J. A. McDONALD, INC.

P.O. Box 132, Lyndon Center, VT 05850 (802) 626-5201
E-Mail jamcdonaldinc@charter.net

CLARENDON BRO 1443 (48)

LIGHTING PLAN

J. A. McDonald, Inc. has been awarded a contract by the State of Vermont to replace Bridge #11 on Walker Mountain Road (TH3) in Clarendon, VT. This project has been designed under VTran's accelerated bridge program. The major components of this project, structure excavation/removal, installation of precast abutments and superstructure, bridge/approach and guardrail and bituminous pavement will be done during an allowed 28 day "Bridge Closure Period" (BCP).

Given the aggressive construction schedule, this plan has been prepared in the event JA McDonald determines that night work is required for construction operations during the bridge closure period. Research has shown that proper and adequate lighting is an important factor in night time construction. Work zone safety, quality of work and morale of workers are directly related to the amount of lighting provided in the work zone. The level of light/illumination is determined by the visibility requirements of the workers.

The construction/work zone for this project is relatively small and will be isolated during the bridge closure period from motorist. The plan includes the use of 4 each trailer mounted portable light towers located as shown on the attached sketch. Light towers located at the four corners of the site will have mast raised to maximum height of 30', and lights tilted down to effectively illuminate the work area, minimize glare/shadow and prevent residual light from impacting neighbors.

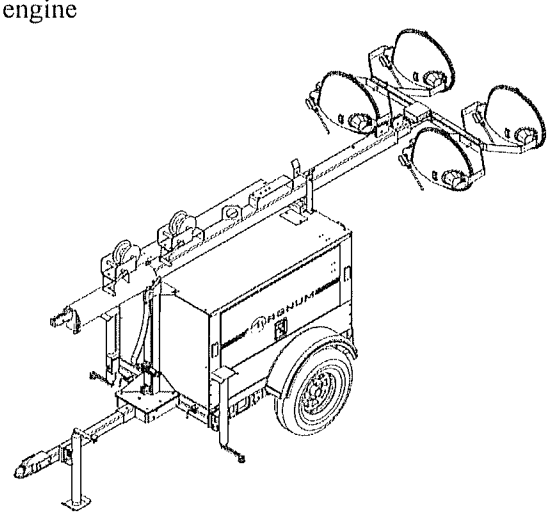
Attached to this plan are the specification for the proposed light towers and Section 2.9 LIGHTING REQUIREMENTS of the **NCHRP Report 476.**

MAGNUM™ PRODUCTS LLC

EMPOWERING REAL PEOPLE

Magnum Light Tower – MLT3080 Specifications

ENGINE



- Mitsubishi® L3E-W461ML - liquid cooled, diesel engine
  - Standby - 12.2 hp @ 1800 rpm
  - Prime - 10.5 hp @ 1800 rpm
  - 3 cylinder
  - 0.95 L displacement
- Fuel consumption (prime) – 0.63 gph (2.38 Lph)
- 60 Hz engine/generator
- Industrial engine exhaust system
- Rubber vibration dampers isolate engine/generator from frame
- Cooling system capable of operating at 120°F ambient
- Full flow oil filter, spin on type
- Fuel filter with replaceable element
- Dry type cartridge air filter
- Polyethylene fuel tank with large diameter opening
  - 30 gal. capacity
  - 48 hr. run capacity
  - 3 ½" fill port

ENGINE CONTROLS

- Engraved, aluminum punched and anodized control panel
- Four position keyed switch – glow plugs (preheat, off, run, start)
- Hour meter
- Automatic low oil/high temperature shutdown system

GENERATOR

- Marathon Electric®
  - Brushless
- 7.3 kW standby output
- 120/240 VAC – 61/30A
- +/-6% capacitor voltage regulation

ELECTRICAL SYSTEM AND CONTROLS

- Individual floodlight circuits with 15A breakers
- Ballast indicator lights
- 30A start limit breaker (assures no load condition exists before starting)
- Standard individually breakered convenience outlets:
  - (2) 120 VAC 20 Amp GFCI duplex outlets (Nema 5-20R type)
  - (1) 240 VAC 30 Amp twistlock outlets (Nema L6-30R type)
- 440 CCA wet cell battery

FLOODLIGHTS

- Four light fixtures – 1000 watts each - metal halide
- Oval aluminum reflector
- Tempered glass lens
- Silicone gaskets for moisture and dust protection
- Individual floodlight On/Off switches

WIRING

- All wiring is sized to the amperage draw required
- AC & DC wiring diagrams are provided

MAST

- 30' maximum extension, 3-section, tubular steel
- Self-lubricating, graphite guides on all sides of mast tubes
- Industrial black powder coat finish
- Automatic locking system in horizontal position for travel
- 1500 lb. automatic self-braking winches
- 360° rotation with locking system
- Coiled mast cord
- Dual winch system located at ergonomic height allowing single person operation
- Equipped with single lifting eye and fork pockets

