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Influence of Pavement Reflectance on Lighting for Parking Lots

by W. Adrian and R. Jobanputra

5420 Old Orchard Road
Skokie, Illinois 60077-1083
847.966.6200 Fax 847.966.9481

www.cement.org

KEYWORDS

asphalt, concrete, lighting, luminance, parking lots, reflectance, surfaces

ABSTRACT

The investigation on which this paper is based compared the lighting performance of concrete and asphalt surfaces. The total light reflected from pavement surfaces was documented by analyzing the results of a large number of samples taken from road pavements across North America. The reflection characteristics of the samples from both types of pavements were measured in a laboratory and the results indicate that concrete pavements reflect considerably more light than asphalt pavements. The essential quantity that appears as the brightness of an object is called luminance. Luminance is the intensity of brightness and is measured in candela per unit area of a surface. Higher luminance values are associated with brighter surfaces. The average luminance of concrete pavements was determined in the investigation to be 1.77 times that of asphalt pavements.

Lighting installations for parking lots were evaluated during the investigation. Typical light fixture patterns were used to compare the average luminance level and visibility levels for concrete and asphalt pavements. The amount of energy used for parking lot lighting systems was calculated for typical parking lot lighting layouts. Average concrete and asphalt pavement surfaces were compared in two ways: (1) by modifying the lamp power and (2) by reducing the number of light poles in order to achieve comparable luminance levels. It was determined that comparable luminance levels could be obtained with less energy when concrete pavement is used compared to when asphalt pavement is used. Asphalt parking lots use 57% more electrical energy than concrete parking lots. It also became evident that better uniformity of the luminance also could be achieved with concrete surfaces.

REFERENCE

Adrian, W. and Jabanputra, R., *Influence of Pavement Reflectance on Lighting for Parking Lots,* SN2458, Portland Cement Association, Skokie, Illinois, USA, 60077, 46 pages.

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Influence of Pavement Reflectance on Lighting for Parking Lots

W. Adrian and R. Jobanputra*

1. INTRODUCTION

Visual functions are dependent on the light level that allows for visibility and performance of visual tasks. When constructing a parking lot, lighting levels have to be taken into consideration. Low light levels in parking facilities will impair an individual's visual capacity, which can cause vehicular accidents, create difficulties locating cars, cause pedestrian's to slip or fall, and may even endanger the security of an individual[3]. The safety of individuals should be a high priority. For any parking lot owner, however, there is also a need to conserve (electrical) energy. With the trend toward saving energy while maintaining safe lighting, the pavement surface reflectivity of a parking lot can greatly influence luminance levels. Luminance is the light from the source that is reflected from the pavement toward the observer (motorist or pedestrian) and is measured in candela per meter squared (cd/m^2) on the pavement. Pavement reflectivity strongly influences the achievable luminance levels.

With regard to the pavement of parking lots, two types of surfaces, asphalt and concrete, are generally used. Concrete appears brighter than an asphalt surface, and the question arises whether this difference can be used for saving energy.

In this investigation, asphalt -and concrete-based surfaces on parking lots were compared in the following areas:

- Q_0 is the measure of total light reflected from a surface; a survey of the frequency distribution of the Q_0 of concrete- and asphalt-based pavement was conducted.
- The selective reflection characteristics of concrete- and asphalt-based surfaces were measured to allow for the determination of the spectral influence of the surface reflections and their interrelation with the spectral power distribution of the lamps used for lighting.
- In addition to luminance, another important criteria for parking lot lighting is the visibility level (VL), which is a measure of the timely detection of targets (objects) such as vehicles, pedestrians, etc. Calculations for both luminance and VL of a typical parking lot lighting system were performed for a comparison between concrete- and asphalt-based surfaces.
- For a typical parking lot lighting system, an analysis was performed to achieve equivalent luminance between the concrete- and asphalt-based surfaces by varying lamp wattage and the number of light poles used in the parking lot. This analysis reveals the difference in energy savings.

* Adrian, W., (President) and Jabanputra, R., Ortap Consulting and Research, 48-1 Allen St. West, Waterloo, Ontario, Canada, N2L 6H2, 519-570-7575.

2. INVESTIGATION OF Q_0 DISTRIBUTION

2.1 Explanation of q and Q_0

The reflection properties of a pavement surface (at a particular point) are defined by the luminance coefficient q, which is the ratio of luminance (L) to the horizontal illuminance (E_H) at a specific point on the pavement surface. High q values are associated with brighter (more reflective) surfaces. The luminance coefficient, q, is dependent on numerous variables: position of observer, light source relative to the point of interest on the pavement surface, nature of road surface material, etc. As shown in Figure 1, q is a function of α, β, γ, δ.[1] However, α (the observation angle from the horizontal) has been standardized to 1^o. Also, due to the isotropic (independent from the direction of illumination and observation) nature of most pavement surfaces, δ proves to be constant. This leaves q as function of β, γ. Therefore, it follows that:

$$q(\beta, \gamma = L / E_H$$

Equation 1: Luminance Coefficient

Q_0 is the reflected total light average in approximately a hemisphere. Therefore, the lightness (or level of whiteness or blackness) of a road surface is represented by Q_0. High Q_0 values are associated with brighter (more reflective) surfaces. The equation for Q_0 is:

$$Q_0 = \frac{\int \Omega_e \, q \cdot d\Omega}{\int \Omega_e \, d\Omega}$$

Equation 2: Formulation of Q_0

Equation 2 represents the light reflected from the pavement onto a solid angle. Ω_e is the solid angle defined by the integration boundaries which accord to the pertinent area on the road surface.

The significant difference between q and Q_0 is that q is measured at a specific point, while Q_0 is representative of the total average luminous reflection of a surface, into a hemisphere. For the purposes of this study, Q_0 is used.

[1] "Canadian Pavement Reflectance Characteristics," Roads and Transportation Association of Canada, 1984

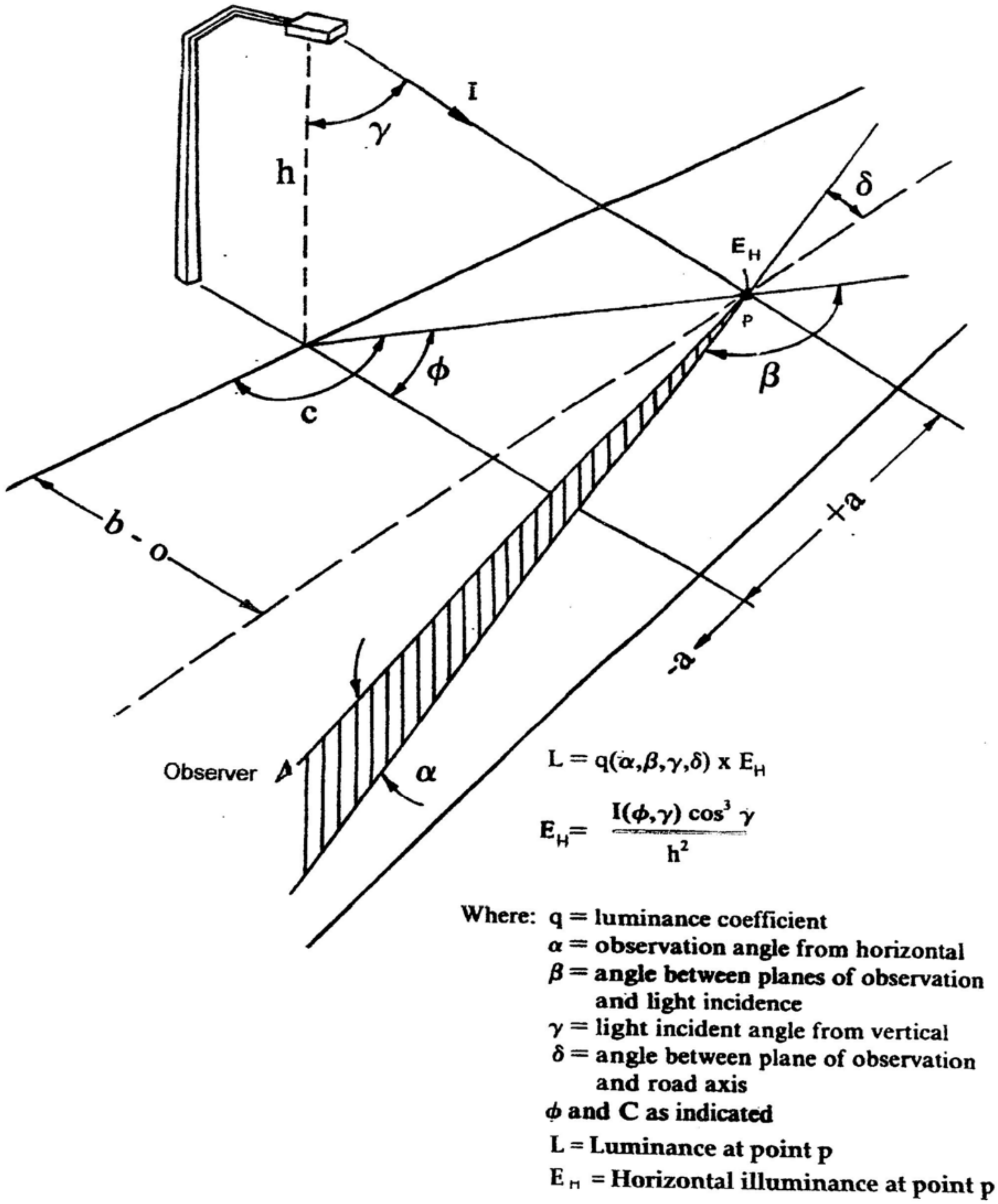


Figure 1. Geometry for luminance calculation.

2.2 Classes of Road Surfaces Based on Q_0

A pavement classification system, based on Q_0 and specularity (shininess) factors, was developed by the CIE (International Commission on Illumination). The measurements were done following the defined geometry as in Figure 1 with α always being 1˚. A collection of road surface classes R1, R2, R3, and R4 have been specified; all roadway pavement types fall within this classification and are specified as shown in Table 1. R1 to R4 are sequenced in specularity with R1 as the most diffuse one. R2 and R3 have the same Q_0 value but R3 has a higher specularity factor than R2.

Table 1. Classification of Road Surfaces Based on Q_0 (from ANSI RP-8)

Road Surface	Q_0 Value	Description of Road Surface
R1	0.10	Portland cement concrete
R2	0.07	Asphalt with a minimum of 60% gravel
R3	0.07	Asphalt with dark aggregate
R4	0.08	Asphalt with a very smooth texture

2.3 Q_0 Frequency Distribution

Using the catalogued reflective characteristics of a large sample of road surfaces used in North America[1], a Q_0 frequency distribution for asphalt and concrete was obtained as illustrated in Figure 2. This reflects the results of a survey of roads in North America, where only 5%-10% are found to be of concrete.

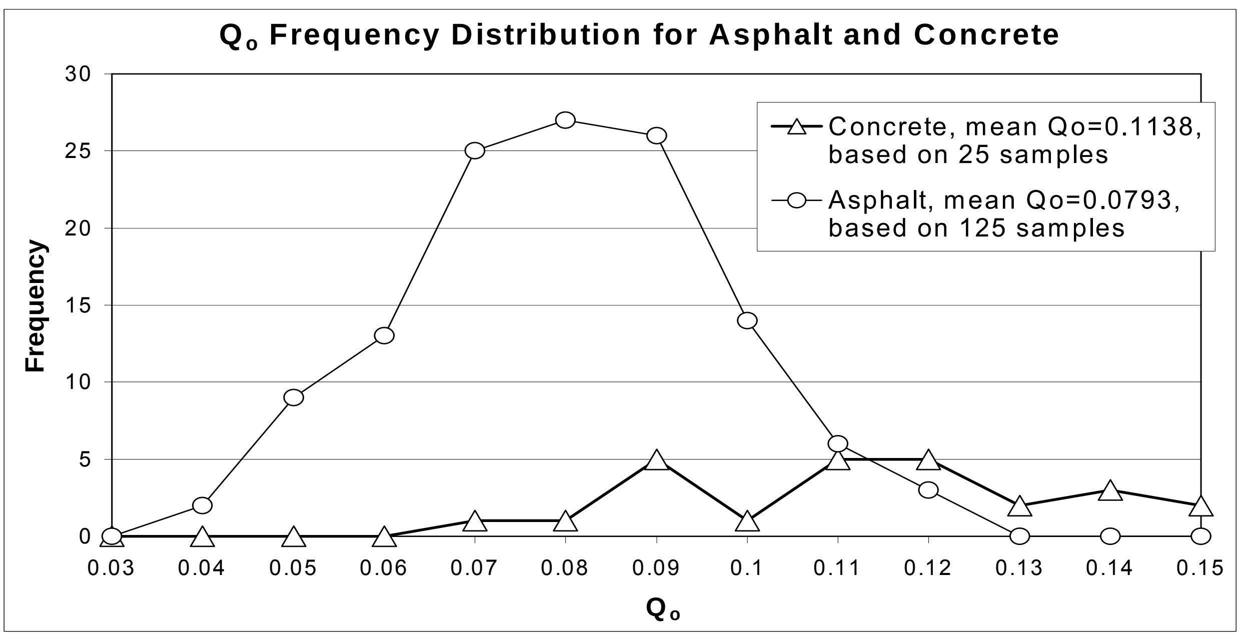


Figure 2. Q_0 Frequency distribution for asphalt and concrete.

