

DMS - 11011

LED ROADWAY LUMINAIRES

EFFECTIVE DATE: JULY 2014

11011.1. Description. This Specification governs the materials, composition and quality of Light Emitting Diode (LED) luminaires used as equivalents to the Department's standard 150-, 250-, and 400-W, high-pressure sodium (HPS), mast-arm-mounted, "cobra-head" style roadway illumination light fixtures (luminaires).

11011.2. Units of Measurements. The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

11011.3. Material Producer List. The Traffic Operations Division (TRF) maintains the Material Producer List (MPL) of all materials conforming to the requirements of this Specification. Materials appearing on the MPL, entitled "[Roadway Illumination and Electrical Supplies](#)," need no further sampling or testing unless deemed necessary by the Project Engineer or TRF.

11011.4. Bidders' and Suppliers' Requirements. The Department will purchase or allow on projects only those products listed by manufacturer and product code or designation shown on the MPL.

Use of pre-qualified product does not relieve the Contractor of the responsibility to provide products that meet this Specification. The Department may inspect or test material at any time and reject any material that does not meet the specifications.

Notify the Department in writing of selected luminaires from the MPL intended for use on each project.

11011.5. Pre-Qualification Procedure.

A. Pre-Qualification Request. Submit requests for evaluation of LED roadway luminaires to the Texas Department of Transportation, Traffic Operations Division, 118 East Riverside Drive, Austin, Texas 78704.

B. Pre-Qualification Submittal. For each type of luminaire, submit a sample meeting all specifications and all pertinent documentation with the pre-qualification request.

Provide additional samples when directed.

Submit all products for evaluation at no cost to the Department.

Include the following documentation with the pre-qualification request:

- Luminaire cut sheets;
- Cut sheets for LED light sources;
- Cut sheets for LED driver;

- Cut sheets for surge protective device;
- LM-79 luminaire photometric reports of a complete luminaire meeting this Specification for each optical configuration, from a National Voluntary Laboratory Accreditation Program (NVLAP)-accredited test laboratory located in the United States, that include:
 - Name of test laboratory;
 - Report number;
 - Date;
 - Complete luminaire catalog number:
 - Including an explanation if catalog number in test report(s) does not match catalog number of luminaire submitted, and
 - Clarifying whether discrepancy does not affect performance, e.g., in the case of differing luminaire housing color.
 - Description of luminaire, LED light source(s), and LED driver(s);
 - Input power, voltage, current, frequency, and power factor;
 - Goniophotometry;
 - Correlated Color Temperature (CCT);
 - Color Rendering Index (CRI);
 - TM-15-11 Backlight, Uplight, and Glare (BUG) rating;
 - Photometric file in LM-63 format (i.e., filename.ies); and
 - Photos of luminaires in test position, with test number written and visible on luminaire.
- Published photometric file in LM-63 format (i.e., filename.ies) for each submitted configuration, available to the public on the manufacturer's website;
- Calculations and supporting test data per Section 11011.8.G, "Calculation of Light Loss Factor," indicating specified lumen maintenance life including:
 - LM-80 data;
 - In-situ temperature measurement test (ISTMT) reports for representative luminaires according to UL 1598, including an explanation of how ISTMT reports relate to luminaires submitted for Department use; and
 - TM-21 analysis using the Energy Star TM-21 Calculator to predict lumen maintenance at 70,000 hr. and 25°C.
- Computer-generated point-by-point photometric analysis of maintained photopic light levels in accordance with Section 11011.8.H, "Performance Requirements," using the .ies files and light loss factor calculated in Section 11011.8.G;
- Summary of reliability testing performed for LED driver(s);
- Test reports showing results of electrical immunity tests in accordance with Section 11011.8.E, "Surge Protective Devices," for each voltage range of luminaire;

- Test reports showing ingress protection rating of IP 66 or better in accordance with ANSI C136.25 for optical assembly for each size luminaire per Section 11011.8.A, “General Requirements,” and driver per Section 11011.8.C, “LED Drivers”;
- Test reports showing results of 3G vibration tests in accordance with ANSI C136.31 for each size of luminaire per 11011.8.B, “Housing”;
- Test reports showing results of ASTM B117 and QUV tests of finish per Section 11011.8.B;
- Documentation per Section 11011.6, “Quality Management System”;
- Contact information for the manufacturer’s administrators or representatives who will oversee testing and tracking of luminaires built for the Department per Section 11011.7, “Manufacturer’s Verification Testing”;
- Written procedure for testing and tracking of luminaires built for the Department per Section 11011.7;
- Written warranty and warranty service procedures per 11011.8.F, “Warranty”; and
- Nationally Recognized Testing Lab (NRTL) certification to UL 1598.