ENCLOSURE

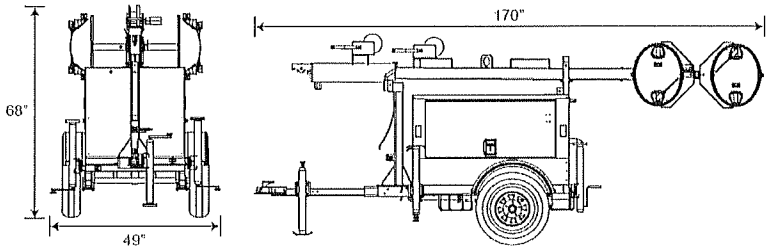
- Steel enclosure – 14-gauge
    - UV& fade resistant, high temperature cured, white polyester powder paint
    - 68 dB(A) at 23 feet – prime power
- Stainless steel hinges on doors
- Multi-lingual operating/safety decals
- License plate holder with light
- Manual holder with operating/parts manuals

TRAILER

- Mast support - 3" square tube, ¼" wall
- Removable tongue - 48" long
- Tubular steel frame - 3/16" wall
- Four, 2000 lb. adjustable leveling jacks – 4 point stance
- All jacks transport and lock in horizontal position for storage
- Side outriggers - 8' 1/4" span
- Safety chains with spring loaded safety hooks
- 2" ball hitch
- Single wall polyethylene fenders
- DOT approved tail, side, brake, and directional lights
    - Recessed rear lights
- 2200 lb. leaf spring axle
- ST175/80D13 – 6 ply
- 40.75 in. axle span

WEIGHTS & DIMENSIONS

- Dry weight: 1662 lbs (754 kg)
- Operating weight: 1875 lbs (850 kg)
- Mast stowed: 170 x 49 x 68 in (4.32 x 1.25 x 1.73 m)



WARRANTY

- Engine and generator covered under OEM warranty – consult factory for details.

CERTIFICATIONS

- CSA certified

MLT3080 Options

COOLANT OPTIONS

- 60/40 Coolant, 60% Ethylene glycol

ENGINE OPTIONS

- Heated fuel filter
- Oil drain valve kit
- Lower radiator hose – engine heater
- Cold weather belt

ELECTRICAL CONTROLS OPTIONS

- 720 CCA wet cell battery
- 720 CCA gel cell battery
- 685 CCA gel cell battery
- Battery disconnect
- Battery charger – 2A trickle
- Autolight controller

CABINET OPTIONS

- Interior cabinet light
- Level indicator

HITCH OPTIONS

- 2.5" lunette ring
- 3" lunette ring
- 3" HD lunette ring
- 2 5/16" ball
- Combination hitch – 2.5" lunette ring / 2" ball

TRAILER OPTIONS

- Tube and sleeve jack
- 6 pin or 7 spade connectors
- Spare tire and carrier
- Parking brake
- Electric brakes
- Surge brakes

LIGHT OPTIONS

- High pressure sodium, quick disconnect lights

MAST CORD OPTIONS

- Drape cord

MAST, WINCH, & FINISH OPTIONS

- Galvanized, manual, dual winch
- Galvanized, electric, dual winch
- Galvanized, electric, dual winch, quick disconnect
- Black, electric, dual winch
- Black, electric, dual winch, quick disconnect

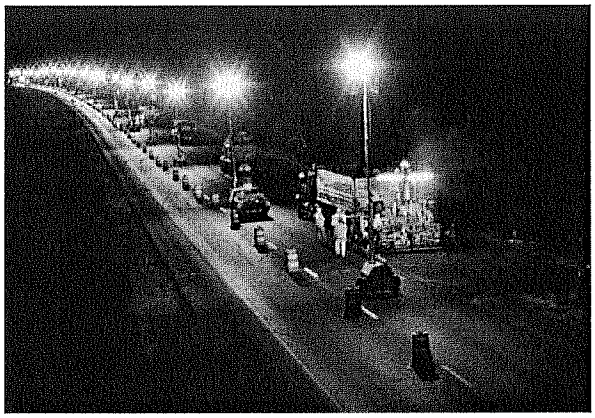
215 Power Drive . Berlin, WI 54923-2420 . Phone: 800-926-9768 . Fax: 920-361-2214
www.m-p-llc.com

NCHRP

REPORT 476

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction



TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

between the two. Inspection staff should periodically attend contractor sessions to ensure that the contractor is making a reasonable effort to train inspection staff and other representatives of the owner agency. From time to time, special sessions may be conducted that can benefit all project staff, including inspectors. Attendance at such sessions helps to develop an overall project awareness and dedication to safety.

2.9 LIGHTING REQUIREMENTS

Previous research has shown lighting to be one of the most important factors in nighttime construction. Safety in the work zone, quality of work, and morale of workers are all directly related to work zone lighting. The requirements for lighting are determined by the visibility requirements of the workers and motorists using the area. Factors that must be considered in defining lighting requirements were summarized in the final report for NCHRP Project 5-13 (*38*). Stated briefly, for any given observer with a defined visual ability, the smaller that the object to be seen is and the less contrast the object has with its background, the more light is needed for adequate visibility. Also, the presence of glare degrades visibility while bright ambient conditions improve visibility.