For this investigation, 150 samples were cut out of actual roads in use. One hundred twenty-five samples were asphalt pavement and 25 samples were concrete. It should be noted that the samples of concrete surfaces are small compared with asphalt and are in the vicinity of 17% of the total number of samples.

Concrete proved to have a mean Q_0 frequency of 0.1138 with a standard deviation equal to 0.0216. This value of Q_0 is considerably higher than that of asphalt surfaces, which had a mean Q_0 frequency of 0.0793 with a standard deviation equal to 0.0164. This indicates that concrete provides a higher luminance than asphalt.

2.4 Q_0 Values for Different Aggregate Material

With respect to the value of Q_0, an investigation was performed to find if a dependency exists between Q_0 and aggregate material for varying coarse aggregate percentages. Pavements containing different coarse aggregate percentages are documented in Figure 3. Some aggregate materials show that Q_0 has a dependency upon the coarse aggregate percentage (e.g. quartzite). However, other materials do not exhibit this relationship (e.g. sandstone). Therefore, no conclusive evidence can be drawn to generalize the dependency of Q_0 on coarse aggregate percentage.

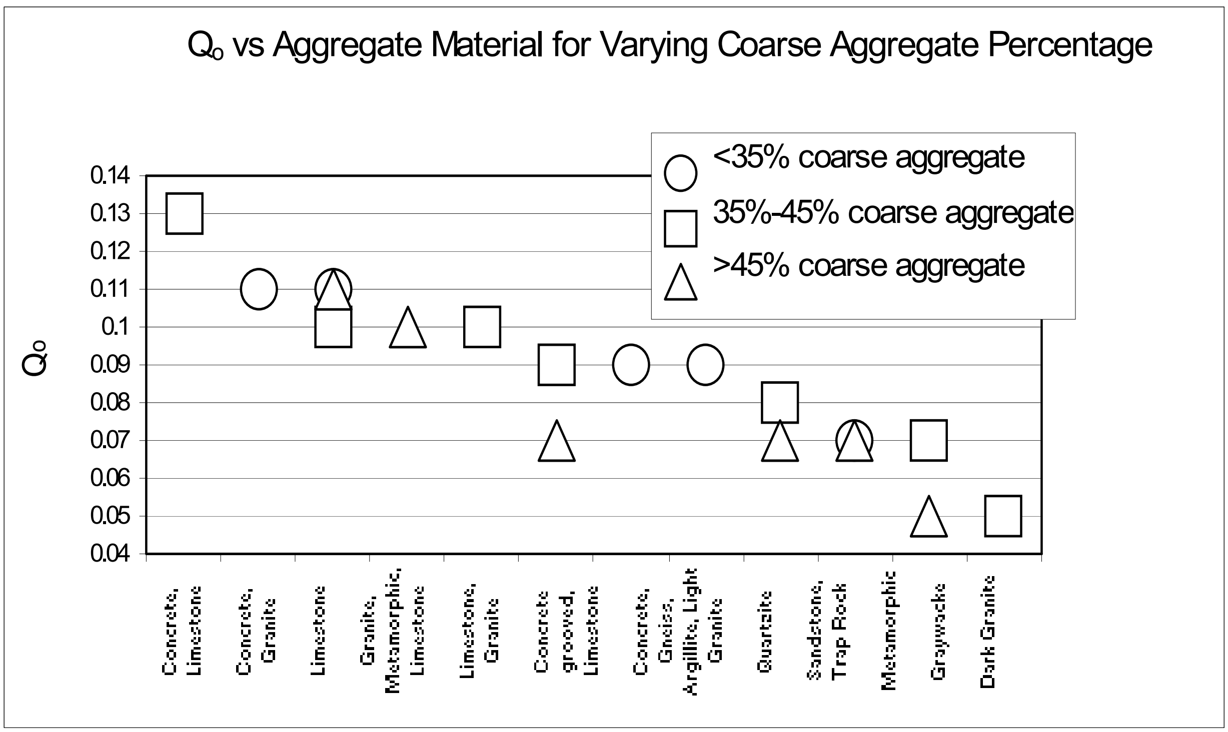


Figure 3. Q_0 vs. aggregate material for varying coarse aggregate percentage.

3. SPECTRAL REFLECTION CHARACTERISTICS

The selective reflection properties of concrete- and asphalt-based surfaces were measured to allow for the determination of the spectral influence of the surface reflections. These data can further be used to interpret their interrelation with the spectral power distribution of the lamps used for lighting.

3.1 Determining the Spectral Reflection

With regard to concrete and asphalt, it is evident that the reflectivity of concrete deteriorates over time (i.e., concrete darkens), while that of asphalt becomes more reflective (i.e., asphalt fades). In analyzing the spectral reflection properties, samples were used that would provide a more accurate interpretation of reflection properties. For this reason, the concrete and asphalt samples were obtained from a walkway and parking lot respectively in use for several years as illustrated in Appendix 1.

To obtain the spectral reflection properties of concrete and asphalt, samples were measured by means of the Zeiss DMR21 Spectral Photometer (as shown in Appendix 1) and the percentage of spectral reflection ranging from wavelength of 400nm to 690nm in 5nm intervals were measured and are displayed in Table 2 in 10nm intervals.

Due to the requirements of the Zeiss DMR21, the freshly cut side of the concrete sample was used for testing and, therefore, had a higher reflectance factor than the used surface of the sample. Using the Minolta Luminance Meter LS-110 (with a 1^0 field), the luminance of the freshly cut edge and the used surface were measured in the laboratory and it was determined that the newly cut edge was 1.82 more reflective than the used surface. Therefore, the concrete reflectance percentage was divided by this factor to compensate for the reflectance factor measurement on the freshly cut side. The reflectance factor of the asphalt sample was measured only on the used surface.

3.2 Analyzing Spectral Reflectance

As illustrated in Figure 4, concrete has a higher reflectance percentage by a factor of 2.34 than that of asphalt. It was observed for both pavement types that the reflectance decreased toward shorter wavelength but shows the same trend over the spectrum. This is presumably due to the fact that asphalt contains similar aggregates to those used in concrete. The results of the reflection measurements are given in Table 2.

With regard to spectral reflectance, it is necessary to determine the total of the reflected light. In order to obtain the total reflected light, the relative spectral reflection has to be multiplied by the V (λ) function (spectral sensitivity of the eye as illustrated in Appendix 2). This is depicted in Figure 5. The area under the total spectral reflectance curves (in Figure 5) represents the fraction of light, which is proportional to Q_0. The Q_0 values for the concrete and asphalt samples were 0.1863 and 0.0795, respectively.

Table 2. Relative Spectral Reflectance in 10nm Intervals of Wavelength

Wavelength(λ)	V(λ)	Concrete Refl(%)	**Concrete Refl(%)/1.82**	Asphalt Refl (%)	Total Concrete Refl (%)	Total Asphalt Refl (%)
400	4.50E-04	0.230	0.121	0.016	5.44E-05	7.05E-06
410	1.50E-03	0.235	0.124	0.016	1.86E-04	2.41E-05
420	5.00E-03	0.243	0.128	0.017	6.40E-04	8.73E-05
430	1.24E-02	0.251	0.132	0.023	1.64E-03	2.81E-04
440	2.50E-02	0.261	0.137	0.028	3.43E-03	6.90E-04
450	4.10E-02	0.267	0.140	0.033	5.76E-03	1.34E-03
460	6.40E-02	0.276	0.145	0.038	9.28E-03	2.40E-03
470	1.00E-01	0.283	0.149	0.041	1.49E-02	4.14E-03
480	1.50E-01	0.288	0.151	0.045	2.27E-02	6.72E-03
490	2.35E-01	0.293	0.154	0.048	3.62E-02	1.12E-02
500	3.50E-01	0.300	0.158	0.052	5.52E-02	1.82E-02
510	5.10E-01	0.306	0.161	0.055	8.21E-02	2.82E-02
520	7.40E-01	0.310	0.163	0.059	1.21E-01	4.36E-02
530	8.70E-01	0.318	0.167	0.064	1.45E-01	5.53E-02
540	9.60E-01	0.325	0.171	0.068	1.64E-01	6.53E-02
550	9.95E-01	0.331	0.174	0.073	1.73E-01	7.24E-02
560	9.90E-01	0.336	0.177	0.077	1.75E-01	7.66E-02
570	9.45E-01	0.342	0.180	0.081	1.70E-01	7.67E-02
580	8.50E-01	0.346	0.182	0.084	1.55E-01	7.12E-02
590	7.40E-01	0.350	0.184	0.087	1.36E-01	6.44E-02
600	6.15E-01	0.354	0.186	0.090	1.14E-01	5.56E-02
610	4.85E-01	0.357	0.188	0.093	9.10E-02	4.51E-02
620	3.63E-01	0.362	0.190	0.096	6.91E-02	3.47E-02
630	2.45E-01	0.363	0.191	0.098	4.68E-02	2.39E-02
640	1.60E-01	0.366	0.192	0.101	3.08E-02	1.62E-02
650	9.70E-02	0.368	0.194	0.103	1.88E-02	1.00E-02
660	5.75E-02	0.370	0.195	0.104	1.12E-02	6.00E-03
670	3.00E-02	0.372	0.196	0.107	5.87E-03	3.22E-03
680	1.52E-02	0.373	0.196	0.109	2.98E-03	1.66E-03
690	7.50E-03	0.375	0.197	0.110	1.48E-03	8.25E-04

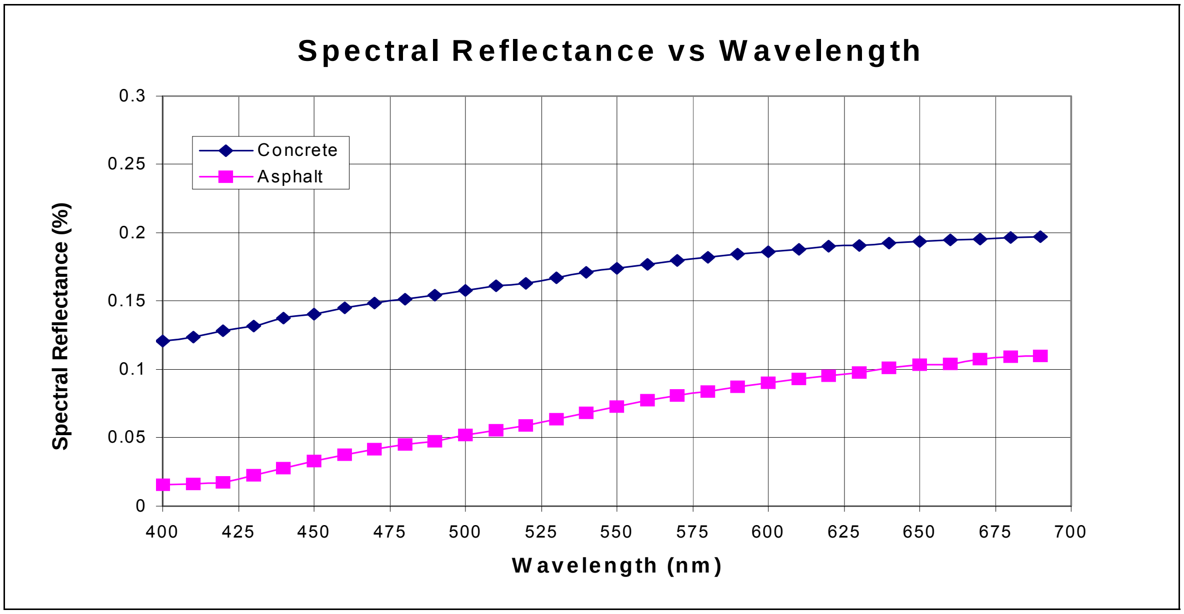


Figure 4. Spectral reflectance vs. wavelength for concrete and asphalt.