C. Evaluation. TRF will notify prospective bidders and suppliers after completion of material evaluation.

1. Qualification. If approved for Department use, TRF will add the material to the MPL.

All approved materials become Department property for comparison testing.

Once qualified, do not change fixture components or construction without prior Department approval. Unapproved changes will result in rejection of the fixture and removal from the MPL.

2. Failure. Products not qualified under this Specification may not be furnished on Department projects and must be corrected of all deficiencies before consideration for qualification.

Costs of sampling and testing are normally borne by the Department; however, the costs of sampling and testing products failing to conform to the requirements of this Specification are borne by the Contractor or supplier. The Director of TRF will assess this cost at the time of testing.

The Department will deduct amounts due from monthly or final estimates on Contracts or from partial or final payments on direct purchases by the Department.

D. Periodic Evaluation. TRF will periodically test luminaires sampled from projects for compliance with this Specification. TRF may remove luminaires from the MPL that inconsistently pass testing, are inconsistent with submitted information, do not meet specifications, or that develop a history of failures in the field.

E. Disqualification. If LED roadway luminaires provided on a project do not match the pre-qualification submittals, the luminaire may be removed from the MPL for one year at the discretion of the Department.

F. Re-Qualification. For materials removed from the MPL for failing to meet any of the specification requirements, the producer may not submit for re-qualification until one year from the date of removal. TRF may waive this time limit if provided with documentation from an independent testing facility stating the materials meet all requirements. TRF will reinstate the one year time limit if, after retesting, the material again fails any of the specification requirements.

11011.6. Quality Management System. The manufacturer must demonstrate a commitment to quality by submitting either:

- Current ISO 9001 certification for luminaire manufacturing facilities or
- Alternative Quality Management System documentation with the following minimum requirements:
 - Written statement of the company's quality management (QM) policy;
 - Name of employee with special QM training and with QM as his/her primary job responsibility;
 - Procedure written specifically for handling orders for fixtures built to Department specifications;
 - Written procedure for keeping track of fixtures built, certified, and tested for Department orders; and
 - Documentation that luminaire has been designed and manufactured in accordance with the manufacturer's stated quality program.

11011.7. Manufacturer's Verification Testing. Sample and test the electrical and photometric properties of luminaires. Track and report shipments of luminaires. Supply results to TRF for evaluation and approval.

Before shipping fixtures, select from each lot or manufacturing run one completed luminaire for every hundred, with a maximum of two, for electrical and luminous intensity distribution testing. Select one completed luminaire from each lot for color characteristics testing. Test fixtures and supply results to TRF for evaluation before shipping. Do not ship fixtures until TRF approves the lot. The Department will randomly sample and test luminaires from projects to verify conformance with the specifications. Failure to conduct testing or conform to the specifications will result in removal from the MPL.

Perform electrical and photometric testing at a test lab located in the United States with NVLAP accreditation for the IES LM-79 test procedure.

Test fixtures in accordance with IESNA LM-79. Include the following data in the test report:

- Photometric file in LM-63 (i.e., filename.ies) format;
- Input power, voltage, current, and frequency;
- Power factor;
- CCT;
- CRI;
- Luminous flux;

- Luminous efficacy;
- BUG rating according to TM-15-11;
- Luminaire description; and
- Unique test number for each fixture.

TRF will evaluate and pass the batch if the submitted testing information meets the following criteria.

- All information listed above is included in the report;
- Measured power factor is 0.90 or greater;
- Measured CCT is within the limits of 11011.8.D, “LED Optical Assembly”;
- Measured CRI is 70 or greater; and
- All photometric files meet the performance requirements in 11011.8.H.

If the testing information does not meet the above requirements, TRF will notify the manufacturer to correct the problem and retest.

Ensure the test lab retains the results for 5 years; provide the Department access to documentation. Retain records of manufacturing lots, test reports, lot quantities, and other pertinent details. Submit records to the Department upon request. Make available to Department inspectors all testing and manufacturing facilities involved in the production of fixtures for use on Department projects, inventories of fixtures produced to Department specifications, and records of fixture testing and tracking.

