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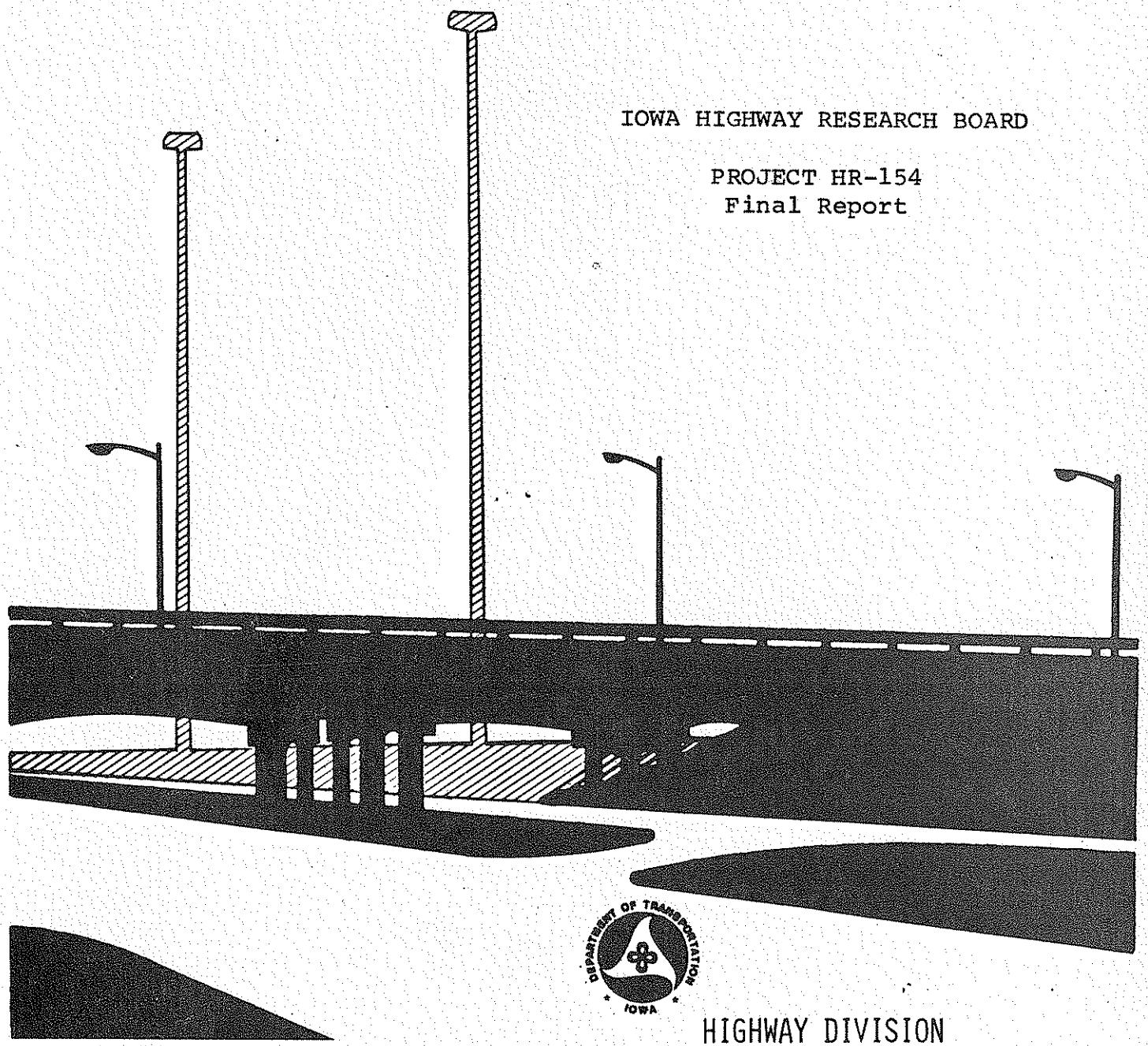
INVESTIGATION of HIGHWAY LIGHTING



IOWA HIGHWAY RESEARCH BOARD

PROJECT HR-154
Final Report

HIGHWAY DIVISION
November 1976

INVESTIGATION OF HIGHWAY LIGHTING

HR-154
Final Report

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ABSTRACT

The Iowa State Highway Commission initiated this research to evaluate a new lowering device for tower luminaires and a new concept of tower luminaire light distribution. Lighting at the West interchange of I-80, I-35, and I-235 in Polk County was also designated as an FHWA experimental project.

As highway lighting has become more widely used, highway officials recognized the increasing importance of reducing safety hazards and improving aesthetic appearance of lighting installations. Also, lighting construction, energy, and maintenance costs were absorbing a larger share of the maintenance budget.

A search began for a method of lighting whereby the fixed objects by the roadside could be eliminated or reduced in number, the costs could be reduced and the quality of lighting improved over existing methods. Lack of design data in this area illustrated the need for research.