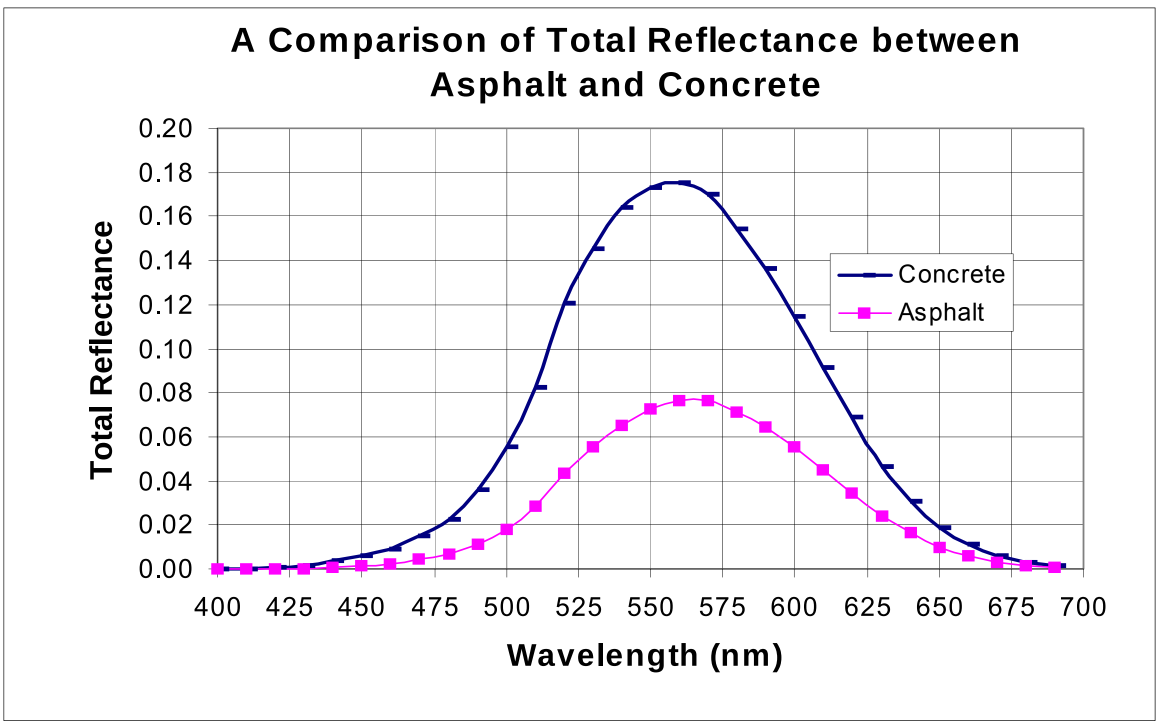


Figure 5. A comparison of total reflectance between asphalt and concrete.

3.3 Selection of Lamp Type Based on Spectral Reflectance

The influence of the spectral reflectance of pavement has a great significance when selecting lamps. The measured spectral reflection showed the same trend in concrete as well as in asphalt with a difference that the Q_0 of concrete was found to be 2.34 times higher than that of asphalt. From the results depicted in Figure 4, it is evident that High Pressure Sodium (HPS) would be more effective in lighting than Metal Halide (MH), since HPS contains more light in longer wavelength of the spectrum than Metal Halide which emits more light in the short wavelengths range (blue).

4. CALCULATIONS FOR A TYPICAL PARKING LOT LIGHTING SYSTEM

For specific lighting installations for parking lots, a typical light distribution of the luminaires was used to compare the average background luminance level (L_B) and visibility level (VL) for concrete and asphalt pavements.

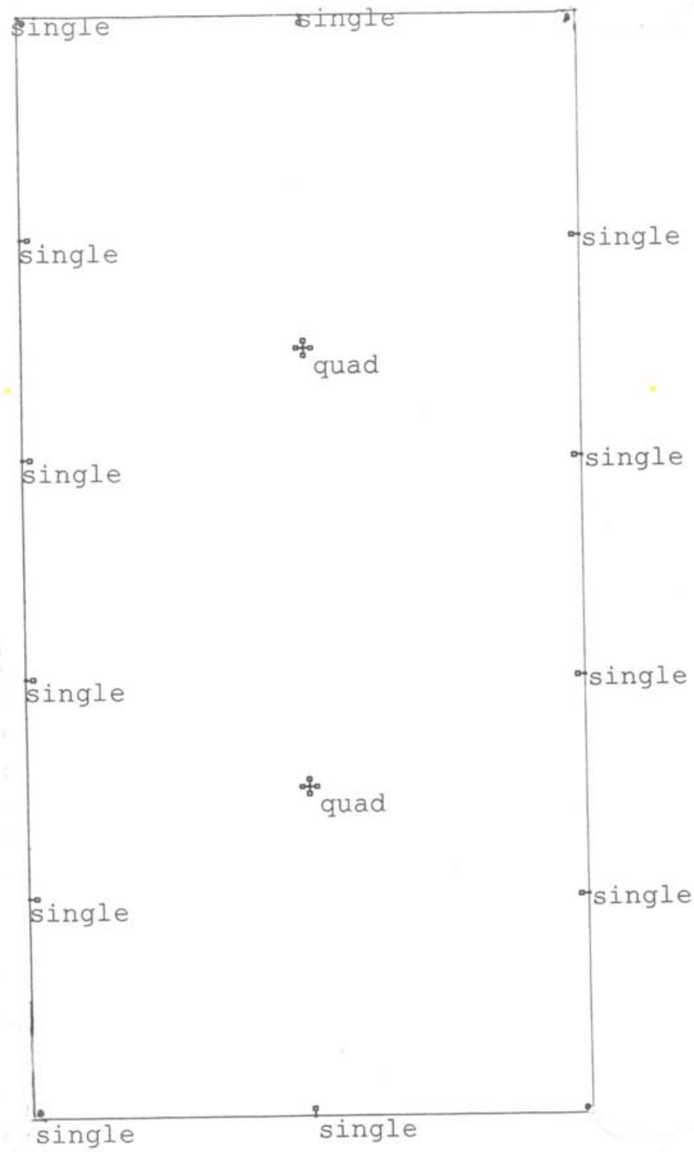
In the calculations, Lumen Micro 7.5™ was used to model the parking lot lighting system scenario and to calculate luminance. The visibility level was calculated according to Adrian's ΔL model[2].

4.1 Parking Lot and Lighting System Configuration

Concerning luminance and visibility level, there are many variables that contribute to their final values. To ensure consistency of the calculations, variables such as pole height, luminaire tilt, geometry of lighting installation, etc. described in Figure 6 were held constant (with the corresponding values).

The McGraw-Edison CS7265 HPS 400 WATT luminaire was used.

[2] Adrian, W. "Visibility of Targets: Method for Calculation," Lighting Research and Technology (21), 1989, page. 181



Single: single luminaire pole
Quad: four-luminaire pole
Mounting Height: 10 m
Tilt: Horizontal
Bracket Arm Length: 0.5 m

Parking Lot Size: 50 m x 100 m

Figure 6. Fixed lighting installation plan.

4.2 Pavement Surfaces Utilized

As noted in Section 2.3, the Q_0 values for concrete and asphalt are 0.1138 and 0.0793, respectively. The software, Lumen Micro 7.5™, uses the road surface classification system (R1, R2, R3, and R4) as shown in Section 2.2. For concrete, the most similar road surface type is R1 (Q_0 of 0.1), while for the typical asphalt road surfaces, type R3 is most suitable (Q_0 of 0.07). The Q_0 values used for luminance calculations have a standard error from the measured values of 12.1% for concrete and 11.7% for asphalt. Since the differences are relatively similar, the standard error can be disregarded.

4.3 Luminance Calculations

4.3.1 Explanation of Luminance. The essential quantity that appears as the brightness of an object is the photometric unit luminance. Luminance is the intensity of brightness (in candela per unit area) of a surface. Higher luminance values are associated with brighter surfaces. As for concrete and asphalt pavements, a comparison of background (horizontal) luminance, L_B, is necessary.

Essentially, a surface can be lambertian or nonlambertian. A lambertian surface is diffuse, thus reflects light uniformly, regardless of the direction of observation. A nonlambertian surface does not reflect light in all directions equally. Road surfaces belong in the nonlambertian category. However, the surface of a vertical target of 10 minarc that is internationally used for visibility level calculations is assumed to be lambertian.

For surfaces of lambertian nature, the luminance is dependent on the illumination and the reflectivity of the surface as follows:

$$L = (E / \pi) \times \rho$$

L = luminance (cd/m^2)
E = illuminance (lux)
ρ = reflectivity of surface

Equation 3: Luminance Formulation of a Lambertian Surface.

For this investigation the luminance calculations for the nonlambertian pavement types have been internally calculated by Lumen Micro 7.5™, which uses IES standards as outlined in Appendix 1 Exhibit 3. IES standards assign constants to variables such as height of the observer, observer setback, etc.

4.3.2 Luminance Observations. It is evident from Table 3, that higher luminances are achieved with concrete surfaces in comparison to asphalt surfaces while using the same geometry of the masts and luminaires. With regard to average luminance comparisons, concrete is 1.77 times more luminous than asphalt

Table 3. Luminance Comparisons Between Concrete and Asphalt

Pavement	Power (WATTS)	L_B-Background Luminance (cd/m^2)			
		Average	Min	Max	Max:Min
Asphalt (R3)	400	3.40	1.06	11.14	10.40
Concrete (R1)	400	6.03	2.67	14.25	5.28

Luminance uniformity is another significant factor in the lighting of parking lots which is represented by the maximum to minimum horizontal luminance ratio (max:min). With high max:min ratios, certain areas of parking lots can have low luminance levels, which are associated with poor visibility. Low max:min ratios present a more uniform luminance distribution. From Table 3 and the iso-luminance curves represented in Figure 7, it is evident that asphalt has a max:min luminance ratio of 1.97 times greater than concrete. In other words, concrete has a more uniform luminance distribution.

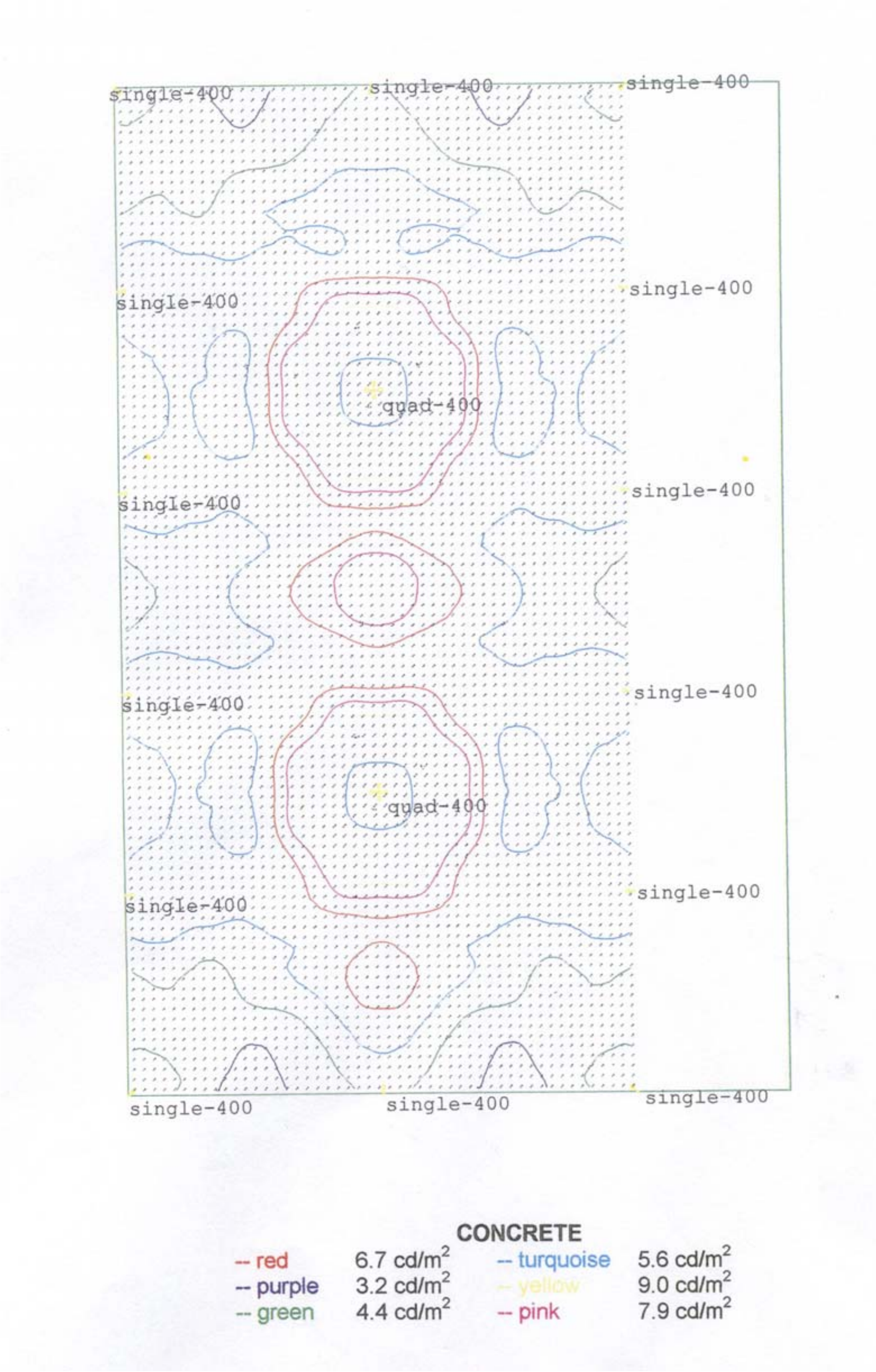


Figure 7a. Iso-luminance diagrams for concrete parking lot pavement.
(This was calculated according IES standards. The values were obtained by Lumen Micro 7.5™.)