Track fixtures built for Department projects. Include CSJ, county, project, date shipped, quantity shipped, lot number, lot quantity, manufacturing date, and inventory balance. Account for all fixtures shipped from each lot, even if not for Department use. Email or fax tracking information to TRF within 2 weeks of shipments to projects. Failure to provide this information will result in removal from the MPL.

Make available to Department inspectors all manufacturing facilities involved in the production of fixtures for use on Department projects, inventories of fixtures produced to Department specifications, and records of fixture testing and tracking.

11011.8. Material Requirements.

- A. General Requirements.** Provide LED luminaires listed to UL1598 and suitable for use in wet locations. Ensure that optical compartment meets IEC Standard 60529-IP66. Supply NRTL certification to verify listing.

Rate luminaire for operating at ambient temperature between -40 and 40°C.

Provide external label per ANSI C136.15.

Provide internal label per ANSI C136.22.

Do not place fuses in pole-mounted luminaires. Provide wall- or underpass-mounted luminaires with internal 10-amp, time-delay fuses and fuse holders.

Provide internal label or marking with date code of when fixture was manufactured.

Request approval from the Department before making any changes to construction, materials, or components in the luminaire. Do not make changes to the luminaire until approved by TRF.

- B. Housing.** Provide luminaire housing, lens frame, and door constructed from 96% copper-free aluminum. Provide for luminaire mounting to a 2-in. pipe arm, capable of adjustments $\pm 5^\circ$ from level. Meet ANSI 136.31, 3.0 G vibration requirements.

Equip luminaire with a three-prong ANSI C136.10 rotatable photocell receptacle and shorting cap.

Paint luminaires light gray with initial gloss in the range of 30–60% (semi-gloss) when installing on galvanized poles. For all other poles, paint luminaires to match the color of the pole as directed. Use a thermoset powder-coat paint system. For pre-qualification, document that the coating meets the following:

- Exceeds a rating of six per ASTM D 1654 after 1000 hr. of testing in accordance with ASTM B 117; and
- Exhibits no greater than 30% reduction of gloss per ASTM D 523, after 500 hr. of QUV testing at ASTM G 154 Cycle 6. Cycle 6 uses UVA-340.

Fabricate exposed hardware, nuts, bolts, washers, and metal parts from stainless steel or aluminum of adequate thickness as approved.

Attach a level indicator to the fixture housing. Ensure that indicator is sensitive to 1° changes in position at any point within 5° of the level position. Ensure that indicator is clearly visible from the ground up to a 50-ft. mounting height. Ensure that indication of level corresponds to level position of fixture.

Ensure weight of the luminaire is less than 60 lb. and the effective projected area is less than 1.6 sq. ft.

Provide a barrier-type terminal block secured to housing for power connection to luminaire in accordance with ANSI 136.14 and ANSI 136.37. Provide lugs with screws for wire sizes up to 6 AWG. Identify each terminal position.

Connect LED driver and other removable electronic components with plug-in connectors to allow replacement of parts in the field.

- C. LED Drivers.** Provide luminaire with replaceable LED driver that will operate at 120 V, 240 V, or 480 V line voltages as shown in the plans. For pre-qualification, provide summary of reliability testing performed for LED driver(s). Provide LED drivers meeting the following specifications:

- Rated case temperature suitable for operation in the luminaire at ambient temperature of -40 to $+40^\circ\text{C}$;
- Power factor (PF) of at least 0.90 at full input power at the specified voltage;
- Compliant with UL standard UL 1012 or UL 1310;
- Rated life expectancy of 100,000 hr. at rated operating temperature inside the luminaire;
- Reduced output power to LEDs if maximum allowable case temperature is exceeded;

- Tolerates sustained open circuit and short circuit output conditions without damage; and
- Potted or rated IP 66 if exposed to the environment.

D. LED Optical Assembly. Provide LED optical assembly with nominal color temperature of 4000K. For verification testing, CCT within the range of 3710K–4260K is allowable.

Provide LED optical assembly with a minimum CRI of 70.

Provide a passive thermal management system. Do not use fans or other mechanical cooling systems.

