ROAD SURFACE'S REFLECTANCE INFLUENCES LIGHTING DESIGN

Lighting standard can be met with smaller investment

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The latest American National Standards Institute publication RP-8 entitled *American Standard Practice for Roadway Lighting*[1] recognizes the significant contribution of road-surface reflectance to the performance of the roadway lighting system. The RP-8 brings the North American practice into close alignment with the publications[2] of the International Commission on Illumination (CIE) which has for some time emphasized the importance of pavement reflectance in determining lighting system performance. This means that the pavement surface in effect becomes part of the lighting system. High-reflectance pavements require less illumination than low-reflectance surfaces. It is analogous to painting the ceilings white or black in an uplighted room. The higher reflectance white surface will require less generated light to provide the same room lighting level as the black-surfaced room.

The current standard for Roadway Lighting allows for two methods of designing roadway lighting: (1) the illuminance method and (2) the luminance method.

The illuminance method was the only recommended method used in North America until 1983. This method requires the calculation of the amount of light falling on the pavement surface—the horizontal illuminance. This is not the light the driver sees, but is the incident pavement illuminance.

The new standard allows for the illuminance concept to be used when pavement reflectance is taken into consideration. Four classes (R1, R2, R3, and R4) of pavement materials have been designated (**Table 1**) and lighting levels for each are shown in **Table 2(b)**. Two of the pavement types are commonly used in the United States, R1 and R3. The R1 pavement is the standard PCC pavement and the R3 pavement is the asphalt road surface. It can be seen from **Table 2(b)** that illuminance values for the R3 pavement classification are higher than those for R1. This is due to the difference in pavement reflection characteristic of the two surfaces. Values range from between a 33–50-percent increase in illuminance levels for the R3 pavement over the R1 classification.

The luminance method which is now the preferred method is a measure of the reflected light observed by the driver, and since reflected light depends on a

Table 1. Road surface classifications.

Class	Q_o	Description	Mode of Reflectance
R1	0.10	Portland cement concrete road surface. Asphalt road surface with a minimum of 15 percent of the aggregates composed of artificial brightener (*e.g.*, Synopal) aggregates (*e.g.*, labradorite, quartzite).	Mostly diffuse
R2	0.07	Asphalt road surface with an aggregate composed of a minimum 60 percent gravel (size greater than 10 milimeters). Asphalt road surface with 10 to 15 percent artificial brightener in aggregate mix. (Not normally used in North America.)	Mixed (diffuse and specular)
R3	0.07	Asphalt road surface (regular and carpet seal) with dark aggregates (*e.g.*, trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly specular
R4	0.08	Asphalt road surface with very smooth texture.	Mostly specular

Note: Q_o = representative mean luminance coefficient.

reflecting surface, the road surface now becomes part of the lighting design.

A great deal of study has gone into determining the reflection factors of various types of pavements and studies continue in this area. There are, of course, a wide variety of pavement reflection coefficients. A large number of these have been plotted, and four divisions of pavement reflection factors have been designated to cover the major types of pavements. A table of reflection coefficients for the various angles involved has been developed for each of the four pavement classifications, R1, R2, R3, and R4. In the calculation of luminance one of the four tables is selected to provide the values of the reduced luminance coefficient. Values found in the R tables for the various angles are then placed in the luminance formula. Higher luminance values are obtained generally by using the R1 table.

What does all this mean in terms of lighting system design? It means that the same lighting standard can be met with a smaller investment in equipment and wattage resulting in a lower initial investment and less energy and maintenance costs when using the R1 (PCC) pavement.

Application of the ANSI standard RP-8 in terms of roadway lighting design can be made under either the illuminance or luminance system. Once the design method has been selected and the roadway and area classification has been determined, illuminance and luminance levels can be found in **Table 2** for each type of roadway.

If the illuminance method is selected, the lighting level for a major road in commercial area with an R1-type pavement classification is 12 lx (1.1 fc). Should the pavement classification be R3, the lighting level would be 17 lx (1.6 fc). The R3-type of pavement will require 41.7 percent more illuminance than the R1-type of pavement for the same type of roadway. A collector road in an intermediate area requires 6 lx (0.56 fc) for an R1 pavement and 9 lx (0.84 fc for an R3 pavement, a 50 percent increase in desired illuminance.