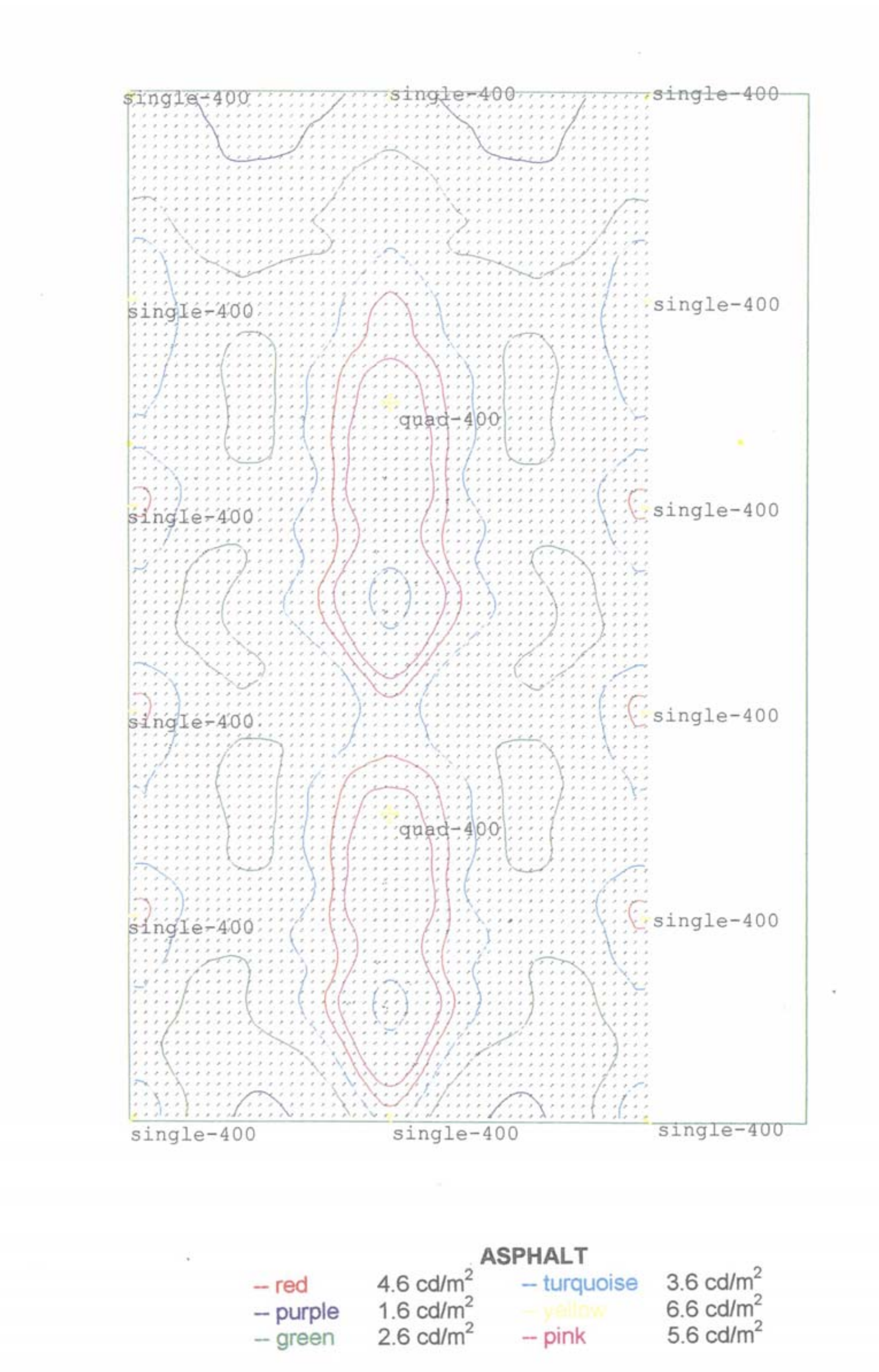


Figure 7b. Iso-luminance diagrams for asphalt parking lot pavement
(This was calculated according IES standards. The values were obtained by Lumen Micro 7.5™.)

4.4 Visibility Level Calculations

Visibility Level (VL) is a methodology proposed by Adrian[2] that has received recognition and is to be used in the North American Standard for Roadway Lighting RP-8. The visibility level (VL) is a measure of the ability to detect targets (objects) such as vehicles, pedestrians, etc. based on characteristics such as contrast between target and background, age of observer, target size, and observation time. Curbs, posts, wheel stops, etc. must also be noticed sufficiently in advance so that appropriate countermeasure can take place in time to avoid contact.

4.4.1 Determining Visibility Level. The theoretical difference in luminance required between the target and its background that the observer can detect with a 99.9% probability is known as the *luminance difference threshold ($\Delta L_{threshold}$)*. The ratio of the actual luminance difference (ΔL) to the luminance difference threshold ($\Delta L_{threshold}$) is labeled the *visibility level*. Thus, it follows that:

$$VL = \Delta L / \Delta L_{threshold}$$

Equation 4: Visibility Level

1. Determining Actual Luminance Difference (ΔL)

The actual luminance difference (ΔL) is the difference in the luminance of the target (L_T) to the background luminance (L_B). Background luminance (L_B) is calculated as described in Section 4.3.1 using IES standards. As for target luminance, the target reflection is assumed to be diffuse. Therefore, the equation for calculating L_T (and ΔL) is:

$$L_T = (E_V / \pi) \times \rho$$

Equation 5: Target Luminance

$$\Delta L = | L_T – L_B |$$

Equation 6: Actual Luminance Difference

When calculating L_T, it is necessary to use the vertical illuminance (E_V) instead of the horizontal illuminance (E_H). This is because a target tends to be an object such as a wheel stop, where an observer views the vertically reflected light from the target. Using the E_V values provided by Lumen Micro 7.5™, the target luminance was calculated for different values by choosing the target reflection factor ρ as 0.5, 0., and 0.2.

2. Determining Luminance Threshold Difference ($\Delta L_{threshold}$)

As stated, the luminance threshold difference ($\Delta L_{threshold}$) is the theoretical difference in luminance (between target and background) so that an observer can detect the object in a given detection time. With regard to detection, factors such as observer's age, target size, observation time, and contrast polarity must be considered; these variables have been fixed with the corresponding constants as outlined in Table 4. All luminance threshold difference calculations were performed using Adrian's Models™. An internationally used standardized target size (angle) to reflect the visual task is 10 minutes (angle). Observation time of 0.2 seconds was found as an average fixation time of drivers[2].

Table 4. $\Delta L_{threshold}$ Variables

ΔLthreshold Variable	Value
Age of Observer	28 years
Target Size (angle)	10 minutes
Observation Time	0.2 seconds

4.4.2 The Effect of Varying Target Reflection *(ρ)*. The value of ρ will have great significance on the target luminance (L_T), which is related to the actual luminance difference (ΔL), hence associated with visibility level. It is evident from Equation 6 that as L_T approaches L_B, the visibility level will approach zero. This indicates that if the target reflectivity is similar to the background luminance, this would result in very low visibility levels. Therefore, the visibility level is dependent upon the target reflectivity and the background luminance L_B.

Background luminance and visibility level calculations for the above mentioned parking lot were done using a 10 meter by 10 meter grid for concrete and asphalt pavements while varying the target reflectance ρ to from 0.1 to 0.8 as shown in Figure 8 and 9 respectively. Regarding concrete, when ρ changes from 0.2 to 0.6, the VL drops and rises again to higher visibility levels due to the switch from positive to negative contrast. In negative contrast, the target appears darker than the background, whereas for positive contrast, the target is brighter than the background. Figure 10 illustrates how VL varies with ρ, calculated for concrete and asphalt. The minima on the graph represent the turning points from positive to negative contrast, or vice versa. For the VL calculations in Figure 10, a uniform background luminance was assumed which led to small deviations from the data given in Figures 8 and 9.

4.4.3 Visibility Level Observations. Although visibility level is an important criterion for the design of parking lots, changing the target reflectivity is quite easy and can always modify VL. It is evident that low target reflectivity would be desired for concrete parking lots (which have high background luminances), while high target reflectivity would be beneficial for asphalt-based parking lots (which have low background luminances).

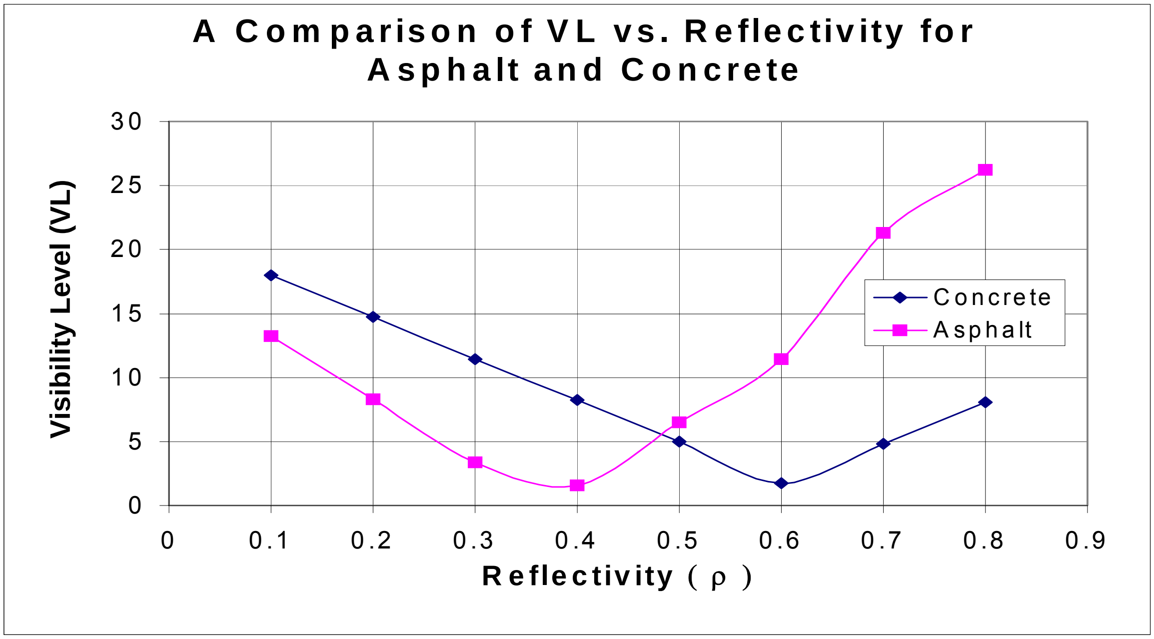


Figure 8. A comparison of visibility level vs. reflectivity of the target for asphalt and concrete.