Lighting requirements are most easily defined in terms of illuminance, which is the amount of light falling on a surface. Illuminance is measured in either footcandles or lux. Illuminance may be increased by increasing the intensity of a light source, increasing the number of light sources, or decreasing the distance of the light sources from the surface area. (See Tech Note 47.)

The system advanced by Ellis et al. was to categorize the majority of highway and bridge maintenance tasks and to assign a minimum level of illuminance to each category (*38*). Given this knowledge concerning how much light is needed in different locations of the work area, a lighting design can be identified that provides the required photometrics.

Appropriate lighting fixtures must be selected, and the appropriate location, arrangement, and spacing must be determined to achieve the required illuminance levels. This information should be included in the lighting plan discussed in Section 3.4. Inspection methods that may be used to determine whether the installed system meets the photometric requirements of the design and plan are discussed in Section 3.2.

This section addresses the amount of lighting that is needed in specific work areas and for different work tasks. It also provides a general discussion of methods that may be used to achieve these levels and the limits and methods required to provide adequate control of glare.

Anyone responsible for developing a lighting plan for night construction work should be knowledgeable in photometrics and vision and should consult the final report for NCHRP Project 5-13 (*38*) and the IES Lighting Handbook (*40*) from which these guidelines were developed.

2.9.1 Classification of Illumination Requirements by Task

Lighting should be adequate to provide the minimum level of illuminance required in different work areas and for different tasks. Each area, task, or both must therefore be categorized as to what level of lighting is required:

- **Level 1.** This level of illuminance is recommended for the general illumination of all work operations by contractor's personnel in areas of general construction operations, including layout and measurements ahead of the actual work, excavation, cleaning and sweeping, landscaping, planting, and seeding. Work areas, such as stockpiles, are illuminated to Level I to enhance safety and improve work efficiency (see Figure 27). This level of illuminance is primarily important in areas where crew movement may take place and is limited to tasks requiring low accuracy, involving slow-moving equipment, and having large objects to be seen. Level I illuminance should also be provided at the area of lane or road closures continuously throughout the period of closure, including the setup and removal of the closures. (See Tech Note 48.)

  This level of illuminance should also be provided during the setup of lane closures or road closures installed in conjunction with nighttime construction operation and should be maintained until the closure is removed. Such lighting should be used at the actual points of closure, including the lane closure tapers. Level I illumination is required in the taper, since work crews will be in this area during setup and takedown and the potential always exists that a worker will drift into this area for some unplanned reason. Leaving the area without minimum illumination creates an unsafe situation, as workers need to see obstacles when they move into this area. Also, the taper is where there is the greatest uncertainty about path, and driver expectancies will often be violated. Level I illumination will provide some additional protection against impaired drivers, allowing them to see workers

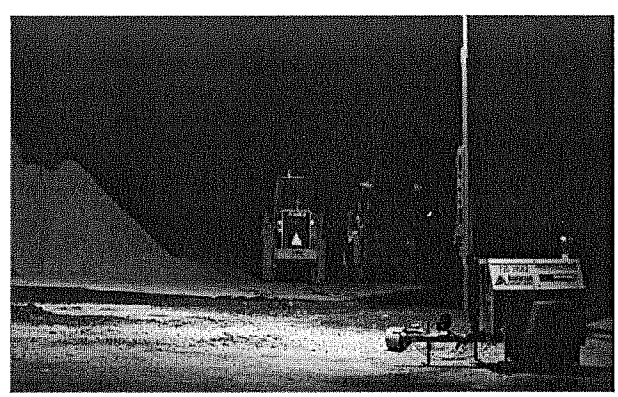


Figure 27. Remote area illuminated to Level I.

and avoid this area during setup and takedown. Lighting need not be required throughout the entire lane closure, except as required at active work sections (*41*).

Whether or not the taper should be lit at times other than setup and takedown depends, in part on the lighting characteristics of the sections adjacent to the taper. The concern here is the possible creation of a transient adaptation effect. That is, as a driver traverses a brighter section of roadway, the eye adapts to that illumination level. Upon going into a darker area, it takes the eye a short period of time to adapt to the lower level of illumination. During the adaptation period, the visibility of objects is reduced. Because, as mentioned, the taper is a transitional area for the driver, any situations that produce reduced visibility should be avoided (*42*).

- **Level II.** This level of illuminance is recommended for areas on or around construction equipment. This level of minimum illuminance is necessary both for safety in operating equipment and for attaining an acceptable level of accuracy. Asphalt paving, milling, and concrete placement and removal are examples.
- **Level III.** This level of illuminance is suggested for tasks requiring a higher level of visual performance or for tasks with a higher level of difficulty. Pavement or structural crack and pothole filling, joint repair, pavement patching and repairs, installation of signal equipment or other electrical or mechanical equipment, and other tasks involving fine details or intricate parts and equipment require Level III illuminance.

2.9.2 Illumination Criteria

Luminaires should be of sufficient wattage and quantity to provide an average maintained illuminance equal to or greater than the following:

- Level I: 59 lux (5 footcandles),
- Level II: 108 lux (10 footcandles), and
- Level III: 215 lux (20 footcandles).