The research consisted of taking field measurements of lighting intensity and uniformity, pavement brightness and system glare. The data was evaluated to enable a comparison of tower lighting vs. existing conventional installations. These measurements were supplemented by

visual observations. Other comparisons included construction and maintenance operations with their resultant costs and the aesthetics of the installations.

Where large interchanges are to be lighted, and for special lighting requirements, it is concluded that tower lighting is advantageous. Tower installations incorporating a luminaire lowering device are superior to other systems for maintenance purposes. Overall safety, performance and appearance are considered to be better, and construction and maintenance costs less than conventional lighting.

INTRODUCTION

The Iowa State Highway Commission initiated Project HR-154, Investigation of Highway Lighting, to evaluate a new tower luminaire lowering device and a new concept of tower luminaire light distribution. Lighting at the West interchange of I-80, I-35, and I-235 in Polk County was designated as an FHWA experimental project and let under Project No. I-80-3(26)125--01-77. Federal funds allocation obligated the former Iowa Highway Commission to compare this lighting installation with other conventional lighting in the state.

EARLY TOWER LIGHTING CONCEPTS

Investigation of tower lighting for the State of Iowa began approximately 10 years ago. The desired results from a new type of highway lighting design included:

(1) Elimination or reduction of fixed objects located near the traveled way. "Conventional" lighting units are placed 16 to 17 feet from the edge of the traffic lane where space permits, and located 150 to 300 feet apart. A large interchange lighting system could require several hundred conventional lighting units.

(2) Improvement of daytime aesthetics of lighted highways by eliminating rows of roadside poles.

(3) Viewing conditions similar to those during daylight hours by lighting beyond the traveled way.

(4) Increase of the effective visibility for specified levels of illumination by reducing glare through placement of light sources farther from the driver's line of vision.

(5) Reduction of construction and maintenance costs for highway lighting, particularly for complex interchanges.

Investigation began part-time. A system using variable rectangular-beamed floodlights was developed with the aid of a computer program. Illumination patterns were fitted together puzzle-fashion to cover the roadway areas. It was believed that the normal "spill" light from such a system would illuminate the areas between roadways enough to produce the desired daylight effect. Criteria for illumination levels were based on conventional lighting concepts. At the time, there were no conclusive recommendations on minimum acceptable lighting levels for tower lighting. Little comprehensive information was available about the glare effects of the variable-beam floodlights when used for tower lighting. As a result, the initial designs had a greater degree of glare control and produced higher illumination levels than later found necessary. The tower positions and luminaire aiming angles needed to produce these effects resulted in the need for more towers and luminaires than the later criteria required.

Project scheduling deadlines forced abandonment of the variable-beam concept, as new information on tower lighting design criteria became available. Experience in other states indicated that a tower lighting system could produce equivalent visibility at approximately half the illumination level of a conventional system. A system of overlapping-area floodlights was promoted by the floodlight manufacturer. It had been successful in other states and a design based on the newer concepts was proposed; it had a lower installation cost. No time was available to revise the original concept for an adequate cost comparison; therefore, design plans were prepared, using the overlapping beam floodlights. Early investigation of tower lighting design strongly revealed the lack of good field data available for this purpose, and further illustrated the need for research.

OBJECTIVES

This research evaluated and compared the tower lighting system to existing conventional systems. To be investigated were:

(1) Construction, energy, and maintenance costs;

(2) Safety to the traveling public as affected by the presence of fixed objects, such as conventional lighting poles installed near the traffic lanes;

(3) The effect of construction operations;

(4) Day and night aesthetic appearance;

(5) Comparisons between lighting systems of observed overall visibility and measured and observed performance;

(6) Performance of the luminaire lowering device;

(7) Maintenance operations and maintenance costs of the system; and

(8) Field data which record performance depreciation of the luminaires with age, to be used in calculating a maintenance factor for design purposes.

CONSTRUCTION

The installation consists of 17 towers, as shown in Figure 1. Eight 1000-watt, metal-halide luminaires are mounted on each, for a total of 136 luminaires. The nominal mounting height above the roadway is 140 feet. A conventional lighting system with 400-watt mercury vapor luminaires and 40-foot mounting height would have required approximately 300 lighting units. Based on our most recent bid prices, the estimated construction cost today would be $450,000 for the tower lighting system and $900,000 for the conventional system.

Special equipment for the tower construction operations included pile driving machinery for footing construction, and a crane to erect the towers. The largest tower in this installation, shown in Figure 2, is 180 feet long and weighs approximately 12 tons. Some towers were located well outside the hazardous zone near the traffic lanes, and the construction operations could all take place outside this zone. Where towers were located at the minimum lateral clearance of 50 feet to the roadway, many operations were performed from the shoulder area, with need for traffic control.