Two other examples are the freeway Class B and the local residential street. A Class B freeway requires 4 lx (0.37 fc) for a type R1 pavement classification and 6 lx (0.56 fc) for a type R3 classification of pavement or a 50-percent increase in required illuminance. The local residential street requires 3 lx (.28 fc) for the R1-type of pavement versus 4 lx (.37 fc) for the R3 pavement or a 33-percent increase in required illuminance. Similar results would be obtained using the luminance system.

Selecting as an application of this method, a major road in a commercial area, **Table 2(a)** requires 1.2 cd/m^2 average luminance. A comparison can than be made of the acquired spacing of luminaires using either R1 or R3 pavement classification. The results using a computer program based on the ANSI practice will depend on the road and lighting geometry, but will in general indicate a greater number of lighting fixtures per unit length of roadway for the R3 pavement classification.

Examples of the various types of installations give a clearer picture of the differences involved. As previously indicated, a major road in a commercial area with an R1 pavement classification requires 12 lx (1.1 fc). This can be translated into a complete design when certain road geometries and lighting equipment parameters are known. Assume a 50-ft pavement width with fixtures mounted on poles at a 40-ft height and bracketed out over the pavement at a distance of 6 ft. See **[1]** Also select a 250-W high pressure sodium lighting fixture or luminaire to provide the light. A layout such as this, using a maintenance factor of 0.75 and a coefficient of utilization of .52 will result in a pole spacing of 195 ft with an R1 pavement.

Using the R3 pavement, the system must now produce 17 lx (1.6 fc) resulting in a pole spacing of 135

Table 2. Recommended maintained luminance and illuminance values for roadways

(a) Maintained luminance values

Road and Area Classification		Average Luminance L_{avg} (cd/m²)	Luminance Uniformity L_{avg} to L_{min}	Luminance Uniformity L_{max} to L_{min}	Veiling Luminance Ratio (maximum) L_v to L_{avg}
Freeway Class A		0.6	3.5 to 1	6 to 1	0.3 to 1
Freeway Class B		0.4	3.5 to 1	6 to 1	0.3 to 1
Expressway	Commercial	1.0	3 to 1	5 to 1	0.3 to 1
	Intermediate	0.8	3 to 1	5 to 1	
	Residential	0.6	3.5 to 1	6 to 1	
Major	Commercial	1.2	3 to 1	5 to 1	0.3 to 1
	Intermediate	0.9	3 to 1	5 to 1	
	Residential	0.6	3.5 to 1	6 to 1	
Collector	Commercial	0.8	3 to 1	5 to 1	0.4 to 1
	Intermediate	0.6	3.5 to 1	6 to 1	
	Residential	0.4	4 to 1	8 to 1	
Local	Commercial	0.6	6 to 1	10 to 1	0.4 to 1
	Intermediate	0.5	6 to 1	10 to 1	
	Residential	0.3	6 to 1	10 to 1	

(b) Average maintained illuminance values (E_{avg}) in lux

Road and Area Classification		Pavement Classification R1	R2 and R3	R4	Illuminance Uniformity Ratio (E_{avg} to E_{min})
Freeway Class A		6	9	8	3 to 1
Freeway Class B		4	6	5	
Expressway	Commercial	10	14	13	3 to 1
	Intermediate	8	12	10	
	Residential	6	9	8	
Major	Commercial	12	17	15	3 to 1
	Intermediate	9	13	11	
	Residential	6	9	8	
Collector	Commercial	8	12	10	4 to 1
	Intermediate	6	9	8	
	Residential	4	6	5	
Local	Commercial	6	9	8	6 to 1
	Intermediate	5	7	6	
	Residential	3	4	4	