Although most tasks require maintenance of horizontal illumination, some tasks (such as bridge painting, concrete and steel repairs on bridges, and work on overhead signs and sign structures) require that vertical illuminance be maintained.

Horizontal illumination refers to measurements made with the photocell parallel to the road surface. For purposes of roadway lighting, the photocell is placed on the pavement. Vertical illumination refers to measurements made with the photocell perpendicular to the road surface. Vertical measurements require that the direction and the height above ground be specified. See Tech Note 47.

2.9.3 Paving and Milling Operations

For paving and milling operations, including bridge decks, New York State requires Level II illuminance 15 m (50 ft) ahead of and 30 m (100 ft) behind the paving or milling machine. Although these distances have been found appropriate by New York, other distance boundaries may be acceptable (*41*).

In addition, New York State recommends Level I illuminance for a minimum of 120 m (400 ft) ahead of and 245 m (800 ft) behind the paving or milling machine, or for the entire area of concrete placement or pavement work if less than this distance. This area is extended as necessary to incorporate all vehicle and equipment operations associated with the paving operation. The only exception to the requirement for Level I illuminance throughout the area of construction operations is that finish rollers will work beyond the area of Level I illuminance using floodlights mounted on the roller. This exception is necessary because, given the length of time pavement may take to cool, the finish roller may drop farther than 245 m (800 ft) behind the paver (*41*).

In the night paving project in Figure 28, portable light towers throughout the work area provide Level I illumination. Floodlights on the paver and rollers supplement the towers to provide Level II illumination at the paving operation.

The New Jersey DOT has developed specifications to mount luminaires on paving equipment to achieve Level I and II illumination. The DOT reports good results with equipment-mounted lighting to meet these levels (*43*).

2.9.4 Uniformity

The uniformity of illuminance, defined as the ratio of the average illuminance to the minimum illuminance over the work area, should not exceed 10:1, with 5:1 being more desirable (*38, 41*).

2.9.5 Glare

The eye reacts in two distinct ways to the presence of glare. One reaction is described as discomfort glare. This reaction is

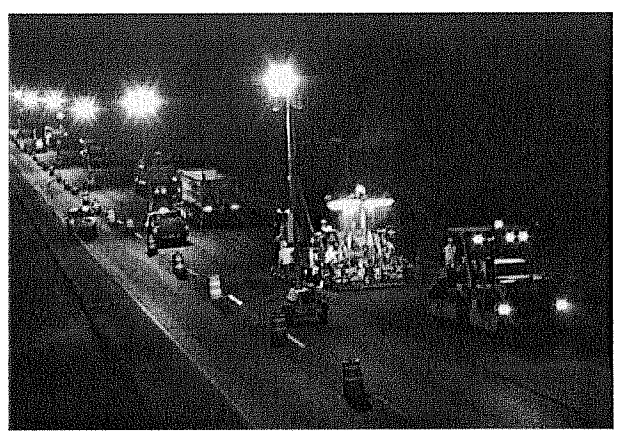


Figure 28. Level I and II illuminance at a nighttime paving project.

measured subjectively and has no direct effect on vision. Discomfort glare may, however, result in fatigue that may have a deleterious effect on vision. The other reaction of the eye to glare is referred to as disabling glare. Disabling glare results from light scatter within the eye that effectively reduces contrast and, therefore, visibility of objects. Disabling glare is measured in terms of veiling luminance in units of candela per square meter. Because the sensation of glare is related to the adaptation of the eye, the Illuminating Engineering Society (IES) has set the criteria for glare in terms of the ratio of veiling luminance to pavement luminance under the assumption that pavement luminance controls the level of driver adaptation. The IES recommends that veiling luminance be no greater than a third of average pavement luminance. Therefore, in well-lit areas where the level of pavement luminance is high, a higher level of glare becomes tolerable (*40, 44*).

2.9.5.1 Principles for Controlling Glare

The most direct way to minimize glare is to locate the luminaire so that the axis of maximum candlepower is located away from the most critical line of sight of motorists. Critical lines of sight would include looking at the road ahead, reading signs, and observing directions from flaggers. Three factors affect the angle between a luminaire's beam angle and the normal lines of sight, and all three factors interact with each other. These factors are the distance between the viewer and the luminaire, the height of the luminaire relative to the observer distance, and the direction in which the luminaire is aimed. As mounting height is increased, the angle drawn from the light source to any point on the road surface within the work area decreases. The greatest candlepower from the luminaire is thus directed to the work zone, and reduced candlepower is directed to the travel lanes (*38*).

2.9.5.2 Methods to Minimize Glare

At a minimum, the following requirements must be met to avoid objectionable glare on roadways open to traffic in either direction:

- Tower-mounted luminaires should generally be aimed either parallel or perpendicular to the roadway.
- All luminaires should be aimed such that the center of the beam axis is no greater than 60 deg above the vertical (straight down).
- None of the luminaires should provide a luminous intensity greater than 20,000 candela at an angle of 72 deg above the vertical (straight down).

Luminaires vary in beam patterns. By selecting a cutoff luminaire, a greater proportion of candlepower may be directed to the work area and glare reduced. (See Tech Note 49.)