$L_{background}$ - BACKGROUND LUMINANCE FOR CONCRETE (cd/m^2)

meters	5.00	15.00	25.00	35.00	45.00
95.00	3.97	3.64	5.10	3.64	3.97
85.00	5.34	5.49	5.93	5.49	5.34
75.00	6.17	6.48	11.17	6.48	6.17
65.00	5.80	6.35	11.44	6.35	5.80
55.00	5.20	5.61	7.19	5.61	5.20
45.00	5.21	5.56	6.98	5.56	5.21
35.00	5.99	6.39	10.88	6.39	5.99
25.00	5.96	6.46	11.64	6.46	5.96
15.00	5.34	5.47	6.75	5.47	5.34
5.00	3.98	3.51	5.77	3.51	3.98

Average Luminance = 5.97 cd/m^2

VL - VISIBILITY LEVEL FOR CONCRETE (ρ = 0.5)

meters	5.00	15.00	25.00	35.00	45.00
95.00	4.95	0.00	9.34	1.09	5.89
85.00	3.64	1.15	6.98	0.78	4.27
75.00	5.40	2.52	14.40	2.43	5.25
65.00	4.75	2.44	15.99	2.33	4.48
55.00	1.71	1.81	9.30	0.92	2.91
45.00	1.93	3.57	6.13	2.67	3.12
35.00	5.08	2.31	13.97	2.20	4.82
25.00	4.77	2.51	16.05	2.43	4.62
15.00	2.78	1.21	9.90	0.85	3.41
5.00	3.90	2.65	8.82	1.54	4.84

Average VL= 4.62

VL - VISIBILITY LEVEL FOR CONCRETE (ρ = 0.3)

meters	5.00	15.00	25.00	35.00	45.00
95.00	10.56	7.41	13.74	8.06	11.12
85.00	10.42	7.61	12.65	7.82	10.80
75.00	11.78	10.16	18.44	10.11	11.69
65.00	11.26	10.07	19.44	10.00	11.10
55.00	9.21	7.25	14.45	7.79	9.92
45.00	9.34	6.18	12.49	6.72	10.06
35.00	11.53	10.01	18.12	9.94	11.38
25.00	11.33	10.15	19.51	10.10	11.24
15.00	9.90	7.56	14.68	7.78	10.28
5.00	9.92	5.74	13.69	6.41	10.49

Average VL= 10.75

VL - VISIBILITY LEVEL FOR CONCRETE (ρ = 0.2)

meters	5.00	15.00	25.00	35.00	45.00
95.00	13.36	11.12	15.94	11.55	13.73
85.00	13.81	11.98	15.48	12.13	14.06
75.00	14.98	13.98	20.46	13.95	14.92
65.00	14.52	13.89	21.17	13.84	14.41
55.00	12.95	11.79	17.03	12.14	13.43
45.00	13.05	11.05	15.67	11.41	13.52
35.00	14.75	13.85	20.20	13.81	14.65
25.00	14.61	13.97	21.24	13.94	14.55
15.00	13.46	11.95	17.07	12.09	13.72
5.00	12.94	9.94	16.13	10.39	13.31

Average VL= 14.16

Figure 9 Calculation Grids for Concrete Surface (R1)

$L_{background}$ - **BACKGROUND LUMINANCE FOR ASPHALT (cd/m^2)**

meters	5.00	15.00	25.00	35.00	45.00
95.00	1.80	1.47	2.54	1.47	1.80
85.00	2.82	2.44	3.57	2.44	2.82
75.00	3.29	2.73	5.49	2.73	3.29
65.00	3.05	2.83	7.26	2.83	3.05
55.00	2.85	3.21	8.60	3.21	2.85
45.00	2.83	2.74	6.93	2.74	2.83
35.00	3.09	2.64	4.80	2.64	3.09
25.00	3.07	2.87	7.30	2.87	3.07
15.00	2.92	3.18	8.49	3.18	2.92
5.00	2.37	1.98	6.66	1.98	2.37

Average Luminance = 3.40 cd/m^2

VL - VISIBILITY LEVEL FOR ASPHALT (ρ = 0.6)

meters	5.00	15.00	25.00	35.00	45.00
95.00	9.35	20.43	1.43	18.43	7.74
85.00	9.60	22.56	2.08	21.91	8.61
75.00	7.22	18.66	3.35	18.82	7.46
65.00	8.31	17.01	9.96	17.21	8.73
55.00	11.57	16.06	11.90	14.73	9.73
45.00	11.47	23.45	6.00	21.95	9.62
35.00	8.37	19.53	0.66	19.73	8.78
25.00	8.88	17.07	9.82	17.23	9.13
15.00	10.10	14.61	13.04	14.07	9.13
5.00	5.43	15.79	10.83	14.13	4.08

Average VL =

VL - VISIBILITY LEVEL FOR ASPHALT (ρ = 0.3)

meters	5.00	15.00	25.00	35.00	45.00
95.00	0.33	6.72	5.79	5.52	1.30
85.00	1.11	6.97	6.12	6.58	1.71
75.00	2.86	4.39	10.30	4.49	2.72
65.00	2.05	3.33	14.87	3.45	1.80
55.00	0.05	2.49	16.39	1.69	1.05
45.00	0.00	7.26	12.40	6.36	1.10
35.00	2.04	4.99	8.40	5.11	1.79
25.00	1.72	3.34	14.79	3.43	1.57
15.00	0.88	1.64	17.05	1.32	1.47
5.00	3.25	3.34	15.21	2.34	4.06

Average VL = 4.78

VL - VISIBILITY LEVEL FOR ASPHALT (ρ = 0.2)

meters	5.00	15.00	25.00	35.00	45.00
95.00	5.17	0.14	9.40	0.94	5.81
85.00	6.46	0.82	10.22	1.08	6.86
75.00	7.90	2.74	13.78	2.67	7.81
65.00	7.23	3.51	17.32	3.43	7.06
55.00	5.71	4.29	18.64	4.82	6.44
45.00	5.73	0.83	15.59	1.43	6.46
35.00	7.24	2.28	12.27	2.20	7.08
25.00	7.02	3.53	17.28	3.47	6.92
15.00	6.37	4.84	19.05	5.05	6.76
5.00	7.58	2.89	17.39	3.55	8.12

Average VL =

Figure 10 Calculation Grids for Asphalt Surface (R3)

3. ACHIEVING EQUAL LUMINANCE LEVELS

Using similar dimensions for the parking lot described in Section 4.1, an analysis was performed to achieve equal luminance levels on concrete and asphalt surfaces by varying the lamp wattage and the number of luminaires used in the parking lot. This analysis was necessary for the purpose of calculating energy consumption savings.

Visibility Level calculations were performed for the modified parking lot scenarios, using average L_B values and taking ρ to be 0.5. It should be noted that the visibility level is dependent upon ρ as discussed in Section 4.4; therefore, it was not used as the sole basis for the study.

5.1 Varying Lamp Power (WATTS)

The luminaire configuration for the typical parking lot lighting system was kept unchanged (as shown in Section 4.1) while the power of the luminaires for the concrete parking lot was decreased. Four standard luminaire wattage types (400, 250, 150, and 100 WATT) were utilized and the results were recorded in Table 5. For the purpose of consistency, the iso-intensity patterns of the selected luminaires were kept relatively identical.

It should be noted from the data in Table 5 that the max-to-min ratio for the concrete based parking lot remains relatively unchanged when lower power lamps are used. Therefore, the iso-luminance diagrams for the concrete scenarios are identical as indicated in Appendix 1, Exhibit 4. This implies that besides requiring less lighting, concrete parking lots also will have a more uniform pavement luminance distribution, which is a desirable attribute.

By means of Figure 11, it is evident that the relationship between lamp power (WATTS) and surface luminance is linear for the parking lot as long as the light pole configuration is kept constant.

Table 5.Results from Varying Lamp Power

Pavement	**Power (WATTS)**	**L_B- Pavement Background Luminance (cd/m^2)**				**E_V – Vertical Illuminance (lux)**	**L_T-Target Luminance**	**ΔL**	**$\Delta L_{threshold}$**	**Visibility Level (VL)**
		Avg.	Min	Max	Max:Min					on ρ= 0.5
Asphalt	400	3.40	1.06	11.14	10.40	29.025	4.619	1.219	0.187	6.515
Concrete	400	6.03	2.67	14.25	5.28	29.025	4.619	1.411	0.284	4.968
Concrete	250	3.62	1.60	8.55	5.27	17.415	2.772	0.848	0.254	3.335
Concrete	150	1.95	0.82	4.25	5.00	9.340	1.487	0.463	0.223	2.076
Concrete	100	1.16	0.49	2.43	4.60	5.545	0.883	0.277	0.192	1.446

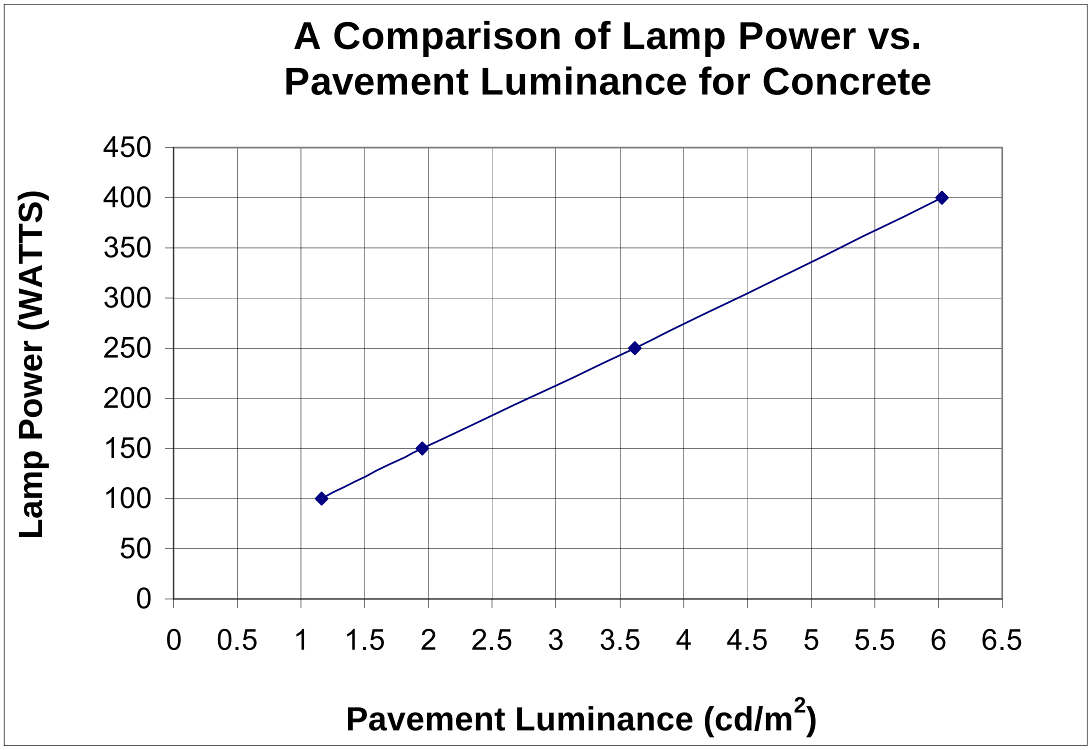


Figure 11. A comparison of lamp power vs. surface luminance for concrete.

5.1.1 Power Savings with Lower Lamp Power. The average surface luminance of an asphalt parking lot using 400 WATT lamps was found to be 3.40 cd/m^2, while for the same scenario with a concrete surface the average luminance level was 6.03 cd/m^2 (as indicated by Table 5). Results indicate that a 250 WATT lamp used in a concrete parking lot would produce background luminance equal (or greater) to a 400 WATT lamp used in an asphalt parking lot with the same geometric configurations. Therefore, by using a concrete surface, energy savings of up to 41% are obtained. This can be derived from the ratio of listed lumen output of the lamps with (42,500 for 400 WATT and 25,000 lumens for 250 WATT) wattage as illustrated in Figure 12[3].

With the assumption that an average parking lot lighting system operates up to five hours a day, in one year the asphalt-based parking lot would use 6,026.62 kW·hr or 60% (see Appendix 2, Exhibit 5 for calculations) more energy than the concrete parking lot.

