs operated at lower than rated voltage to yield long life. The approximate power to each bulb is about 3 watts.

There has been an installation of FAA "pancake lights" at the Idlewild Airport in New York on Runway 4R-22L in which 45-watt units have been installed on 20-ft centers on the centerline of the high-speed exits. After being used in service experimentally, the lights were reconnected electrically so that the power input to the bulb was reduced to approximately 6 to 8 watts. This was done after observations and pilot comments indicated that the 45-watt light output was too high.

The Federal Aviation Agency has installed a number of its "pancake" lights using 45-watt sources at the National Aviation Facilities Experimental Center in Atlantic City, New Jersey. These have been placed on the centerline of the runway and an exit taxiway and in various other configurations on the runway for study of the pattern of lights. There has been no official report on the studies at NAFEC at the present time, but a number of unofficial comments have been made by people participating in the tests. These indicate that the centerline system is performing very well. The New York installation at Idlewild is being used continuously and shows that the centerline lights on the exit taxiway are providing adequate guidance for pilots during all of the weather that has been experienced so far, including some landings in poor visibility weather.

The U.S. Air Force has completed one full installation at the Lockbourne Air Force Base in Ohio and has another installation under construction at Andrews Air Force Base near Washington, D.C.

The taxiway centerline to Runway 1R at the San Francisco Airport has been installed for several months. The contract for the installation of the lights was completed on August 23, 1960. Runway 1R was closed for resurfacing and repair until November 15, 1960. Since that date, the runway has been in constant service, and the centerline lights on the taxiway leading to the runway have been in continuous operation. These lights are shown in Figures 3, 4, and 5. Figure 3 shows the centerline lights without the conventional side lights as viewed in a southerly direction. Figure 4 shows the centerline lights, together with the conventional side lights, and Figure 5 shows the conventional side lights, without the centerline lights. It is evident from Figure 5 that a pattern of lights that is not close enough together and not in the central field of vision is not particularly informative, even though all the individual sources may be seen. If, however, the lights are close together and tie the foreground in with the more distant spaces, the guidance is much improved. In poor visibility the situation is basically the same, except that almost all of the background visual clues are eliminated by the attenuation of the atmosphere. The only remaining source of information is that derived from the immediate foreground, using whatever pattern there is left.

Since the reopening of Runway 1R at the San Francisco Airport, comments of a number of pilots on the taxiway centerline lights have been received, and they are generally favorable. From these comments it appears that the centerline lights provide better guidance than do conventional side lights. These fixtures have required no maintenance to date. The cost of installing the fixtures, exclusive of providing the source of power, was $3,600, or approximately $2.00 per lineal foot of taxiway. The cost of the 80 fixtures, which were furnished free of charge, is estimated to be about $800, or approximately $0.44 per lineal foot of taxiway.

The Richmond Field Station installation is on a straight, asphalt roadway (Fig. 6). The work was done by a crew of the University of California's Institute of Transportation and Traffic Engineering. The fixtures are 5 in. in diameter and are inset 3/8 in. into the surface of the pavement, using an epoxy resin. The cost of installation is estimated at approximately $1,500 for 1,000 ft or $1.50 per lineal foot.

FOG STUDIES ON TYPICAL ROADWAY SITUATIONS

The visual needs of the vehicle operator in fog are greater than in the clear weather, but the amount of visual information available is many hundreds of times less. What is necessary is to have the visual information in the immediate foreground tie directly to the limit of the visual range and provide guidance and lead lines in the direction that the vehicle operator wishes to go. This situation is one in which the lighted lineal lines are particularly significant.

To provide further information on the concept of lineal perception as applied to roadway problems, several typical situations have been set up on a model basis for study. The patterns have been examined in the fog chamber at the University's Richmond Field Station. The typical installations are four basic patterns taken directly from the Planning Manual of Instructions, Department of Public Works, Division of Highways, State of California, May 1952: (a) a two-lane to four-lane transition section, (b) a four-lane multiple roadway changing from undivided to a two-lane divided roadway (derived from a three- to four-lane design in the Manual), (c) the typical turn-off from an expressway, and (d) an inlet or on-ramp to an expressway. The layouts for the models are shown in Figures 7, 8, 9, and 10, which were copied directly from the Planning Manual.