E. Surge Protective Devices. Provide luminaire with a surge protective device (SPD), in addition to driver's internal protection, to withstand repetitive noise transients from utility line switching, nearby lightning strikes, and other interference. Provide SPD that will protect the luminaire from common mode transient peak voltages up to 10 kV (minimum) and transient peak currents up to 10 kA (minimum). Provide SPD tested in accordance with ANSI/IEEE C62.45 per ANSI/IEEE C62.41.2 Scenario I Location Category C-High for Line-Ground, Line-Neutral, and Neutral-Ground. Provide SPD listed or recognized by a NRTL to UL 1449, 3rd edition. For pre-qualification, test luminaires at a test lab accredited by American Association for Laboratory Accreditation (A2LA) for Electrical Fast Transient (EFT) and Surge Immunity. Provide test reports for 240 V and 480 V luminaires, showing the fixture can survive the following tests.

1. Testing. Perform Electrical Immunity Tests 1, 2 and 3, as defined by their Test Specifications, on an entire powered and connected luminaire, including any control modules housed within the luminaire but excluding any control modules mounted externally, such as a NEMA socket connected photo-control. Place a shorting cap across any such exterior connector.

Connect the luminaire to an AC power source with a configuration appropriate for nominal operation. The AC power source must have a minimum available short-circuit current of 200 A. Test the luminaire at the manufacturer-specified nominal input voltage or at the highest input voltage in the input voltage range.

Superimpose electrical immunity test waveforms on the input AC power line at a point within 6 in. (15 cm) of entry into the luminaire using appropriate high-voltage probes and a series coupler/decoupler network (CDN) appropriate for each coupling mode, as defined by ANSI/IEEE C62.45-2002. The test area for all tests must be in accordance with ANSI/IEEE C62.45-2002, as appropriate.

Prior to electrical immunity testing, perform a set of diagnostic measurements, and record the results to note the pre-test function of the luminaire after it has reached thermal equilibrium. These measurements should include at a minimum:

- For all luminaires, Real Power, Input RMS Current, Power Factor, and THD at full power/light output; and
- For luminaires specified as dimmable, Real Power, Input RMS Current, Power Factor, and THD at a minimum of 4 additional dimmed levels, including the rated minimum dimmed level.

Apply tests in sequential order (Test 1, followed by Test 2, followed by Test 3). If a failure occurs during Test 3, then re-apply Test 3 to a secondary luminaire of identical construction.

Following the completion of Tests 1, 2, and 3, repeat the same set of diagnostic measurements performed pre-test for all tested luminaires, and record the results to note the post-test function of the luminaire(s).

A luminaire must function normally and show no evidence of failure following the completion of Tests 1, 2, and 3 (for a single tested luminaire), or the completion of Tests 1 and 2 on a primary luminaire and Test 3 on a secondary luminaire. Abnormal behavior during testing is acceptable.

Following the completion of testing, the existence of any of the conditions listed below constitutes a luminaire failure.

- A hard power reset is required to return to normal operation;
- A noticeable reduction in full light output is observed (e.g., one or more LEDs fails to produce light or becomes unstable);
- Any of the post-test diagnostic measurements exceeds by $\pm 10\%$ the corresponding pre-test diagnostic measurement; and
- The luminaire or any component in the luminaire (including but not limited to an electrical connector, a driver, a protection component, or module) has ignited or shows evidence of melting or other heat-induced damage. Evidence of cracking, splitting, rupturing, or smoke damage on any component is acceptable.

2. Test Specifications.

NOTE: L1 is typically “HOT”, L2 is typically “NEUTRAL” and PE = Protective Earth.

- a. Test 1—Ring Wave.** Subject the luminaire to repetitive strikes of a “C Low Ring Wave” as defined in IEEE C62.41.2-2002, Scenario 1, Location Category C. Apply the test strikes as specified in Table 1. Prior to testing, calibrate the ring wave generator to simultaneously meet both the specified short circuit current peak and open circuit voltage peak minimum requirements. Note that this may require raising the generator charging voltage above the specified level to obtain the specified current peak. Use calibrated current probes/transformers designed for measuring high-frequency currents to measure test waveform currents.

Compare test waveform current shapes and peaks for all strikes to ensure uniformity throughout each set of test strikes (coupling mode and polarity/phase angle), and calculate and record the average peak current. If any individual peak current in a set exceeds the average by $\pm 10\%$, check the test setup and repeat the test strikes.