[3] "Philips Lighting: Lamp Specification Guide – SG-100," Philips Lighting Inc., page 54

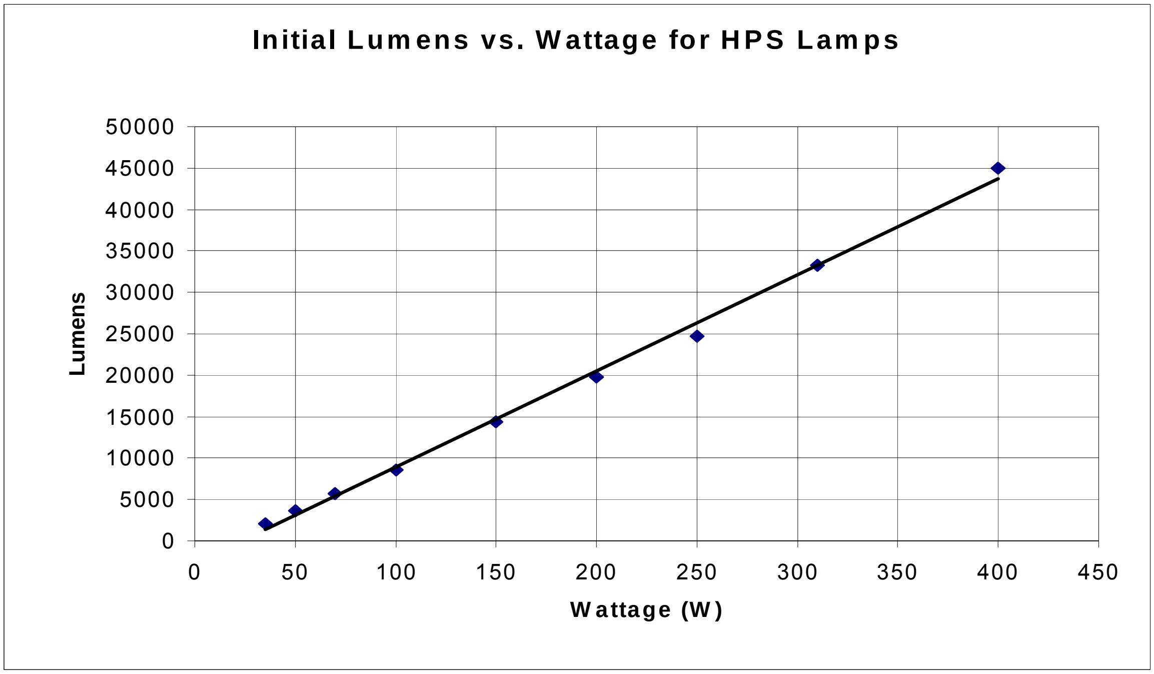


Figure 12. Lumens vs. wattage for HPS lamps according to manufacturer's catalogue

5.2 Modifying Pole Configuration

To create equal background luminances, an attempt was made to reduce the number of luminaires in the parking lot lighting system as explained in Section 4.1. Again, the asphalt scenario was kept unchanged with a L_B of 3.40 cd/m^2, while the number of luminaires was reduced in the concrete scenario in order to achieve an average L_B of about 3.40 cd/m^2.

As shown in Table 6, fourteen different luminaire configurations were attempted in order to achieve an equal background luminance. Appendix 2 Exhibit 7 shows the different luminaire configurations as well as the corresponding iso-luminance diagrams. The process that was used to obtain equal L_B was to reduce the number of luminaires while keeping the lighting geometry symmetric.

5.2.1 Power Savings for Modified Pole Configuration. The number of poles saved for lighting a parking lot is shown in Table 6. For an asphalt surface, 22 luminaires are needed, while for a concrete surface only 14 luminaires are required to produce an equivalent (or greater) background luminance, a saving of 8 luminaires.

With the assumption that an average parking lot lighting system operates up to five hours a day (same assumption as in Section 5.1.1) in one year, the asphalt parking lot would use 5,844.00 kW·hr or 57% more energy per year than the concrete parking lot (see Appendix 1, Exhibit 5 for calculations).

Table 6. Luminance Calculations for Alternate Luminaire Configurations

Cnfg	Pavement	Luminaire	L_B-Background Luminance (cd/m^2)				E_V – Vert Illum (lux)	L_T-Target Lum (cd/m^2)	ΔL (cd/m^2)	$\Delta L_{threshold}$ (cd/m^2)	VL	Comments
			Avg.	Min	Max	Max:Min						
1	**Asphalt**	**22**	**3.40**	**1.06**	**11.14**	**10.40**	**29.025**	**4.619**	**1.219**	**0.187**	**6.515**	**Same as Figure 7 b**
1	Concrete	22	6.03	2.67	14.25	5.28	29.025	4.619	1.411	0.284	4.968	**Same as Figure 7 a**
2	Concrete	20	5.20	2.61	11.03	4.25	24.828	3.951	1.249	0.254	4.909	Attempting to reduce
3	Concrete	18	4.35	2.54	7.69	2.96	20.985	3.340	1.010	0.223	4.524	luminaires and achieve
4	Concrete	16	3.52	2.18	5.70	2.65	16.993	2.704	0.816	0.192	4.251	same luminance
5	Concrete	18	4.78	2.31	10.80	4.76	22.815	3.631	1.149	0.239	4.805	
6	Concrete	16	3.94	2.25	7.47	3.29	18.973	3.020	0.920	0.208	4.427	
7	Concrete	16	4.34	2.09	10.66	5.21	20.693	3.293	1.047	0.223	4.696	
8	Concrete	**14**	**3.49**	2.03	7.32	3.58	16.850	2.682	0.808	0.191	4.239	achieved equiv lum
9	Concrete	**14**	**3.50**	2.04	7.32	3.58	16.893	2.689	0.811	0.191	4.247	achieved equiv lum
10	Concrete	**14**	**3.51**	1.54	13.63	9.07	16.993	2.704	0.806	0.191	4.208	achieved equiv lum
11	Concrete	**14**	**3.45**	2.34	5.86	**2.45**	16.593	2.641	0.809	0.189	4.279	achieved equiv lum
12	Concrete	15	3.88	2.29	10.65	4.71	18.563	2.954	0.926	0.206	4.502	
13	Concrete	13	3.04	2.21	5.33	2.38	14.568	2.318	0.722	0.173	4.170	didn't achieve equiv lum
14	Concrete	13	3.09	1.55	10.38	6.86	14.880	2.368	0.722	0.175	4.124	didn't achieve equiv lum

6. CONCLUSIONS

Based on the reflection characteristics of 150 pavement samples, we learn from the frequency distribution of $Q_{0,}$ the total reflected light from the surface, that the average Q_0 of concrete (0.1138) is higher than that of asphalt (0.0793). It should be noted that the number of samples of concrete surfaces are small in comparison with asphalt, in the vicinity of 17% of the total number of samples in this study.

For specific lighting installations for parking lots, the luminance level and visibility level were investigated using a typical light distribution of the luminaires. Due to the higher reflection of concrete surfaces expressed by Q_0, higher luminances were obtained on concrete surfaces. It is evident that with the same geometry of the lighting installations, 400 WATT HPS lamps would be necessary on asphalt and only 250 WATT HPS on concrete to create equal average pavement luminance levels.

The advantage of a higher reflective surface also can be expressed as the number of poles (luminaires) that are necessary to provide the same luminance level. In Table 6, applying the same wattage of the lamps shows that where 22 poles are required for asphalt parking lots, only 14 poles are required for concrete parking lots, a saving of 8 poles. The asphalt parking lot uses 5,844 kW-Hr per year more energy than the concrete parking lot,

The VL was also calculated and showed that it is very dependent on the assumed reflectance of the 10-minute target. As shown in Figure 10, for high target reflectances, the target can be better seen on asphalt as a background, while for low target reflectances, the target can be better seen on concrete.

The measured spectral reflection shows that the same trend occurs in concrete as well as in asphalt, with the difference being that the Q_0 of concrete is 2.34 times higher than for asphalt. It can be observed that the reflection decreases for light with short wavelength as shown in Figure 4 and increases for light of long wavelength. This has a great meaning for the selection of specific lamps. High Pressure Sodium (HPS) lamps which emit more light in the long wavelength range would be more efficient than the Metal Halide (MH) lamps which emit more blue (short wavelength) light.

7. RECOMMENDATIONS

It has been shown in this report that concrete pavements have an advantage over asphalt pavements with regard to the energy necessary for lighting. If we consider the necessary lamp wattage to achieve the same luminance levels on concrete and asphalt surfaces, it is evident that approximately 250 WATT lamps have to be installed for concrete, and 400 WATT lamps for asphalt surfaces. This is a saving of 150 Watts of electrical power. Assuming a parking lot lighting system of 22 luminaires operating for five hours daily as a year average, a saving of 6,027 kW·hr is obtained (Appendix 1, Exhibit 5). This is 37% less than the electrical energy required for an asphalt parking lot.

If luminaire configurations are modified which are based on a nearly equal luminance level on both surfaces, one achieves with 14 luminaires on concrete the same result as with 22 luminaires on asphalt (with 400 WATT lamps installed in the luminaires). This reflects a saving of 5,844 kW·hr in electrical energy. The savings in initial installation and maintenance costs by using fewer poles shold be added to the savings in the cost of electricity.

On the basis of substantial savings in electrical energy and installation cost, and improved lighting uniformity, it is evident that for lighting purposes concrete should be preferred over asphalt.

The spectral reflection of concrete and asphalt surfaces shows the same trend over the spectrum and decline with shorter wavelength. This means that spectral power distributions of light sources that show higher portions in the blue part are less efficient than power distributions that contain predominantly light of the long wave spectrum. In terms of practical lamps used for outdoor lighting, the High Pressure Sodium lamp would be more efficient than the Metal Halide lamp based on the same lumen output.

With respect to the visibility level, it has been shown in Figure 10 that the brighter concrete surface is naturally better with low reflections of the targets below $\rho = 0.45$ than he darker asphalt. Therefore, the recommendation is to paint the targets, for example sign posts, with a dark color to give the target more contrast in order to achieve higher visibility levels when using concrete pavements.

ACKNOWLEDGEMENTS

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8. REFERENCES

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2. Adrian, W., “Visibility of Targets: Method for Calculation,” *Lighting Research and Technology*, 21, 1989, page181.

3. *Philips Lighting: Lamp Specification Guide – SG-100*, Philips Lighting, Inc., page 54.

4. *Lighting for Parking Facilities: RP-20-98*, Illuminating Engineering Society of North America, 1998.

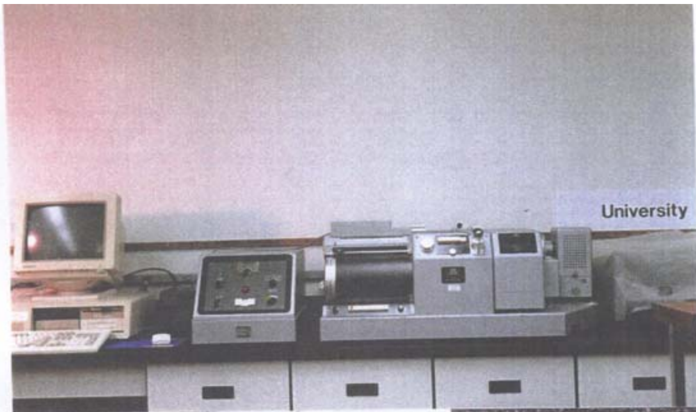
5. *ALADAN: User’s Manual & Lighting Design Guide*, GE Lighting Systems, Inc., 1995.

6. Lumen Micro 7.5™, Lighting Technologies, Inc.

APPENDIX 1

EXHIBIT 1

Pictures of Zeiss DMR21 and Samples



ZEISS DMR21 Spectral Photometer

Concrete Sample on Asphalt Road Surface

Asphalt Sample on Asphalt Road Surface

29

EXHIBIT 2

Spectral Sensitivity of the Eye - V(λ)

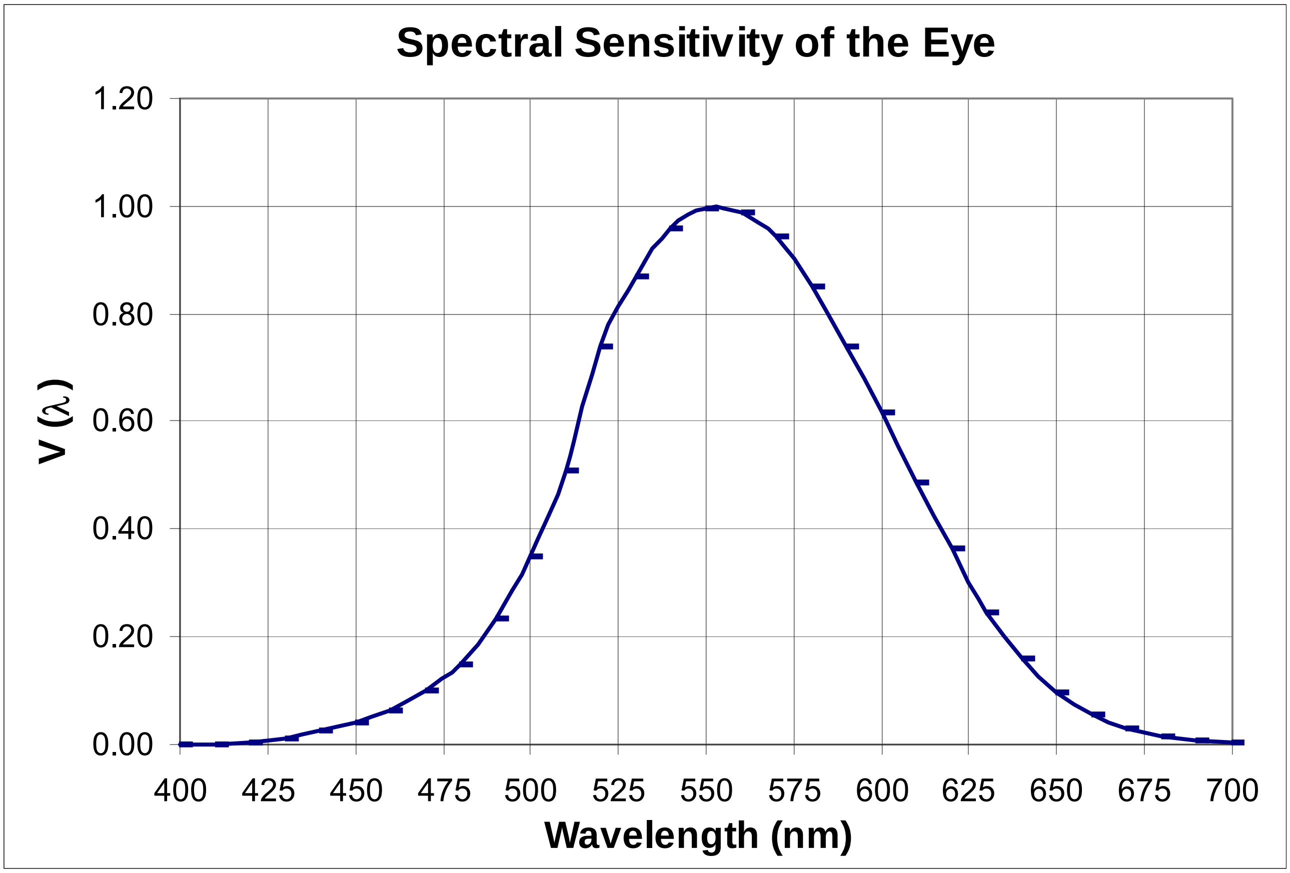


EXHIBIT 3

IES Standards

Definitions:
Downstream in the observation direction.
Upstream is toward the observer.
Luminaire cycle is the distance between fixtures in same row.
One cycle = 1 single side or 2 stagger spacing increments.
"No spec" means no specification in IES document (RP-8).