The models were set up on a 100 to 1 scale. The light sources are approximately to the same scale, although the exactly correct-size light sources were unobtainable. The light bulbs are actually made for toy headlights. They have a filament length of about 1/16 in. and operate on 16 volts at 0.1 amperes. All of the lights shown in the models are on 10-ft centers. The patterns for the roadways were laid out on strips of masonite, and the bulbs were placed in holes drilled in the masonite. The roadways were made by using various colors of cloth tape placed on the surface of the masonite to simulate typical road surfaces.

Previous data taken on brightnesses of the lights in a fog chamber indicate that for a very low transmission of fog, in the order of 2 percent, the lights would have a contrast of 1.0 in the daytime and 64 at night at the same distance used to measure the transmission. When one considers that the threshold of contrast is much less than either of these values, it is obvious that the visual range extends beyond the baseline used to measure the transmission. Thus the calculations show (2) that the lights should be visible up to about 450 ft in the daytime and approximately 1,000 ft at night in a fog

Figure 3. Centerline lights on taxiway, San Francisco International Airport, without edge lights.

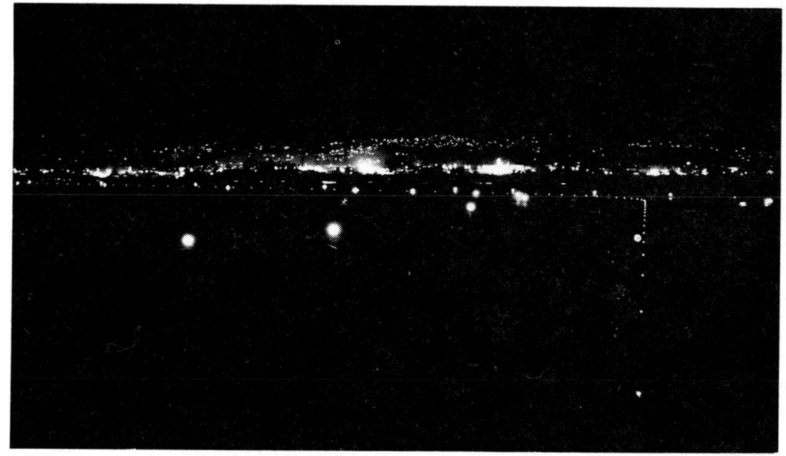

Figure 4. Centerline lights on taxiway, San Francisco International Airport, with conventional edge lights.

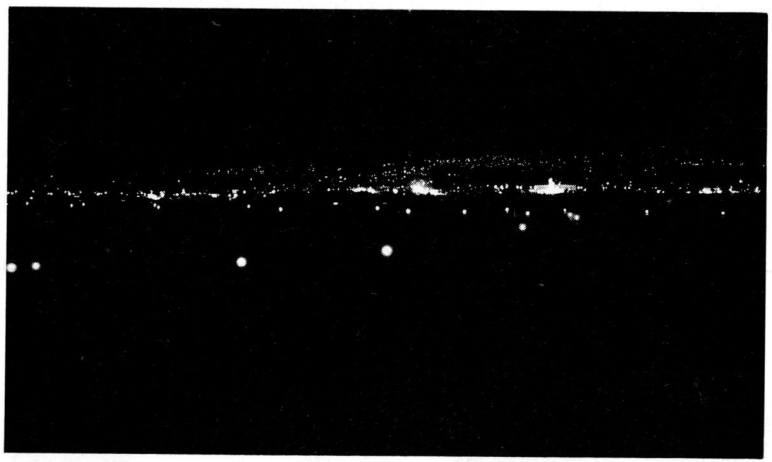

Figure 5. Same taxiway as Figures 3 and 4, conventional edge lights only.

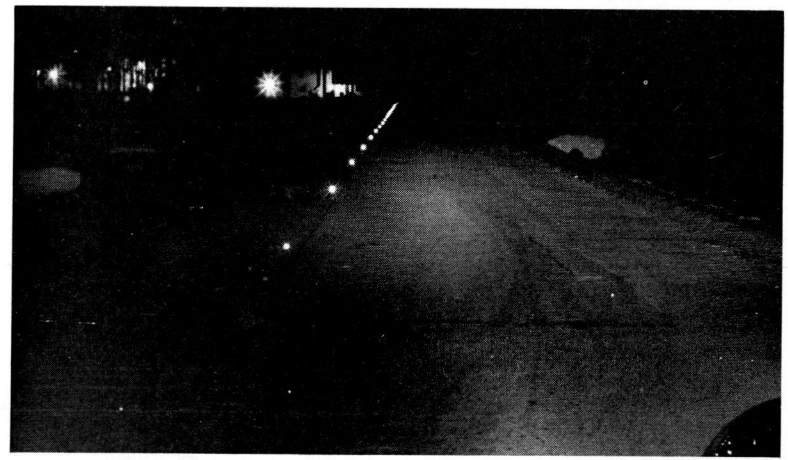

Figure 6. Surface-mounted lights on centerline of roadway at Richmond Field Station, University of California.