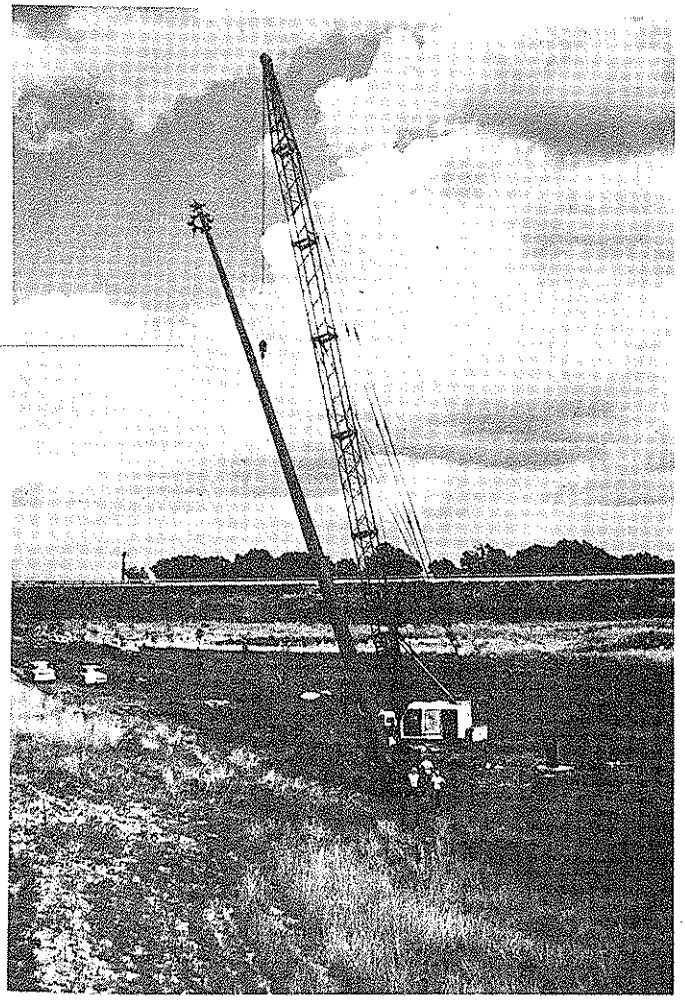

Figure 2. Erection of the largest tower in the installation

Traffic control was also required while the towers were transported from the rail terminal to the construction site. In contrast, nearly all operations for conventional lighting construction are done from the shoulder area, requiring traffic control.

The trenching and electrical circuit installation requires some traffic control for both conventional and tower lighting. Since the majority of the circuitry for conventional lighting is in the shoulder area, its installation needs more traffic control during construction.

DATA COLLECTION

Field Measurement Procedures

The majority of the investigative work and equipment took and recorded measurements to compare the performance of the experimental tower lighting system with existing conventional systems. Visual observations were used to supplement the data. It was anticipated that these data would be useful as future lighting design aids.

Measurements of horizontal footcandles (HFC), vertical footcandles (VFC), pavement brightness, and glare were taken with a Spectra Pritchard Photometer Model 1970-PR. Point-by-point readings were recorded manually and continuous readings were taken with a Brush Model 220 chart recorder. A pneumatic-tired handcart was fabricated to carry the photometer and portable power supply for the taking of point-by-point measurements.

Glare and pavement brightness measurements are relative to an observer's viewing position. The photometer was mounted in a vehicle at the eye position of a front-seat passenger and aimed through the windshield. The data were then traced continuously

on the recorder chart while the vehicle was moving. To provide accurate indications of the vehicle's position, the traveling speed was maintained at a selected rate, and reference marks were impressed upon the recorder chart by a 5th wheel attached to the vehicle. Additional reference points were added by an event marker on the chart recorder. Point-by-point HFC and VFC readings were taken at marked 100-foot intervals along the right hand edge of the traffic lane. The instrument mounting on the handcart included a geared photographic head for quick positioning of the photometer. A color and cosine-corrected footcandle adaptor was attached to the photometer objective lens. The HFC readings were taken from a true level plane and the VFC readings were taken from a vertical plane facing traffic. The attitude of the instrument was checked before each reading with a spirit level.

Horizontal Footcandle and Maintenance Factor Data

To compare average lighting levels and uniformity of lighting levels, one set of point-by-point HFC readings were taken at marked, 100-foot intervals along all traffic lanes of the interchange. Also, a set of

readings was taken at each lighting unit and at the midpoint between lighting units for a segment of conventionally-lighted freeway. HFC readings averaged 0.5 initially throughout the central portion of the interchange. The cycle of brightest to darkest readings ranged over distances of 50 feet to 100 feet for the conventionally lighted area and 500 to 1500 feet for the tower-lighted area. The uniformity ratio (ratio of average-to-dark illumination) for HFC ranged from 3.2 : 1 to 1.8 : 1 for the conventionally lighted area and 2.8 : 1 to 1.2 : 1 for the tower-lighted area.