Several agencies have reported using a tethered balloon with a 4,000-watt halogen light source to get both portability and the luminaire height needed to control glare. This technology is capable of reaching Level II illumination within a 20-m (65-ft) radius (see Figure 29). Information may be obtained at www.airstar-light.com.

In some cases, it may be impossible to control glare with the physical installation of the luminaire itself. For example, it may be impossible to get sufficient mounting height given restrictions on where poles may be located.

Glare aimed at oncoming traffic with shadows and nonuniform illumination within the work space may result if portable light towers are not fully extended, with the luminaires aimed at least 30 deg below horizontal (see Figure 30).

Even when the lighting design is very successful in controlling glare, there may be a few locations where glare may still need to be controlled. In these cases, it may be possible to mount shields, visors, or louvers on the luminaire itself or to use glare avoidance screens or barrier walls to protect workers and motorists from glare. One agency reported using glare screens of 70-percent shaded cloth or plywood.

Figure 29. Light balloons attached to pavers and other equipment.

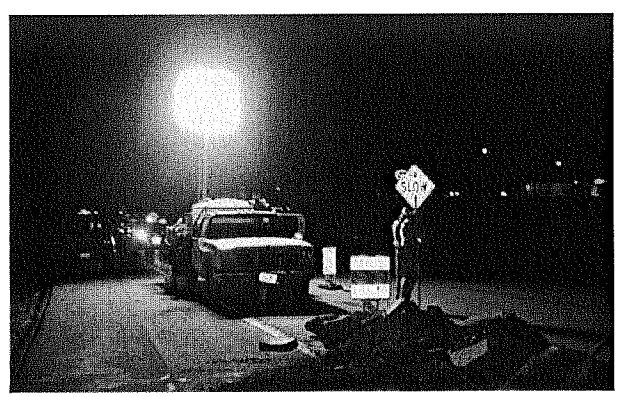


Figure 30. Glare aimed at oncoming traffic.

2.9.6 Configuration of Lighting System

Existing street and highway lighting may not eliminate the need for additional lighting of the work zone. Before the lighting system can be designed and a layout created, the user must choose among lighting systems based on temporary, portable, or mobile equipment. The choice among these systems is a function of cost, efficiency, power requirements, and ability to satisfy minimum requirements while controlling glare. Consideration should be given to the amount of illumination provided by existing fixed lighting in determining the wattage, quantity, or both of lights to be provided. Whenever existing fixed lighting is contributing to the work zone lighting, this contribution must be included in the lighting plan.

2.9.6.1 Temporary Systems

Temporary systems are used to light an entire work zone area. They use existing or temporary poles to mount luminaires. Temporary systems allow luminaires to be uniformly spaced at relatively high mounting heights that result in a uniform lighting with low glare. This type of system may be cost-effective when it is to supplement an existing fixed lighting system, when the work activity will last a significant period, or both.

2.9.6.2 Portable Systems

Portable systems integrate the luminaire, power supply, and pole into one fixture that can easily be moved from one location to another. Portable systems may consist of either ground-mounted or trailer-mounted light towers. Portable trailer-mounted light towers can be easily transported throughout the project (see Figure 31), as well as easily raised into position at the work site (see Figure 32). Light towers may also be affixed to paving machines, finishing machines, and milling machines. Although easy to operate and maintain, these systems often provide more light than needed, which reduces their cost-effectiveness. Spacing and positioning of these devices typically results in very nonuniform illumination, which, together with the low mounting height, often results in a severe glare hazard.

If these systems are the primary means of illumination, they are required to provide Level I illuminance throughout the work area. They must then be supplemented as necessary by equipment-based systems to provide Level II and III illuminance where it is needed.

2.9.7 Mobile Equipment-Based Systems

Mobile equipment-mounted systems generally do not conform to any criteria that may be used to calculate expected illuminance levels. As such, they should not be relied upon for the primary lighting for areas or tasks requiring Level II or III lighting. All construction equipment—including rollers,

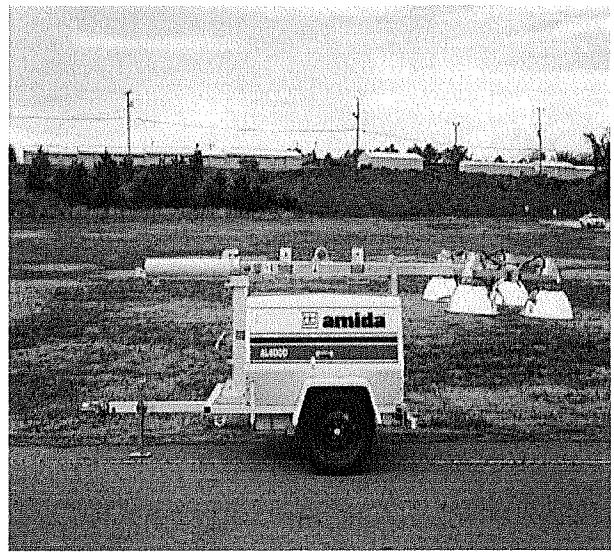


Figure 31. Portable trailer-mounted light tower being transported throughout the project.

backhoes, loaders, and other equipment—operating in work areas not illuminated to a minimum of Level I illuminance must be equipped with floodlights that provide a minimum of 1 fc (10.8 lux). Construction equipment that operates solely in areas illuminated by tower lighting that meets the minimum lighting requirements do not require floodlights (*41*).