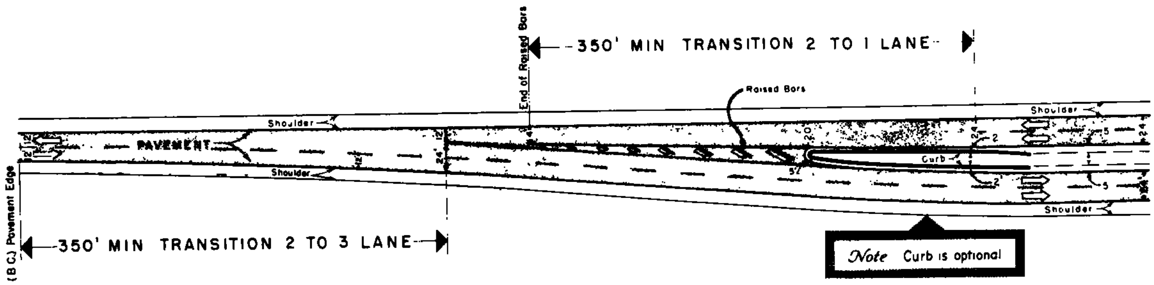

Figure 7. Two-lane to 4-lane transition.

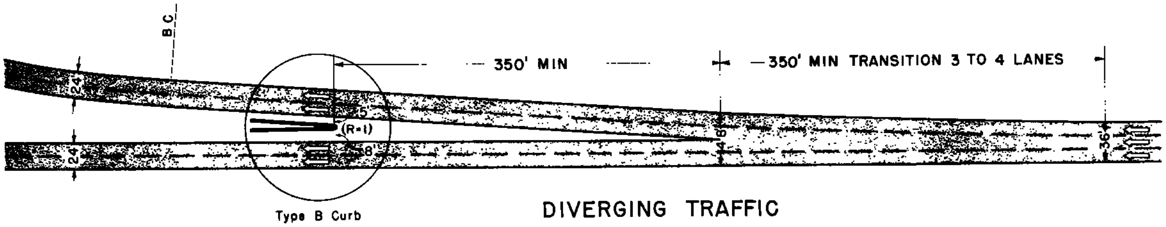

Figure 8. Three lanes diverging to 4 lanes (basis for 4-lane-undivided to 4-lane-divided model).

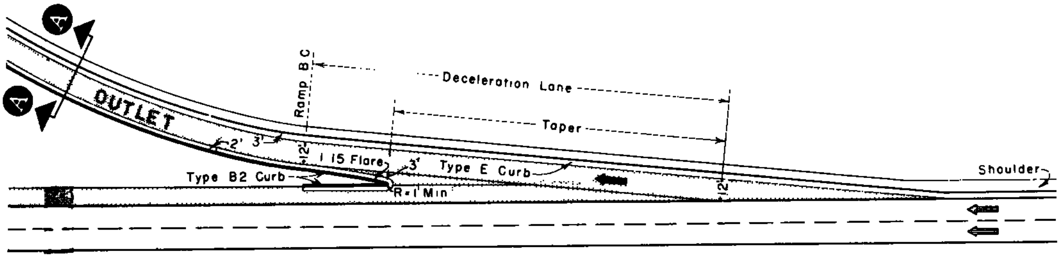

Figure 9. Typical turn-off from an expressway.

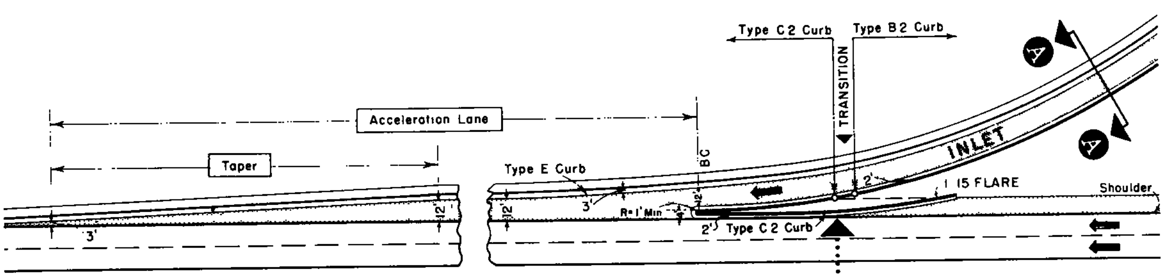

Figure 10. An inlet or on-ramp to expressway.