Notes

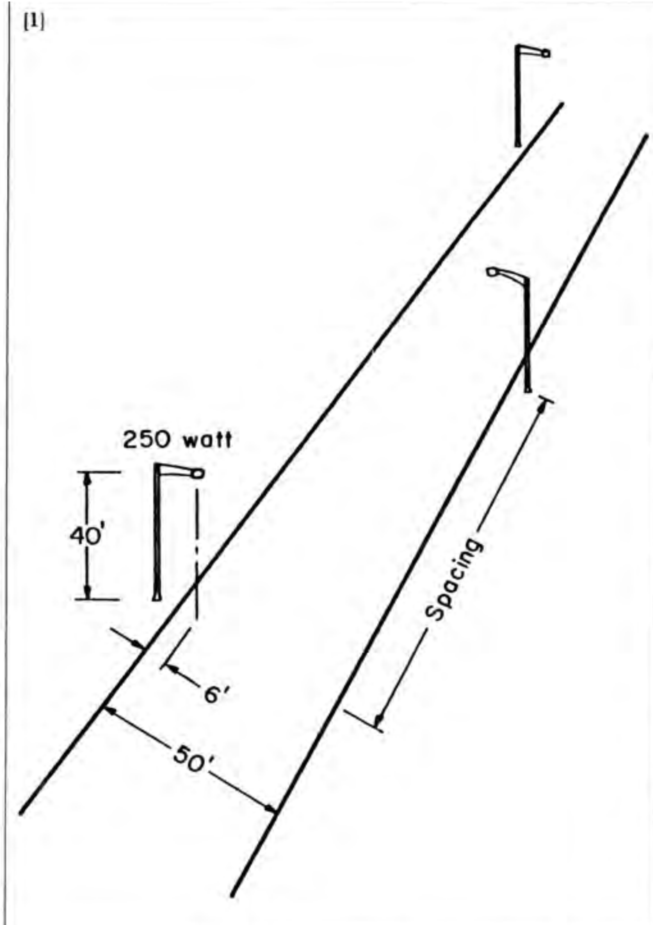
L_v = veiling luminance

1. These tables do not apply to high mast interchange lighting systems, *e.g.*, mounting heights over 20 meters. See Appendix B5.
2. The relationship between individual and respective luminance and illuminance values is derived from general conditions for dry paving and straight road sections. This relationship does not apply to averages.
3. For divided highways, where the lighting on one roadway may differ from that on the other, calculations should be made on each roadway independently.
4. For freeways, the recommended values apply to both mainline and ramp roadways.
5. The recommended values shown are meaningful only when designed in conjunction with other elements. The most critical elements as described in this practice are: (RP-8-IES)
   - **(a)** Lighting System Depreciation (see paragraph 3.7)
   - **(b)** Quality (see paragraph 3.2)
   - **(c)** Uniformity (see paragraph 3.3)
   - **(d)** Luminaire Mounting Height (see paragraph 3.4)
   - **(e)** Luminaire Spacing (see paragraph 3.5)
   - **(f)** Luminaire Selection (see paragraph 3.6)
   - **(g)** Traffic Conflict Area (see paragraph 3.8)
   - **(h)** Lighting Termination (see paragraph 3.10)
   - **(i)** Alley (see paragraph 3.11)
   - **(j)** Roadway Lighting Layout (see paragraph 3.12)

ft. On a per-mile basis the R1 pavement system will require 27 pole-mounted fixtures and the R3 system will require 39 pole-mounted fixtures—a difference of 12 lighting units per mile. Both of these systems will meet the average illuminance requirements of the standard and both will comply with the uniformity levels required by the standard: in this case a ratio of average to minimum illuminance of 3:1 or lower.

A second example would consider a freeway Class A. Assume a 48-ft pavement with luminaires mounted at 50 ft, 10 ft behind the edge of the pavement and using a 250-W high pressure sodium light source with a coefficient of utilization of 0.32 and a maintenance factor of 0.75. The lighting unit spacing for an R1 pavement classification to produce 6 lx (.56 fc) would be 245 ft requiring 22 units per mile. Spacing of lighting units with an R3 pavement would be 163 ft to produce 9 lx (.84 fc) and require 32 units per mile. Again, both systems exceed the uniformity requirements of the standard.

[1]



Cost comparisons for these examples depend, of course, on the labor and material charges which vary widely depending on the locality involved and other factors. Designs of lighting installations vary as to type of material used for poles, mounting height, construction methods for foundations, luminaire type, *etc.* Estimates of cost and bids vary because of these factors. Selection of a cost per unit then becomes arbitrary, but can be useful in evaluations.