Data collection to establish a maintenance factor curve was scheduled for three times per year for three years. The readings were in HFC, taken along the Loop-ramps "E", "F" and "G" of the interchange. These readings would be compared with the initial set of HFC readings for the area. The maintenance schedule for the luminaires called for a group relamping and cleaning of luminaires after two years. This would occur during our investigative period and provide comparisons between the initial readings of new luminaires and those occurring after one complete maintenance cycle.

Reduction in light output of highway-lighting luminaires is caused by the normal depreciation in lamp output as it ages, and by contamination or deterioration of the remaining components, particularly the optical system. Data gathering must be coordinated closely with cleaning and re-lamping schedules if the data are to be meaningful.

The utility company responsible for lighting system maintenance agreed to cooperate by keeping the investigators informed of maintenance operations and by performing the group re-lamping and cleaning within a two-week period to establish a common starting time for the new light output depreciation cycle.

HFC readings were taken on Loops "E", "F", and "G" for the maintenance factor investigation. These were gathered over a little more than one year. In November, 1973, a Highway Commission Administrative Order required that four luminaires on each tower be disconnected as an energy saving measure. The luminaires remained out of service from approximately December 1, 1973 to May 1, 1974.

By contract with the utility company, re-lamping was scheduled to start in August 1974. Operations began in

September and were not completed until December. Therefore, a wide variation in burning time existed between towers. Tower No. 11 was totally out of service from September through December, 1974 due to a jamming of the lowering device. Further readings were considered to have little meaning since Tower No. 11 was centrally placed in the interchange and therefore affects most locations. The manufacurer's lamp output maintenance curve in Figure 3 shows the percentage of output

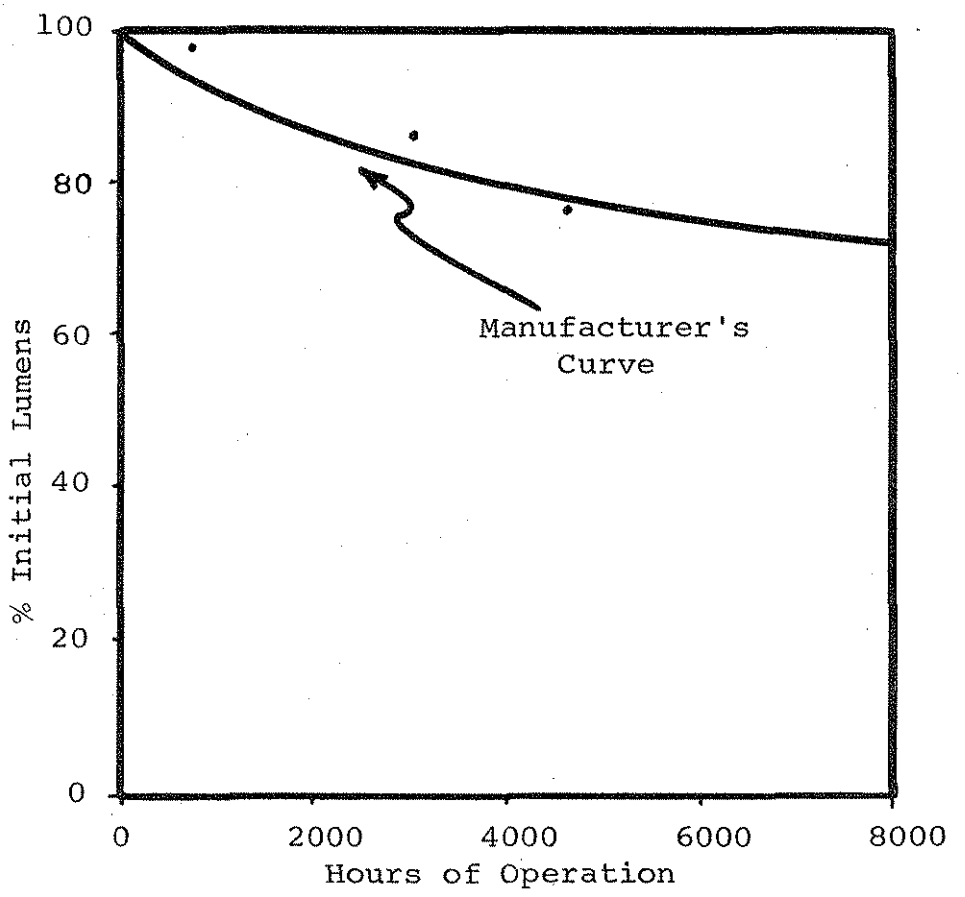

Figure 3. Manufacturer's maintenance curve vs. measured field data

reduction with respect to hours of operation. Also illustrated on the curve are results from the maintenance factor investigation, showing the reduction in average HFC for corresponding time intervals. The manufacturer's curve was verified for the period of time involved. This further shows that the reduction in light output was due to lamp output depreciation, and not to the effects of dirt or contamination on the luminaire optics.