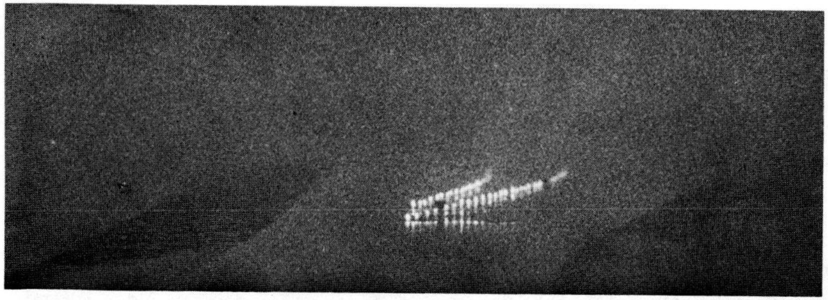

Figure 11. Daytime fog, 2- to 4-lane transition.

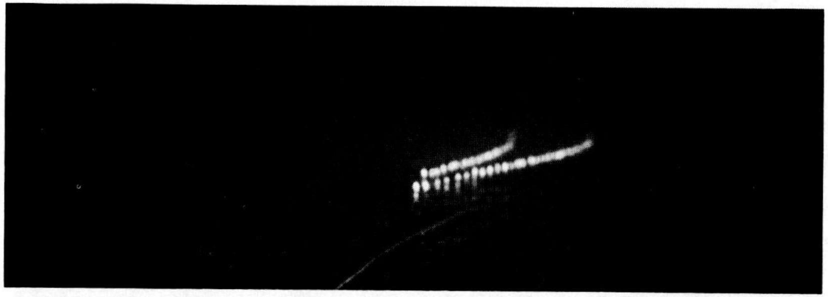

Figure 12. Nighttime fog, 2- to 4-lane transition.

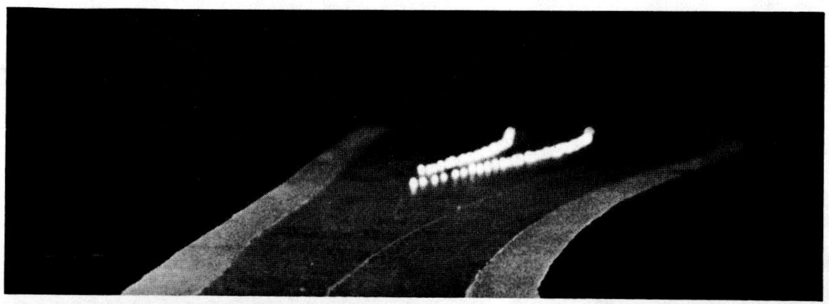

Figure 13. Nighttime, clear weather, 2- to 4-lane transition.

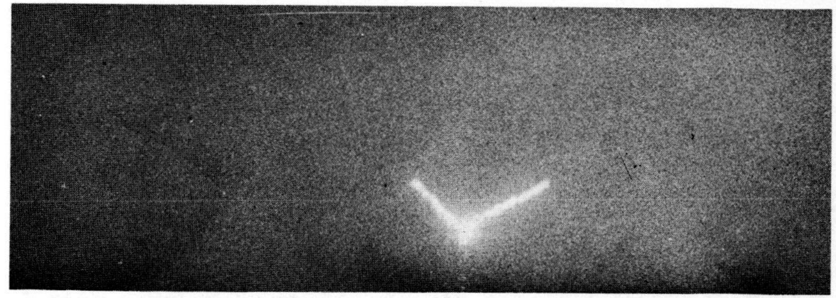

Figure 14. Daytime fog, 4 lanes to 2 lanes divided.