Table 1
0.5 μ S–100kHz Ring Wave Specification

Parameter	Test Level/Configuration
Short Circuit Current Peak	0.5 kA
Open Circuit Voltage Peak	6 kV
Source Impedance	12 Ω
Coupling Modes	L1 to PE, L2 to PE, L1 to L2
Polarity and Phase Angle	Positive at 90° and Negative at 270°
Test Strikes	5 for each Coupling Mode and Polarity/Phase Angle combination
Time between Strikes	1 minute
Total Number of Strikes	= 5 strikes \times 3 coupling modes \times 2 polarity/phase angles = 30 total strikes

- b. Test 2—Combination Wave.** Subject the luminaire to repetitive strikes of a “C High Combination Wave” as defined in IEEE C62.41.2-2002, Scenario 1, Location Category C. Apply the test strikes as specified in Table 2. Prior to testing, calibrate the combination wave generator to simultaneously meet both the specified short circuit current peak and open circuit voltage peak minimum requirements. Note that this may require raising the generator charging voltage above the specified level to obtain the specified current peak. Use calibrated current probes/transformers designed for measuring high-frequency currents to measure test waveform currents.

Compare test waveform current shapes and peaks for all strikes to ensure uniformity throughout each set of test strikes (coupling mode and polarity/phase angle), and calculate and record the average peak current. If any individual peak current in a set exceeds the average by $\pm 10\%$, check the test setup and repeat the test strikes.

Table 2
1.2/50 μ S–8/20 μ S Combination Wave Specification

Parameter	Test Level/ Configuration	
1.2/50 μ S Open Circuit Voltage Peak	Low: 6 kV	High: 10 kV
8/20 μ S Short Circuit Current Peak	Low: 3 kA	High: 10 kA
Source Impedance	2 Ω	
Coupling Modes	L1 to PE, L2 to PE, L1 to L2	
Polarity and Phase Angle	Positive at 90° and Negative at 270°	
Test Strikes	5 for each Coupling Mode and Polarity/Phase Angle combination	
Time Between Strikes	1 minute	
Total Number of Strikes	= 5 strikes \times 3 coupling modes \times 2 polarity/phase angles = 30 total strikes	

- c. Test 3—Electrical Fast Transient (EFT).** Subject the luminaire to “Electrical Fast Transient Bursts,” as defined in IEEE C62.41.2 -2002. The test area must be in accordance with IEEE C62.45-2002. Apply the bursts as specified in Table 3. Direct coupling is required; the use of a coupling clamp is not allowed.

Table 3
Electrical Fast Transient (EFT) Specification

Parameter	Test Level/ Configuration
Open Circuit Voltage Peak	3 kV
Burst Repetition Rate	2.5 kHz
Burst Duration	15 mS
Burst Period	300 mS
Coupling Modes	L1 to PE, L2 to PE, L1 to L2
Polarity	Positive and Negative
Test Duration	1 minute for each Coupling Mode and Polarity combination
Total Test Duration	= 1 minute \times 3 coupling modes \times 2 polarities = 6 minutes

- F. Warranty.** The manufacturer will replace failed luminaires, when non-operable due to defect in material or workmanship, within ten years of installation with a luminaire that meets all specifications, delivered to the project location. Photocells are subject to the warranties of their respective manufacturers.

The warranty must cover maintained integrity and functionality of:

- Luminaire housing, wiring, and connections;
- LED light source(s)—negligible light output from more than 10% of the LED packages constitutes luminaire failure; and
- LED driver(s).

The warranty period will begin 90 days after date of manufacture as shown on internal label, or as negotiated by owner such as in the case of an auditable asset management system.

Provide documentation of warranty service procedures, including forms, manufacturer contact information, and shipping addresses.

G. Calculation of Light Loss Factor (LLF). For pre-qualification, submit calculations per IES TM-21 predicting lumen maintenance at the luminaire level using In Situ Temperature Measurement Testing (ISTMT) and LM-80 data. Meet all of the conditions below.

- The LED light source(s) have been tested according to LM-80. Provide verification from the LED or luminaire manufacturer that the LM-80 report corresponds to the LEDs in the luminaire being tested.
- The LED drive current specified by the luminaire manufacturer is less than or equal to the appropriate drive current specified in the LM-80 test report.
- The LED light source(s) manufacturer prescribes/indicates a temperature measurement point (T_s) on the light source(s).
- For the hottest LED light source in the luminaire, the temperature measured at the T_s during ISTMT is less than or equal to the appropriate temperature specified in the LM-80 test report for the corresponding drive current or higher, within the manufacturer's specified operating current range.