Vertical Footcandle Data

Although the VFC is less commonly used in highway lighting design calculations than the HFC, early experience with tower lighting showed that illumination on vertical surfaces contributed more to visibility than conventional lighting. A set of point-by-point readings were taken along Ramp "B" and Loop-ramp "F". Care was taken to keep auto headlights from affecting the results. VFC readings averaged 0.38 throughout the areas measured. The bright-to-dark range was from 1.8 : 1 to 5.8 : 1 over distances of 200 to 500 feet.

Pavement Brightness Data

The level and uniformity of pavement brightness contribute significantly to night visibility at illumination levels recommended for highway lighting.

Continuous readings of pavement brightness were taken along all traffic lanes of the interchange, and along seven miles of conventionally lighted freeway. The photometer was aimed at the traffic lane, 150 feet ahead of the vehicle. A two-degree aperture was used in the instrument; it created a coverage area approximately 10 feet wide. Thus the averaging effect would tend to improve the measured brightness uniformity for conventional lighting, because the smaller bright spots produced are less than a full lane wide. Pavement brightness uniformity rations for conventional lighting ranged from 5.5 : 1 to 1.5 : 1, and for tower lighting, 3.5 : 1 to 1.5 : 1.

Glare Data

Glare readings were taken continuously from the same areas where pavement brightness data had been taken. The equipment was set up as for brightness, except that a Fry-Pritchard Glare Integrator was placed over the photometer objective lens. The glare intergrator is a variable-density diffusing and scattering lens that admits light to the photometer from various angles of incidence according to its predicted glare effect. Glare measurements ranged from 0.05 to 0.2 foot-lamberts

in the conventionally lighted areas. In the tower lighted areas, measurements were much lower, from 0.02 to 0.06 foot-lamberts.

EVALUATION

The uncluttered daytime appearance of the tower lighting installation was preferred over that of the conventional lighting installation. Figure 4 shows that one tower is used to light the entire loop of an interchange.

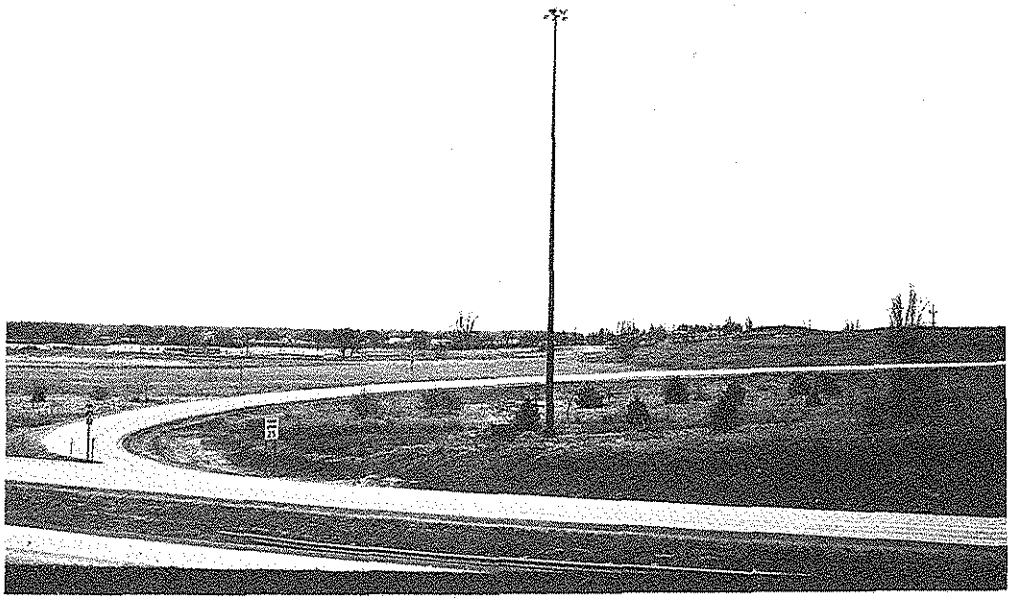

Figure 4. Typical tower installation

The number of poles required for a conventional lighting system is shown in Figure 5. Aesthetically, this is less pleasing. Further, the poles are a safety hazard because they are close to the traffic lane.