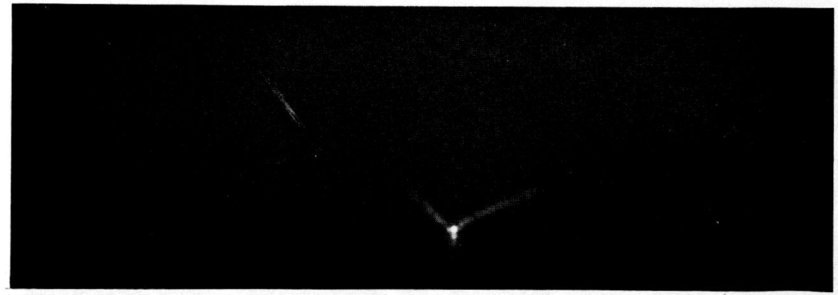

Figure 15. Nighttime fog, 4 lanes to 2 lanes divided.

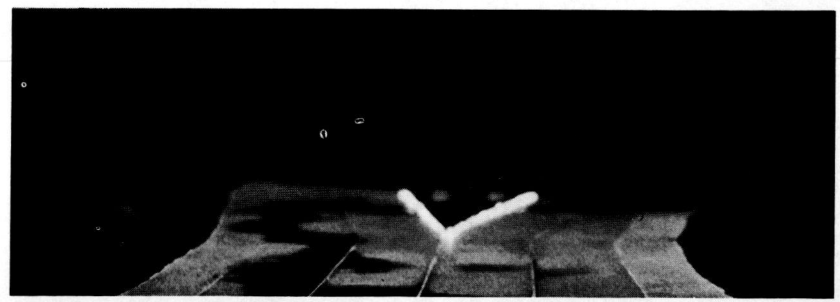

Figure 16. Nighttime, clear weather, 4 lanes to 2 lanes divided.

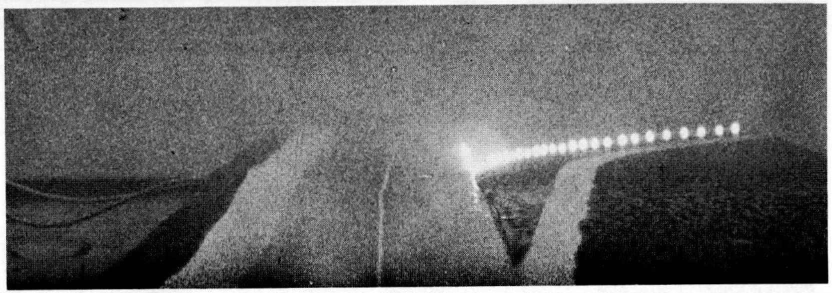

Figure 17. Daytime fog, typical turn-off from an expressway.

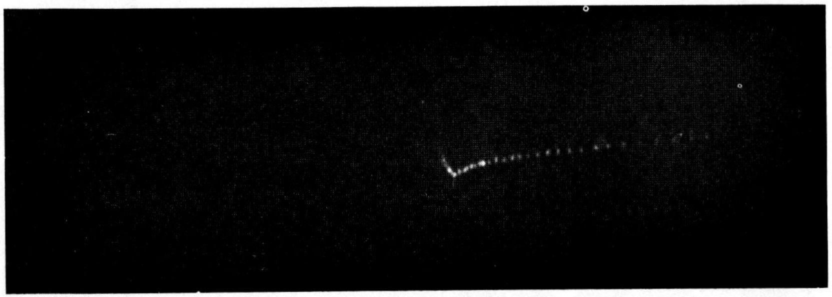

Figure 18. Nighttime fog, typical turn-off from an expressway.

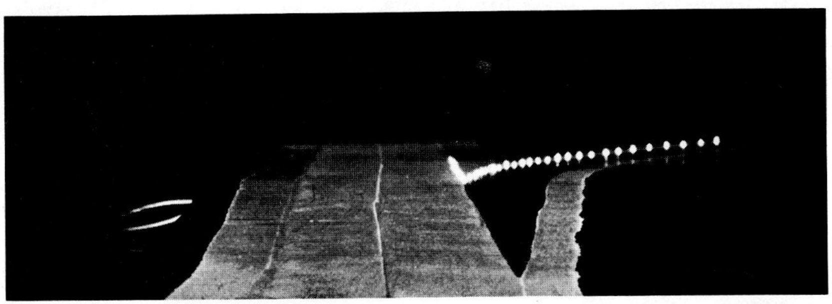

Figure 19. Nighttime, clear weather, typical turn-off from an expressway.

Figure 20. Daytime fog, on-ramp to expressway.