When being driven beyond a lighted work area, slow-moving equipment, such as pavers and milling machines, require a minimum of 1 fc (10.8 lux) for a distance up to 5 m (15 ft) in the direction of travel. Fast-moving equipment—such as backhoes, loaders, motor graders, or rollers—requires this level of illuminance for up to 20 m (65 ft) in the direction of travel. These requirements do not replace the minimum illuminance requirement for each specific task (*38*).

2.9.7.1 Supplemental Lighting

Equipment-mounted systems may also be advantageous to increase the level of lighting from Level I to Level II or III (see Figure 33). Illumination immediately in front of and behind a paver is often improved by this type of lighting. Also, a supplemental luminaire may be mounted on a vehicle and moved from joint to joint in pavement repair operations to increase illumination to Level II or III.

2.9.7.2 Mounting

Suitable brackets and hardware must be provided to mount lighting fixtures and generators on machines and equipment. Mountings should be designed so that light fixtures can be aimed and positioned as necessary to reduce glare and provide

Figure 32. Portable trailer-mounted light tower raised into position at the work site.

the required illuminance. Mounting brackets and fixtures should not interfere with the equipment operator or any overhead structures and must provide for secure connection of the fixtures with minimum vibration.

2.9.7.3 Headlights

Whether or not floodlights are provided, all construction equipment must be equipped with conventional vehicle headlights to permit safe movement in nonilluminated areas. Headlights should not be permitted as the sole means of illumination while working.

2.9.7.4 Advantages

Equipment-mounted lighting may offer a number of advantages when compared with area floodlighting (*38*). These advantages include the following:

Figure 33. Supplemental flood lights mounted on equipment.

- There can be high-intensity illumination on the work plane.
- The positioning of lights between operator and task eliminates shade.
- The operator can adjust light to direct high-intensity illumination where needed.
- The rate of nighttime work can approach the daytime rate.
- The equipment can be operated independently of general illumination.
- The possibility of general shutdown of work due to failure of lighting and power-generating equipment is minimized.
- The need for equipment such as floodlighting trailers and generators is minimized, thus eliminating time and labor spent in transporting and erecting such equipment.

2.9.8 Lighting Equipment

Guidelines for the selection of lighting equipment to meet the photometric requirements of a project are discussed in the final report of NCHRP Project 5-13 (*38*) and are not covered in detail here. Lighting equipment includes the luminaire; the lamps that it houses; and the poles, mast arms, wiring, and other hardware necessary for installation. Knowledge of the fundamental characteristics of lighting equipment and the photometric characteristics that result is essential for success in designing any lighting system. Prior to designing any system, representatives of equipment manufacturers should be contacted to obtain the most recent information concerning current products and their photometric output (*38*).

2.9.8.1 Fuel

The fuel tank capacity and the availability of fuel on-site must be sufficient to permit uninterrupted operation of all portable generators used to furnish adequate AC power to operate all required lighting equipment throughout the complete night shift.

2.9.8.2 Electrical

Adequate switches must be provided to control the various lights. All wiring must be weatherproof and installed according to local, state, federal, and OSHA requirements. All power sources must be equipped with a ground-fault circuit interrupter to prevent electrical shock.

2.9.9 Photometrics

Photometric characteristics are largely determined by the luminaire. Some type of cutoff luminaire is highly recommended to shield the light source above some minimum vertical angle and, therefore, reduce glare, although there may be situations where it is not essential. A brief discussion of photometrics and measurement methods is given in Tech Note 50.

2.9.10 Lighting Design Process

A procedure for developing a lighting plan for night construction is illustrated using the project represented in Figure NWTA-7 in Appendix A.

2.9.10.1 Example Problem

The work area is a four-lane highway with 12-ft (3.6-m) lanes, 6-ft (1.8-m) shoulders, and no median. The construction consists of joint removal and replacement in a 1,000-ft (305-m) section of concrete pavement on the two northbound lanes (shown by the shaded region in NWTA-7). The operation will consist of several sequential steps that will progress simultaneously from joint to joint, including (1) sawcutting the area to be removed, (2) removing existing material, (3) preparing subbase and concrete surfaces, (4) placing and finishing new concrete, and (5) sawcutting and sealing new joint. Guardrail has been installed on the outside of the shoulders because of the steep embankments on both sides of the roadway, which would not be suitable for installing temporary lighting. Therefore, the placement of the light towers is restricted to the shoulders or the travel lanes within the work area.