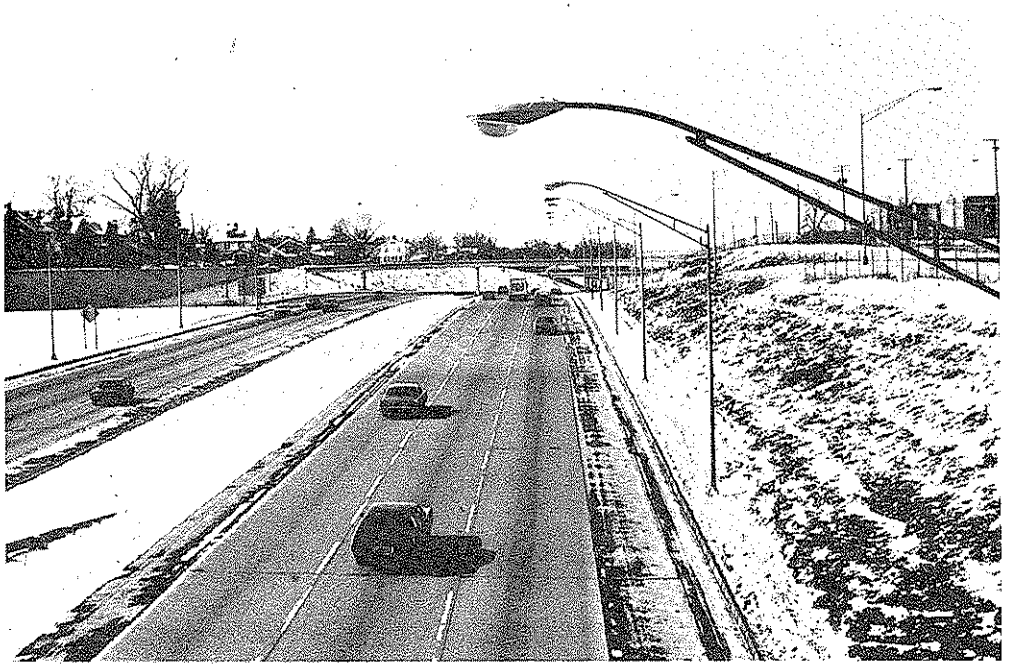

Figure 5. Typical Conventional Lighting

At night the lighting support structures are less visible, and the appearance of the luminaires is dominant for both systems. Without regard to lighting performance, conventional lighting may have a slight advantage in appearance because of its delineation on ramps and curves. Observers agreed that a desirable feature of interchange lighting by towers was the continuous illumination of the roadways and adjacent areas (Figures 6 and 7). Good visibility for all traffic movements was observed.

The most impressive tower lighting feature was the improvement in visibility in adverse weather.