Luminaires:
One Luminaire cycle (min) upstream from array edge.
Four Luminaire cycles (min) downstream from array edge.

Array (longitudinal):
Increment = 5 m maximum.
Start adjacent to pole.
Stop 1 increment short of next pole in same row.

Array (transverse):
2 rows per lane.
Start at ¼ lane width from left curb.
Increment (spacing) = ½ lane width.

Illumination:
Use array set-up above.
Average of all array points.
Average/Minimum uniformity.
Maximum/Minimum uniformity.

Luminance:
Use array set-up defined above.
Observer eye height is 1.45 m (4.757ft).
Observer setback 83 m (273.3ft) from each meter point.
Observer tracks transversely with each meter row.
Average of all array points.
Average/Minimum uniformity, all points.
Maximum/Minimum uniformity, all points.
Longitudinal uniformity, Maximum/Minimum in any single ¼ lane row (referenced, but no spec).

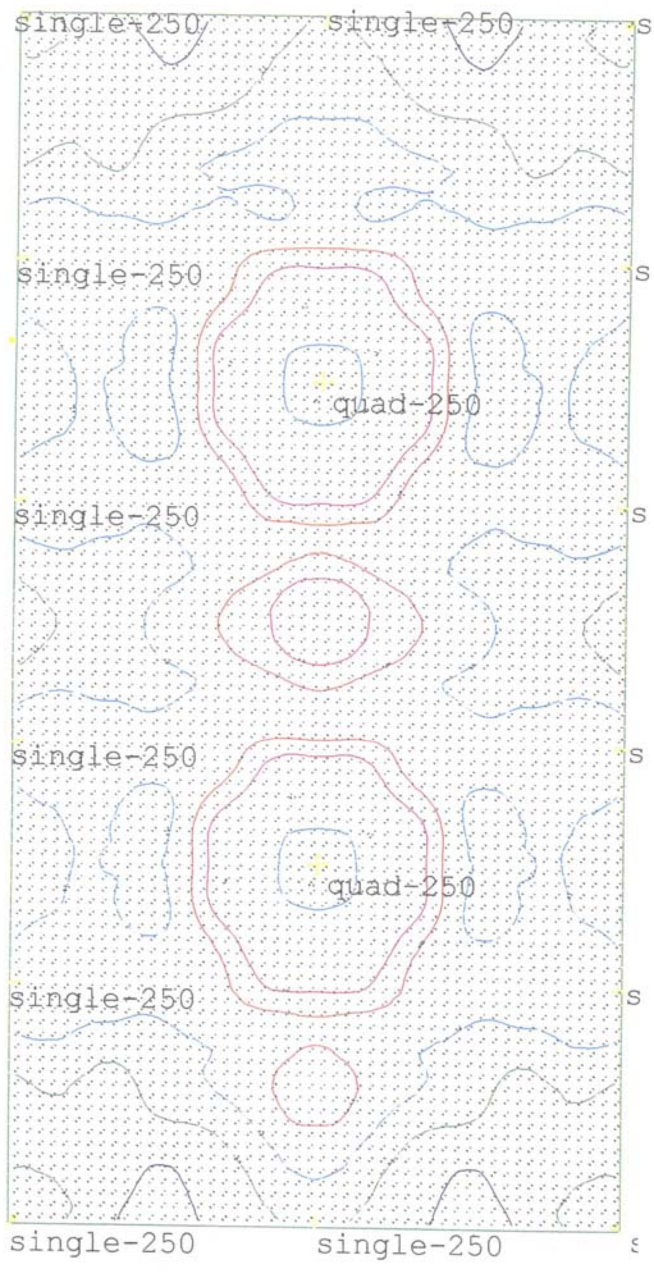
Veiling Luminance (disability glare):
Multiple observers.
Use fixtures defined above.
Place observers at transverse array locations defined above.

Place observers at longitudinal array locations defined above.
Observer looks parallel to curb.
Observer looks parallel to road surface.
Veiling Luminance Ratio (Veiling Luminance/Average Luminance).

Discomfort Glare:
No spec.

EXHIBIT 4A

Iso-Luminance Diagrams for Varying Power

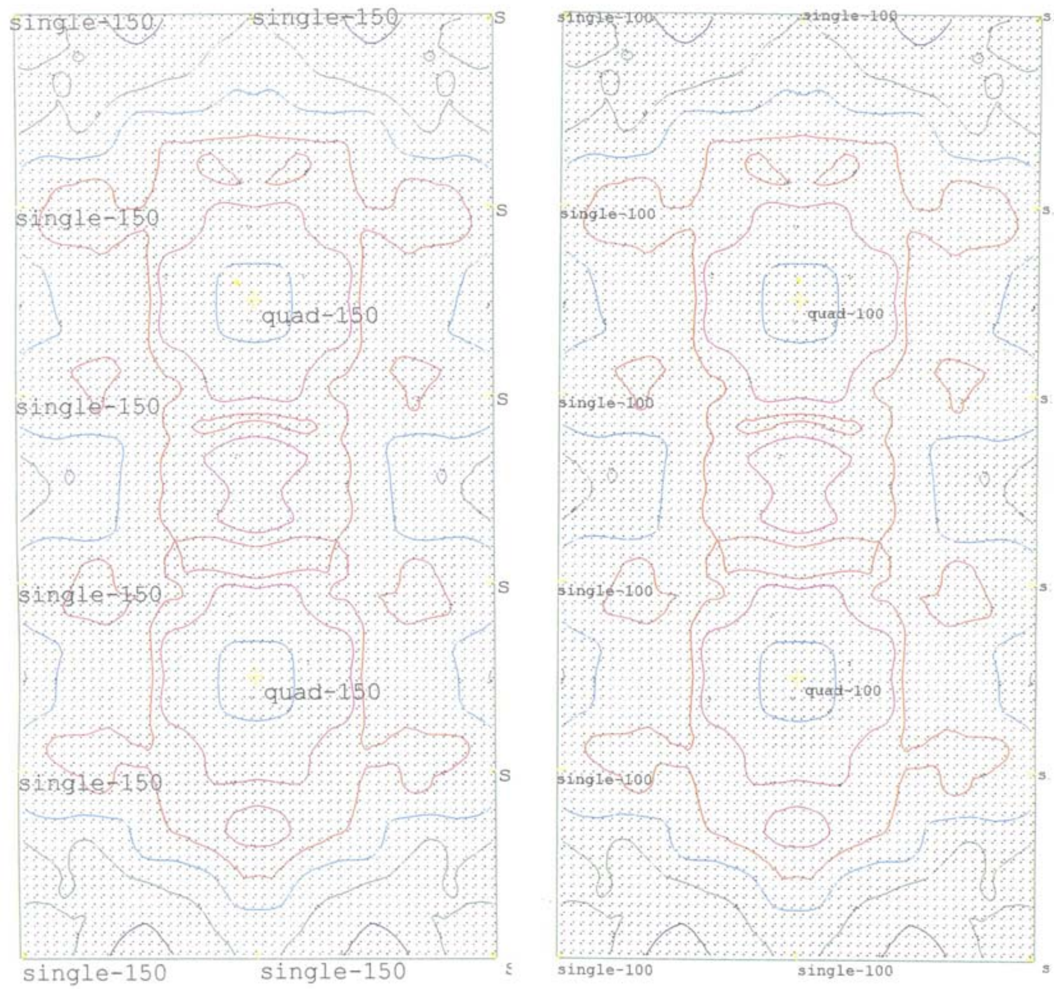


CONFIGURATION 1: 250 WATT LAMPS - CONCRETE

-- red	4.0 cd/m^2	-- turquoise	3.3 cd/m^2
-- purple	1.9 cd/m^2	-- yellow	5.4 cd/m^2
-- green	2.6 cd/m^2	-- pink	4.7 cd/m^2

EXHIBIT 4B

Iso-Luminance Diagrams for Varying Power



150 WATT LAMPS - CONCRETE				100 WATT LAMPS - CONCRETE			
-- red	2.0 cd/m^2	-- turquoise	3.7 cd/m^2	-- red	1.2 cd/m^2	-- turquoise	2.2 cd/m^2
-- purple	1.0 cd/m^2	-- yellow	2.7 cd/m^2	-- purple	0.6 cd/m^2	-- yellow	1.6 cd/m^2
-- green	1.3 cd/m^2	-- pink	2.4 cd/m^2	-- green	0.8 cd/m^2	-- pink	1.4 cd/m^2

EXHIBIT 5

Calculations for Energy Savings

Assumptions:

- Lighting System to be active 5 hours per day.
- 365.25 days/year
- Therefore, in one year:
  Hours of Operation in one year = 5 hours/day x 365.25 days/year
  = 1826.25 hours/year

Varying Lamp Power:

400 WATT: = 22 luminaires x 400 WATT/luminaire x 1826.25 hours
= 16,071.00 kW·hr

250 WATT: = 22 luminaires x 250 WATT/luminaire x 1826.25 hours
= 10,044.38 kW·hr

Therefore, 250 WATT Lamp consumes only 62.5% of the electrical energy of a 400 WATT lamp.

Power Difference = | 400 WATT Power – 250 WATT Power | kW·hr
= | 16,071.00 – 10,044.38 | kW·hr
= 6,026.62 kW·hr

Modifying Luminaire Configurations:

22 luminaire: = 22 luminaires x 400 WATT/luminaire x 1826.25 hours
= 16,071.00 kW·hr

14 luminaire: = 14 luminaires x 400 WATT/luminaire x 1826.25 hours
= 10,227.00 kW·hr

Therefore, the 14 luminaire configuration consumes only 63.6% of the electrical energy of a 22 luminaire configuration.