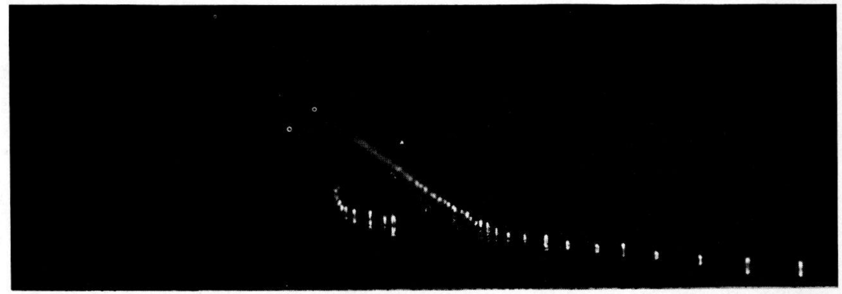

Figure 21. Nighttime fog, on-ramp to expressway.

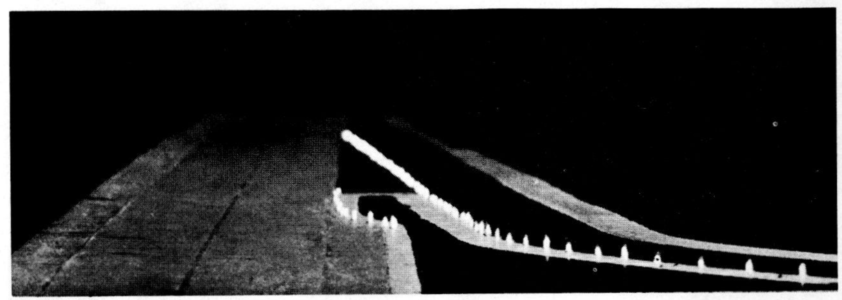

Figure 22. Nighttime, clear weather, on-ramp to expressway.

having a transmission as low as $\frac{1}{2}$ of 1 percent in an 800-ft baseline. Such a fog would be very dense and would be approximately the same as the conditions shown in Figures 11 to 22. There are a few situations in which fog densities greater than those shown would be encountered. Such situations do occur occasionally, but even under the most severe fog conditions the lights on close centers would be seen from 4 to 10 lights away. This would provide some guidance which would be most welcome under these critical conditions. The photographs of the four typical installations (Figs. 11 to 22) show a daytime fog situation, a nighttime fog condition, and a clear-weather nighttime situation in which the roadway is illuminated by fixed lights. In the case shown, a small projector was used to simulate street lights. The pictures are self explanatory and show the remarkable guidance provided around points of conflict at typical roadway situations. The models were set up to demonstrate the principle and are not to be used as a design guide. It is possible that other spacings would be more suitable and that somewhat different lighting configurations might be better than those used. The lights were layed out using the premise that the lines of light should be the same as the painted lines that are used for marking the points of conflict on the roadway.

CONCLUSIONS

The work done to date on airport runways, taxiways and high-speed turn-offs, plus the preliminary work on roadways and on model studies in the fog chamber, demonstrates the versatility and utility of the principle of lineal guidance obtained by light sources inset into pavement surfaces.

The principle of guidance as now proposed is generally accepted for airport use. It is hoped that the next step will be to apply the principle to some of the more critical areas on roadways. This is being considered, and some tests have been made by the Connecticut Department of Highways in conjunction with one of the leading lighting equipment manufacturing companies. Another trial installation has been proposed for the Golden Gate Bridge at San Francisco. This installation would be a combination lane-marking system and center-lane reversal system. The operation would be accomplished by shifting the double line from the center to one lane each side of center, using lighted lights on suitable switching circuits.

The extra-visual information provided by lighted lane-lines under good visibility conditions is a desirable feature. This means of providing added visual information under poor visibility conditions is highly desirable.

Under poor visibility conditions the range of visibility of lighted lane-lines is far greater than with any of the present paint markings or border materials. In general, the visual range can be approximately doubled, using lighted lights, over that which is available using reflective-type marking materials.

The low-wattage units placed on close spacings have been found to be preferable to higher-wattage units placed on wider spacings. One reason for this is that the continuity of the lineal pattern is improved and the glare per individual unit is greatly reduced.

It is hoped that several trial installations of lighted lane markers can be made on actual roadway locations in the near future, so that the usefulness and versatility of the system can be proved in actual field trials.

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