2.9.10.2 Example Solution

In most cases, especially if the contractor has done night construction before, the design process will consist of tailoring lighting equipment that the contractor owns or has rented to the new work area. This tailoring includes adjusting the height, spacing, tilt, and fixture locations to meet the illumination and glare requirements discussed in Sections 2.9.1 and 2.9.5. For this example, it is assumed that the contractor already owns portable light towers that can adjust from 12 ft to 30 ft in height with 1,000-watt, metal-halide lamps (MH1000) and a National Electrical Manufacturers Association (NEMA) 6 beam spread. A set of IsoFootcandle diagrams for different height and aiming combinations of the MH1000 are also available to the contractor. These diagrams, which exist for different lamp types, beam spreads, heights, and tilt, can usually be obtained from the lamp manufacturer (see Figure 34).

The following steps illustrate the procedure used to determine the number of light towers required, their location, the number of lamps per tower, and their height and aiming.

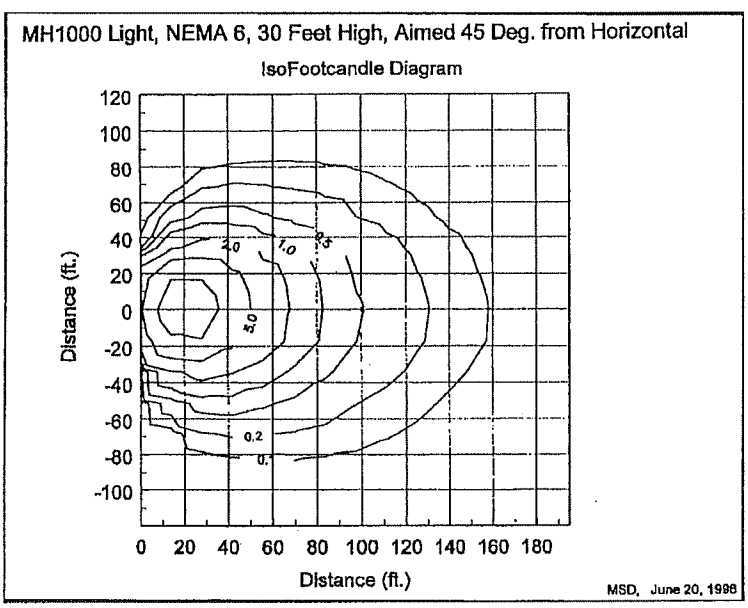


Figure 34. IsoFootcandle diagram.

2.9.10.3 Identify the Recommended Lighting Levels

Joint removal and replacement is an activity that requires a visual task of small sizes. According to Tech Note Table 3, at least 20 fc should be provided at the joint locations during concrete placement, finishing, and cutting of the new joints. The remainder of the 1,000-ft section should be lighted with 5 fc for worker movement and general safety. Road closures and tapers should also be illuminated with 5 fc for worker safety during setup and takedown and for aiding drivers who may be uncertain of which path to take.

2.9.10.4 Assess the Work Zone and Surrounding Area and Select Possible Tower Locations

As the problem states, guardrail has been installed outside of each shoulder because of the steep banks on both sides of the roadway. With this restraint, along with the suggestion in Section 2.9.5 to aim the lights either parallel or perpendicular to the direction of motorist travel, there are three plausible locations for the towers: (1) on the right shoulder aimed perpendicular, parallel, or both to the travel lanes; (2) on the left shoulder aimed perpendicular to the travel lanes; or (3) within the two closed lanes on the upper and lower boundary of the 1,000-ft concrete section and aimed parallel to the direction of travel.

Light towers on the left shoulder would have to project over a large distance because they are located far away from the work area. Towers within the lanes aimed parallel to the motorist travel not only would have to project over a large distance, but also may get in the way of workers and equipment. Therefore, the most desirable location would appear to be the right shoulder. If lights on the right shoulder alone do not meet the illumination requirements, the other locations may need to be used. Towers on the right shoulder should also be sufficient for lighting the road closures and tapers.

2.9.10.5 Determine the Mounting Height and Aiming Points

Most portable light towers have an adjustable mounting height ranging from about 12 ft to 30 ft and lights that can be aimed at any angle (ranging from 0 deg to 90 deg from the horizontal). The IsoFootcandle diagrams discussed earlier should be used to choose the right combination of height and tilt. The diagrams show two common patterns: (1) for a given lamp size and tilt, the horizontal illumination will increase as the mounting height decreases and (2) for a given lamp size and height, the maximum horizontal illumination observed increases as the angle from the horizontal increases.

Because the light towers will be on the right shoulder—aimed perpendicular, parallel, or both to the travel lanes—a height and aiming combination should be chosen that will provide at least 5 fc in the area up to 24 ft from the base of the tower (this provision ensures that 5 fc of illumination will cover both lanes of the work area). For the road closure and taper, a height-aiming combination is needed that will also provide at least 5 fc at the proper spots.

A review of numerous IsoFootcandle diagrams for the MH1000 indicates that a 30-ft height with one lamp aimed 45 deg from horizontal will provide 5 fc out to 50 ft from the base of the tower in the direction that the center of the beam is pointed (see Figure 35). For practical purposes, multiple lamps are usually mounted on each tower and are aimed in different directions. This placement allows an increased tower spacing while still providing the proper illumination. For example, if three MH1000 lamps are mounted on a tower, each aimed 45 deg from horizontal with one pointed perpendicular and two pointed parallel in opposing directions, the IsoFootcandle diagrams can be overlaid to show that the tower will have a 50-ft radius of at least 5 fc and a 60-ft radius of at least 2.5 fc (see Figure 35).