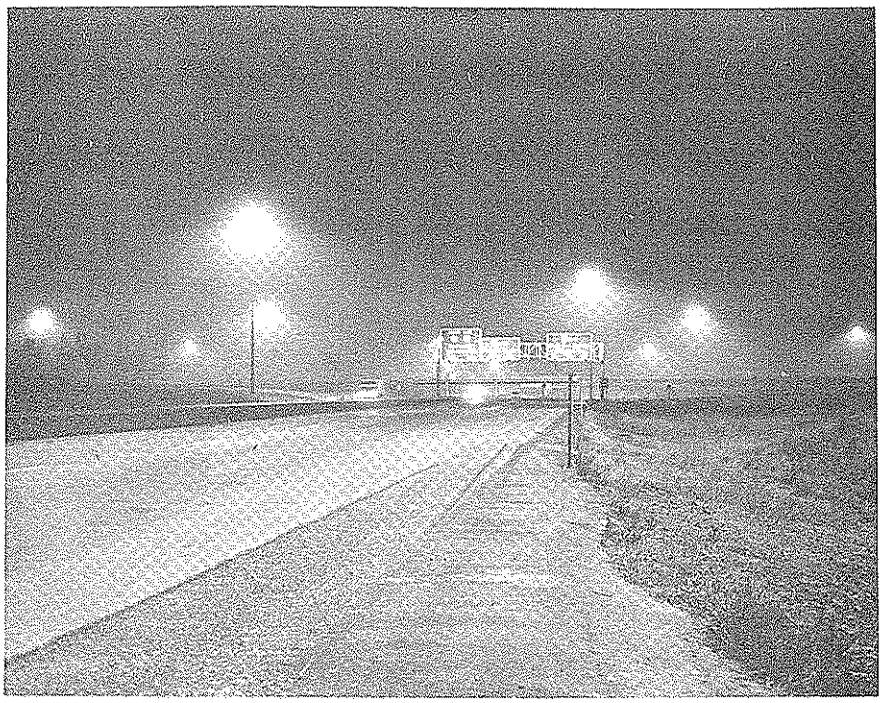

Figure 6. Illustration of overall visibility under tower lighting

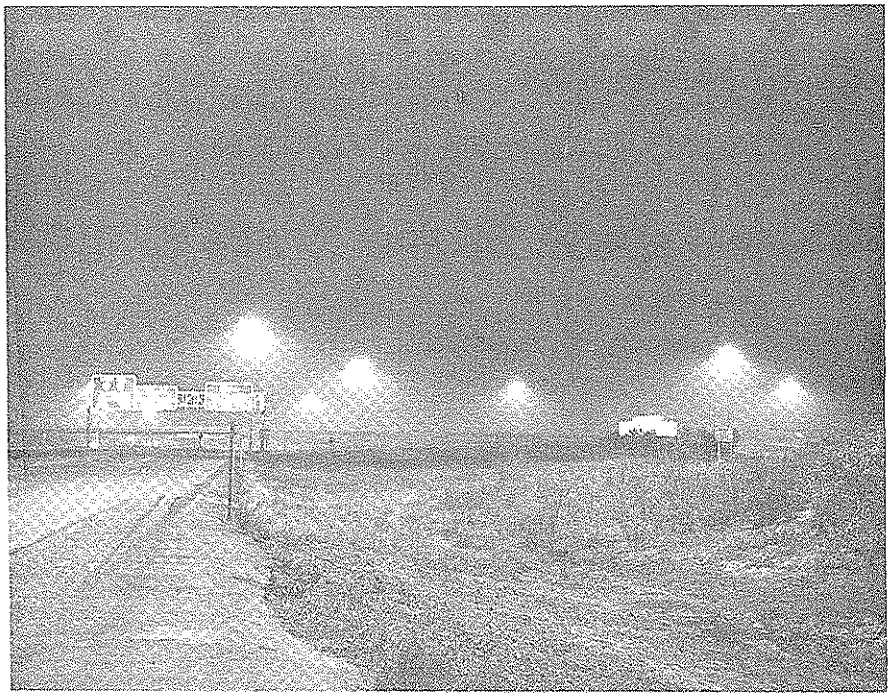

Figure 7. Illumination of adjacent areas with tower lighting

One observer found that visibility was barely adequate, even at reduced speeds, on the unlighted freeway in fog. Only slight improvement was noticed under conventional highway lighting, while the visibility under tower lighting allowed travel speeds close to normal. Thus far, all observers that have driven through the tower lighted area in fog have agreed that the tower lighting improves visibility more than conventional lighting.

Lighting Intensity and Uniformity

Horizontal Footcandles

As shown previously, the average lighting intensity for the tower lighting installation is lower than the intensity for the conventional lighting installation. The eye does not necessarily see average intensities. Average intensity, therefore, must be used with available qualitative data and sound judgement to evaluate a lighting design. The eye perceives "spot" intensities and contrasts. The uniformity of light intensity is, therefore, a useful qualitative factor. The ratio between the average intensity and the darkest spot, for a given area, is the most widely accepted criterion for calculating or measuring uniformity. It is called "uniformity ratio" or "average-to-dark ratio."

Although intensity and uniformity in HFC, as described do not entirely evaluate lighting performance as the eye perceives, they are relatively easy to calculate, and when backed by subjective observations, they can be used as design tools. Acceptable uniformity ratios are from 4:1 to 3:1, the lower ratios being more desirable. Uniformity ratios of average-to-dark HFC were within acceptable limits for both types of lighting. The measured uniformity ratios ranged from 3.2 : 1 to 1.8 : 1 for conventionally lighted areas and from 2.8 : 1 to 1.2 : 1 for tower-lighted areas.

Vertical Footcandles

Most tower lighting units are located farther from the traffic lanes than are conventional units. Therefore, the angles of the luminaire emission reaching the traffic lane provide a higher proportion of illumination for vertical surfaces than is the case for conventional lighting.

VFC readings were taken along Ramp "B" and Loop-ramp "F", which were believed to be typical of the remainder of the interchange. As might be expected, the location of the extremes of the illumination ranges in VFC did not concur with those for HFC. Whereas the

peak VFC readings occur 100 to 200 feet "downstream" from the tower, with VFC readings exceeding HFC for the next 300 feet downstream. These distances vary somewhat, depending upon the lateral distance from the tower to the roadway. It was interesting to note that the VFC readings near the exit gore for Ramps "B" and "H" (near Tower No. 6) were double the HFC readings. Observations indicated that this contributed significantly to the discernment of vehicles passing through the area, especially those with large vertical surfaces, such as semi-trailer trucks.

Pavement Brightness

Pavement brightness and its variations are illumination performance factors that the eye actually sees. As the pavement brightness becomes more uniform, the necessary contrast between the pavement and obstacles for silhouette discernment at low lighting levels is improved.

As observed and measured, the variations in brightness were reduced under tower lighting, from a high of 5.5 : 1 to 3.5 : 1, respectively. The variations were spread over larger areas, reducing the rate of change observed while traveling through the area. Frequent changes in brightness sometimes encountered in conventional lighting installations

cause a "flicker effect" that produces eye fatigue.

Glare

Glare is one of the more difficult lighting performance factors to evaluate. The effects of discomfort glare are usually obvious, while the effects of disability (veiling) glare are subtle.

Discomfort glare, as the name implies, causes actual physical pain or discomfort to the observer. The loss of perception due to discomfort glare is not always proportional to the degree of discomfort.