The ISTMT laboratory must meet at least one of the following requirements:

- Be approved by OSHA as a Nationally Recognized Testing Laboratory (NRTL) or recognized as a participant in UL's Client Data Test Program;
- Be approved through an OSHA NRTL data acceptance program or OSHA Satellite Notification and Acceptance Program (SNAP); or
- Be accredited for ANSI/UL 1598 or CSA C22.2 No. 250.0-08, including Sections 19.7 and 19.10–16, by an accreditation organization that is an ILAC-MRA Signatory.

Conduct the ISTMT using the same configuration of luminaires submitted, or another luminaire from the same product family having:

- The same or lower nominal CCT;
- The same or higher nominal drive current;
- The same or greater number of LED light source(s);
- The same or lower percentage driver loading and efficiency; and
- The same or smaller size luminaire housing.

Install luminaire as defined by ANSI/UL 1598 (hardwired luminaires).

Include in the ISTMT report:

- Photos of thermocouple locations and luminaire in testing position;
- Ambient test temperature;

- LED temperature;
- Maximum LED current; and
- Full description of luminaire used in test.

Calculate LLF for each fixture configuration using the submitted ISTMT data, LM-80 data, and Energy Star TM-21 calculator.

- Provide documentation of in situ temperature at 25°C ambient for the luminaire rating submitted for approval;
- Calculate the lumen depreciation at 70,000 hr. at the documented in situ temperature at 25°C ambient using the Energy Star TM-21 calculator;
- $LLF = \text{Manufacturer's documented lamp lumen depreciation (LLD) factor per TM-21 calculations at 25°C at 70,000 hr.} \times 0.90 \text{ Luminaire Dirt Depreciation}$; and
- Total light loss factor is not to exceed 30% system depreciation (0.70) over 70,000 hr.

Calculated LLF will be used for design purposes and to determine if luminaire meets the performance specification.

H. Performance Requirements. For each type of luminaire specified, submit a photometric file in LM-63 format (i.e., filename.ies) and test report of the luminaire generated from LM-79 tests of an actual luminaire in a NVLAP-accredited test lab. Document that the luminaire was tested according to IES LM-79. The Department will verify the performance of the luminaire in a computer simulation using the following criteria in AGI32 Roadway Optimizer.

1. Underpass/150 Watt HPS (High-Pressure Sodium) Equivalent.

a. Layout.

- LLF as calculated in Section 11011.8.G;
- Fixtures mounted level perpendicular to the roadway at 16-ft. mounting height, on both sides of the roadway directly opposite from each other;
- Fixtures spaced at 90 ft.;
- Setback 10 ft. from outside edges of main lanes; and
- Grid points spaced according to IESNA RP-8 for a roadway with four 12-ft. lanes.

b. Test Criteria for Passing.

- Minimum > 0.35 footcandle;
- Average > 1.10 footcandle;
- Average/minimum ratio < 3.0:1; and
- IESNA TM-15-11 BUG rating with an Uplight value of U0.

2. 250 Watt HPS Equivalent.**a. Layout.**

- LLF as calculated in Section 11011.8.G;
- Fixtures mounted level perpendicular to the roadway at 40-ft. mounting height with 8-ft. arms, on one side of the roadway;
- Fixtures spaced at 220 ft.;
- Setback 15 ft. from outside edges of main lanes;
- Grid points spaced according to IESNA RP-8 for a roadway with three 12-ft. lanes.

b. Test Criteria for Passing.

- Minimum > 0.20 footcandle;
- Average > 0.60 footcandle;
- Average/minimum ratio < 3.0:1;
- IESNA TM-15-11 BUG rating with an Uplight value of U0.

3. 400 Watt HPS Equivalent:**a. Layout.**

- LLF as calculated in Section 11011.8.G;
- Fixtures mounted level perpendicular to the roadway at 50-ft. mounting height with 8-ft. arms, on one side of the roadway;
- Fixtures spaced at 270 ft.;
- Setback 15 ft. from outside edges of main lanes;
- Grid points spaced according to IESNA RP-8 for a roadway with four 12-ft. lanes.

b. Test Criteria for Passing.

- Minimum > 0.20 footcandle;
- Average > 0.60 footcandle;
- Average/minimum ratio < 3.0:1;
- IESNA TM-15-11 BUG rating with an Uplight value of U0.