2.9.10.6 Choose Tower Locations on the Basis of Spacing and Check Design for Glare

To locate the individual tower locations, the final IsoFootcandle diagram of the three MH1000 lamps in Figure 35 was overlaid onto the work area (see Figure 36). It was determined that a 110-ft spacing between towers would provide the 5 fc at all spots required for worker movement and general safety. A portable system with two MH1000 lamps, mounted 30 ft high, pointed perpendicular to the travel lanes and aimed 60 deg below the horizontal, should move along with the work crew and be placed on the right shoulder at each joint to provide the required 20 fc for the joint replacement task. Alternatively, a balloon luminaire (shown in Figure 29) could be used to provide the additional lighting at the joints. Also, as Figures 35 and 36 confirm, one tower, placed on the right shoulder directly across from a road closure and taper, with three MH1000 lamps mounted at 30 ft and aimed the

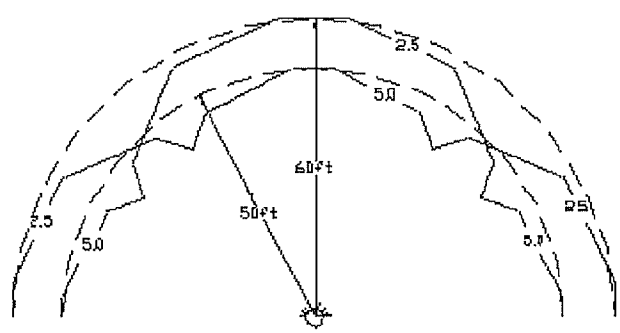


Figure 35. Overlaying IsoFootcandle diagrams for three MH1000 lamps to obtain a 50-ft radius of 5 fc and a 60-ft radius of 2.5 fc.

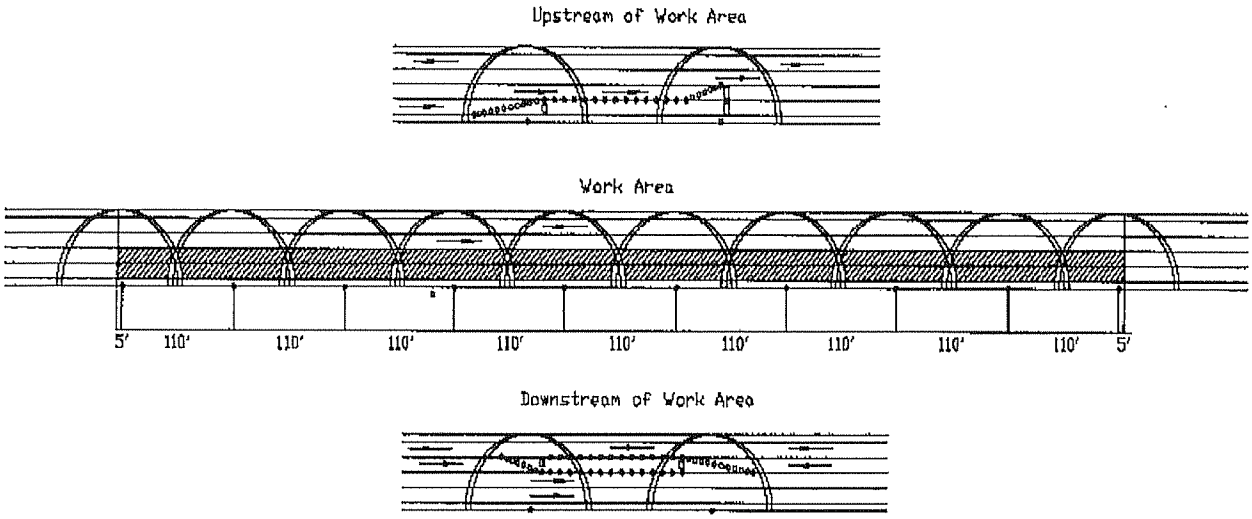


Figure 36. Final tower locations for the work area and the upstream and downstream lane tapers and closures.

same as in the work area, should provide the recommended 5 fc at these locations. Therefore, the lighting plan consists of 14 towers (nine stationary and one portable within the work area, one at each lane closure and one at each lane shift).

The final step of the design procedure is to check the lighting design against the requirements listed in Sections 2.9.1 and 2.9.5 to avoid objectionable glare to drivers. These requirements are reviewed below with regards to the lighting design example:

- Tower-mounted luminaires should be aimed either parallel or perpendicular to the roadway. All of the mounted lights should be aimed either perpendicular or parallel to the travel lanes.
- All luminaires should be aimed such that the center of the beam axis is no greater than 60 deg from vertical. The center of the beam axis should be aimed either 45 deg or 30 deg from vertical for all towers in the lighting plan.
- None of the luminaires should provide a luminous intensity greater than 20,000 cd at an angle of 72 deg above the vertical. Because the center-of-beam axes are only 45 deg and 30 deg from vertical, meeting this requirement should not be a problem.