The loss of perception due to disability glare is caused by the scattering of light in the eyeball. This scattering effect tends to increase with the age of the observer. Disability glare can be compared to the veiling effects of fog, in the presence of some auto headlights or street lights.

Although the photometer could not distinguish between the two types of glare, the measurements indicated a glare reduction of about two-thirds under tower lighting. The observations supported the difference in readings. The observers agreed that discomfort glare was reduced in the tower lighted areas. The general observation of good visibility under tower lighting, especially in fog, indicated lower disability glare levels.

MAINTENANCE

The tower-lighting luminaires are lowered to ground level for maintenance. A luminaire mounting frame is attached to three aircraft-type, stainless-steel support cables. These cables, plus a flexible electrical cable, pass through sheaves at the top of the tower and terminate at a counterweight assembly inside the tower shaft. The counterweight assembly is accessible from the ground level when the luminaires are in the raised position.

To lower the luminaires, the operator disconnects the electrical connections and operates a small winch attached to the counterweight. The winch is powered by a reversible electric drill, which is used for all towers in a given installation.

Some difficulty with the lowering devices has been experienced. An electrical connector for Tower No. 6 failed, and was replaced. A fixed guide cable for the counterweight in Tower No. 11 loosened from its lower mount, and became entangled with the movable cables during a lowering operation. It was necessary to lower the tower to the ground for repairs. The counterweight has, on occasion, become jammed against the edges of backing plates for transverse welds in the tower shaft.

The jamming occurs most frequently when the tower shaft warps due to uneven heating by the sun.

In general, maintenance operations are safer and less costly for tower lighting than for conventional lighting. Special equipment, such as a lift truck, is not required. In this installation, eight luminaires can be serviced at each tower location. Because of the greater lateral clearance to the roadway, hazards to maintenance personnel from traffic through the area are reduced.

As stated earlier, this installation uses eight 1000-watt, metal-halide luminaires per tower. A conventional lighting system for the interchange would have used 400-watt, mercury vapor luminaires.

Our present design practices utilize 400-watt, high-pressure sodium luminaires for tower lighting and 250-watt, high-pressure sodium luminaires for conventional lighting. These new light sources will deliver approximately the same lighting levels as the older, larger sources.

Based on our present practices, the tower lighting installation would consume about 250,000 kwh. annually; an equivalent conventional lighting installation would consume about 350,000 kwh. Typical energy and routine maintenance costs by local utility companies would be

$7,000 annually for the tower lighting installation and $12,000 annually for an equivalent conventional lighting installation.

DESIGN CHANGES

Since this project was constructed, tower lighting for large interchanges has been standard practice. Tower lighting is considered for all interchanges proposed for complete lighting, and is installed in all cases where economically feasible.

Lowering devices have undergone considerable development by all manufacturers. Counterweights are no longer used. Improvements have been made on winch mechanisms. Our specifications now require chamfering of all backing plates and shaping of all moving parts within the tower shaft for free movement during raising and lowering.

The photometer purchased for this research has been used as a design and inspection aid for subsequent tower lighting projects. In one case, data obtained with the photometer were used to prove a discrepancy between the luminaire manufacturer's performance data and the actual field performance. As a result, the manufacturer was required to make necessary modifications before the project was accepted.

CONCLUSIONS AND RECOMMENDATIONS

Based on this research, tower lighting is recommended for all complex interchanges proposed for complete lighting. However, there may be cases for which conventional lighting would be the most feasible or economical alternative.

Specifically, construction, energy and maintenance costs will be lower for complete lighting of large interchanges. The construction operations will offer fewer hazards to the traveling public because much of the construction is located at greater distances from the traffic lanes.

A tower lighted interchange is always safer because the lighting units are fewer in number and are farther away from the traffic lanes. At night, the superior visibility, under adverse weather conditions such as fog, snow, and rain is a definite safety factor.

The clean, uncluttered look of a tower-lighting installation is aesthetically pleasing. At night, the broad coverage of illumination is also more attractive than the "tunnel" effect of conventional lighting.

Tower lighting has less glare, provides more uniform pavement brightness, and requires a lower illumination level for visibility equivalent to that of conventional lighting. As compared to conventional

lighting, the measurements and observations were in general agreement.

The three basic methods of tower luminaire maintenance in practice at the time of construction were:

(1) Climbing the towers via portable, sectioned ladders,

(2) The use of a portable elevator to lift maintenance personnel to the top of the towers, and

(3) Lowering of the luminaires to ground level for maintenance by use of an integral lowering device.

The use of a lowering device is recommended for all tower lighting installations.

Operations and costs for maintenance are favorable to tower lighting. Lift trucks and their resultant hazards are unnecessary. Several luminaires can be serviced from a single location.

Depreciation of light output for tower lighting luminaires is less than for conventional lighting. The results of this research showed a negligible effect of dirt and contamination on the luminaire optical assemblies.

It is expected that tower lighting will continue to be the standard method of interchange illumination.