A price of $2,000 per lighting unit (pole, concrete foundation, luminaire, pole wire, lamp, erection, and testing) is a figure that can be used for comparison between systems where pavement reflectances differ. The above examples would produce the following results.:

Initial Cost–Example No. 1 Major road in a Commercial Area. R3 pavement (Asphalt) 39 lighting units per mile ¼ $2,000/unit = $78,000/mile R1 pavement (PCC) 27 lighting units per mile @ $2,000/unit = $54,000/mile Initial Cost Difference = $24,000/mile

Initial Cost–Example No. 2 Freeway Class A R3 pavement (Asphalt) 32 lighting units per mile @ $2,000/unit = $64,000/mile R1 pavement (P.C.C.) 22 lighting units per mile @ $2,000/unit = $44,000/mile Initial Cost Difference = $20,000/mile

Some current costs of freeway lighting are running as high as $5,000 per unit. Where these higher unit costs exist there is a substantial difference in unit costs depending on the reflectance of the pavement.

The initial or construction costs are but one part of the road lighting costs. Where initial costs end, maintenance and energy costs begin. Just as initial costs vary according to locality so do energy and maintenance costs. Some assumptions, therefore, need to be made. These should be adjusted for the particular local areas of concern.

Current energy charges are in the vicinity of 5 cents per kWh in one particular area. Applying this to example No. 1 we have the following:

Energy Cost Example No. 1 Major Road in a Commercial Area. R3 pavement (Asphalt) 39 ltg. units 4,000 hrs/yr @ $0.05 kWh 250 W = $1,950/mile/yr R1 pavement (PCC) 27 ltg. units 4,000 hrs/yr @ 0.05 kWh 250 W = $1,350/mile/yr Energy Cost Difference = $600/mile/yr

Energy Cost Example No. 2 Freeway Class A R3 pavement (Asphalt) 32 ltg. units 4,000 hrs/yr @ $0.05 kWh 250 W = $1,600/mile/yr R1 pavement (PCC) 22 ltg. units 4,000 hrs/yr @ $0.50 kWh 250 W = $1,100/mile/yr Energy Cost Difference = $500/mile/yr

The maintenance cost of the lighting system should also be considered. Maintenence is carried out by a variety of different maintainers ranging from government or utility employees to various owners and private contractors. Prices vary widely since even the level of maintenance differs. Selecting a price of $4 per lighting unit per month will allow for lamp replacement, luminaire cleaning, and pole and circuit maintenance.

This figure can then be applied to Example No. 1 as follows:

Maintenance Cost Example No. 1 Major Road in a Commercial Area R3 pavement (Asphalt) 39 lighting units @ $4/mo x 12 = $1,872/mile/yr R1 pavement (P.C.C.) 27 lighting units @ $4/mo x 12 = $1,296/mile/yr Maintenance Cost Difference = $576/mile/yr

Freeway maintenance costs would be significantly higher due to traffic control problems when servicing lighting units. A suggested figure would be $6 per month per unit.

Maintenance Cost Example No.2 Freeway Class A R3 pavement (Asphalt) 32 lighting units @ $6/mo x 12 = $2,304/mile/yr R1 pavement (PCC) 22 lighting units @ $6/mo x 12 = $1,584/mile/yr Maintenance Cost Difference = $720/mile/yr

The combined difference due to different pavement reflectances for annual energy and maintenance is as follows: Example No. 1—$1,176 per mile per year Example No. 2—$1,220 per mile per year

The cost comparisons clearly indicate the economical advantages of the high reflectance pavement. No attempt has been made to compute the interest costs involved with these savings due again to the wide variation of these figures in today's market.

The purpose of this article is to emphasize only one aspect of pavement differences; surface reflectance as it relates to the current American National Standard Practice for Roadway Lighting. Those involved with the decisions on what type of pavement will be used on roadways where lighting systems will be installed should be aware of the total economics associated with the picture.

References

1. *American National Standard Practice for Roadway Lighting*, ANSI/IES RP-8, 1983, Illuminating Engineering Society of North America, 1983.
2. *Calculation and Measurement of Luminance and Illuminance in Road Lighting* (1976), CIE Publication No. 30 (Tc-4.6)
3. *Roadway Lighting Handbook* (addendum to Chapter 6), US Department of Transportation, September 1983.
4. *Road Lighting*, Philips Technical Library, 1980.

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