Power Difference = | 22 luminaire – 14 luminaire | kW·hr
= | 16 071.00 – 10 227.00 | kW·hr
= 5,844.00 kW·hr

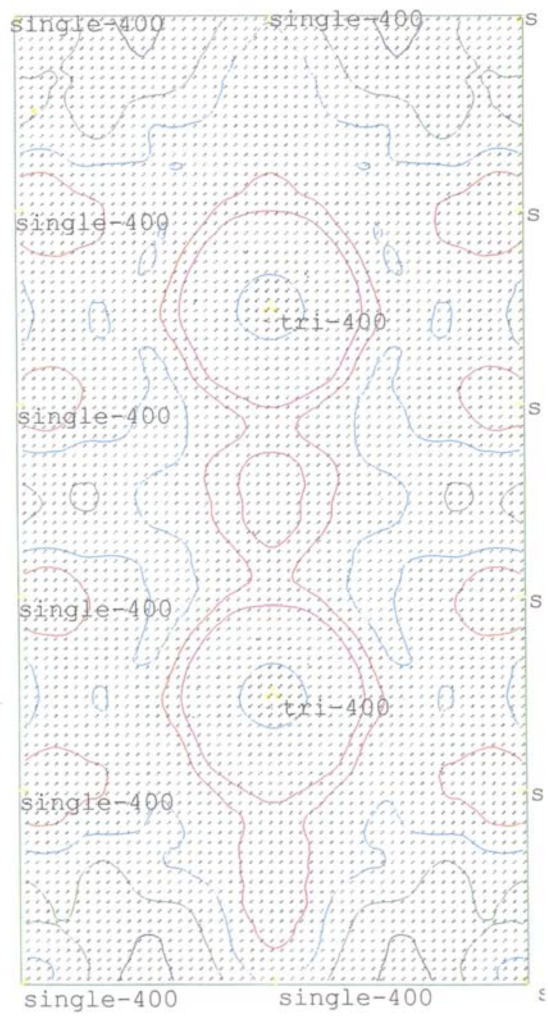
APPENDIX 2

Exhibit 1

Iso-Luminance Diagrams for Pole Configuration

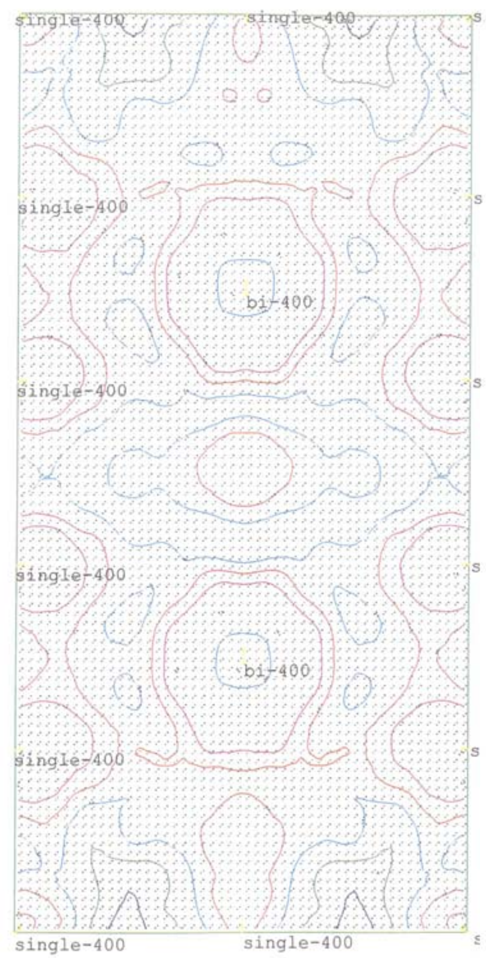
Parameters:
Pole height: 10 m
Arm Length: 0.5 m
Tilt: Horizontal

Terms:
single-400: one luminaire pole (400 WATT HPS lamp)
bi–400: two luminaire pole (400 WATT HPS lamp)
tri-400: three luminaire pole (400 WATT HPS lamp)
quad–400: four luminaire pole (400 WATT HPS lamp)
no-arm-400: one luminaire pole without arm (400 WATT HPS lamp)



CONFIGURATION 2: CONCRETE

-- red	5.6 cd/m^2	-- turquoise	9.8 cd/m^2
-- purple	3.0 cd/m^2	-- yellow	7.2 cd/m^2
-- green	3.9 cd/m^2	-- pink	6.4 cd/m^2

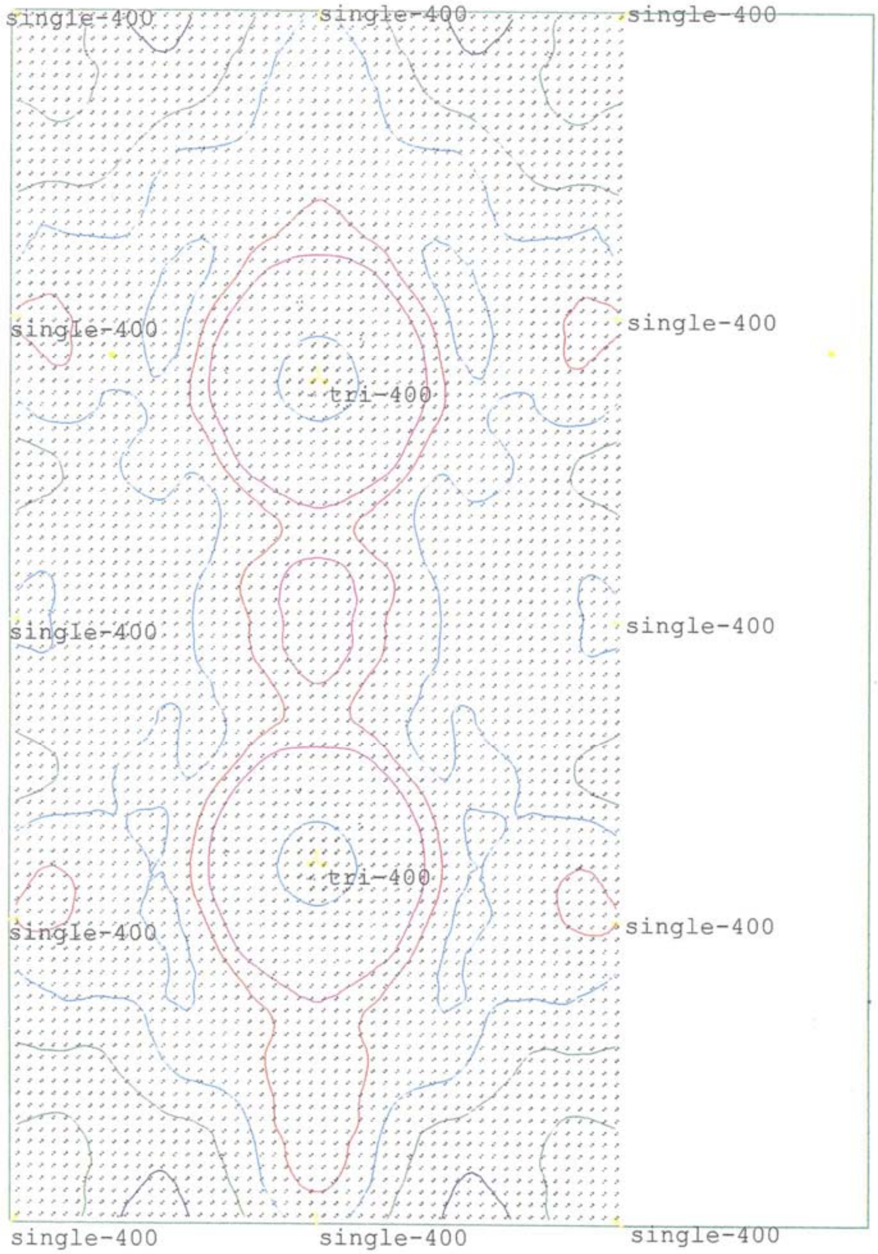


CONFIGURATION 3: CONCRETE

-- red	4.3 cd/m^2	-- turquoise	3.8 cd/m^2
-- purple	2.8 cd/m^2	-- yellow	5.4 cd/m^2
-- green	3.3 cd/m^2	-- pink	4.9 cd/m^2

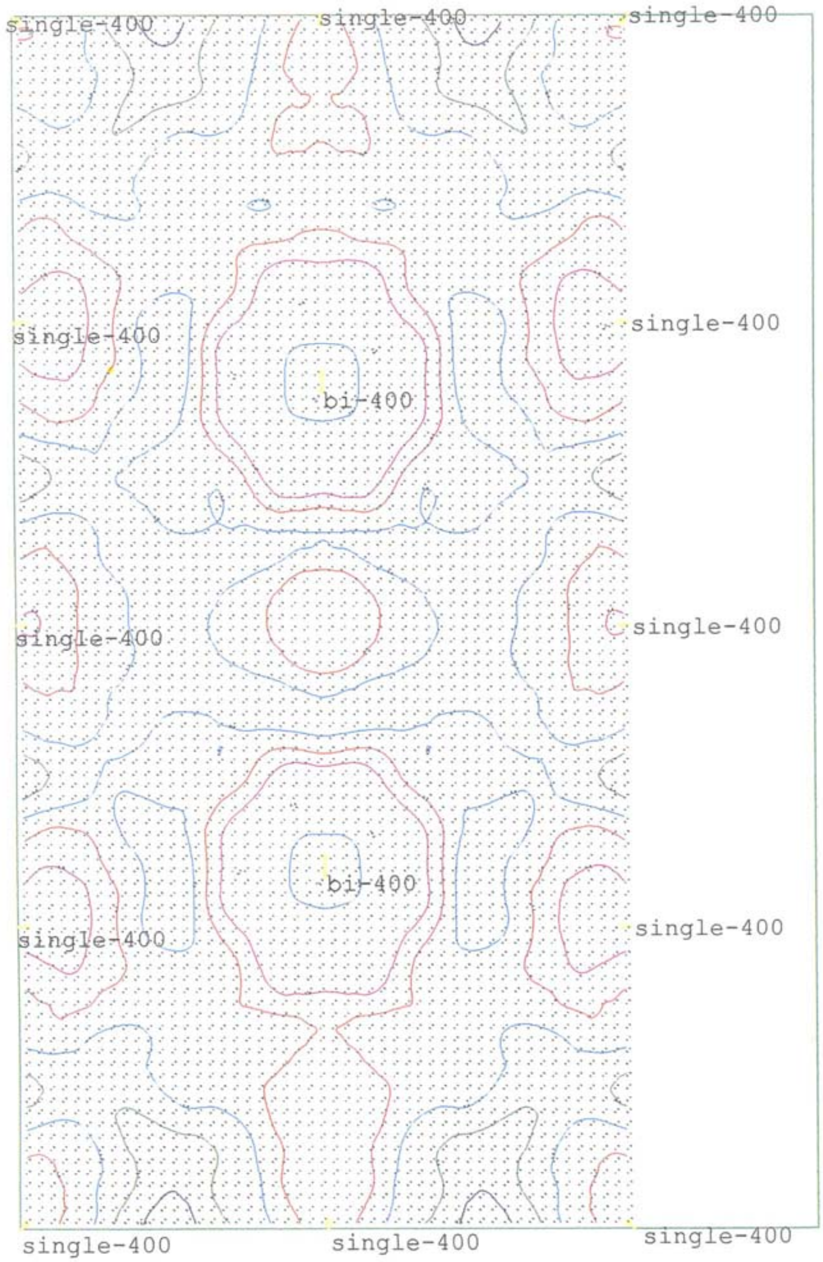
CONFIGURATION 4: CONCRETE

-- red	3.4 cd/m^2	-- turquoise	5.2 cd/m^2
-- purple	2.4 cd/m^2	-- yellow	4.1 cd/m^2
-- green	2.7 cd/m^2	-- pink	3.8 cd/m^2



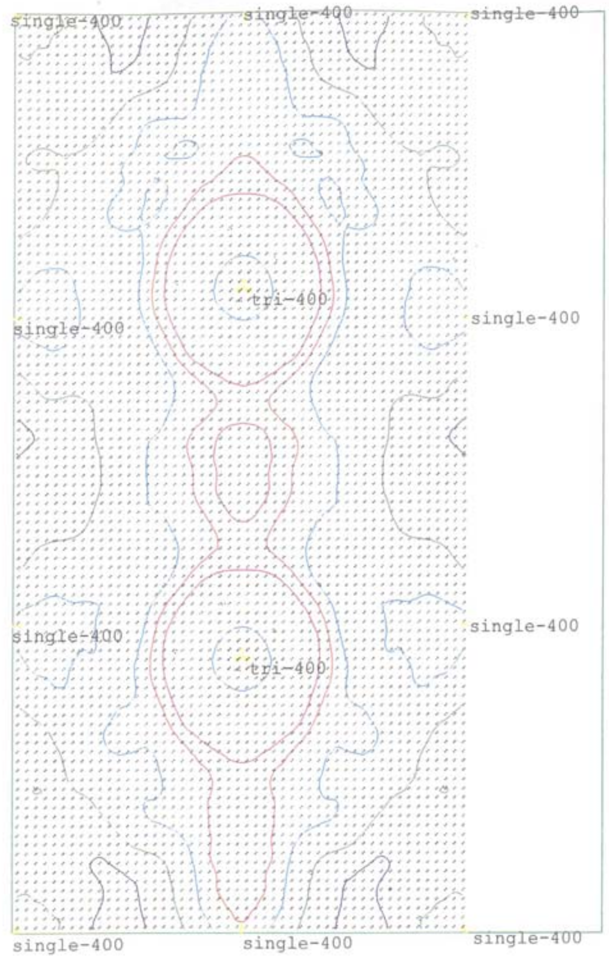
CONFIGURATION 5: CONCRETE

-- red	5.3 cd/m^2	-- turquoise	4.7 cd/m^2
-- purple	2.7 cd/m^2	-- yellow	7.0 cd/m^2
-- green	3.6 cd/m^2	-- pink	6.1 cd/m^2



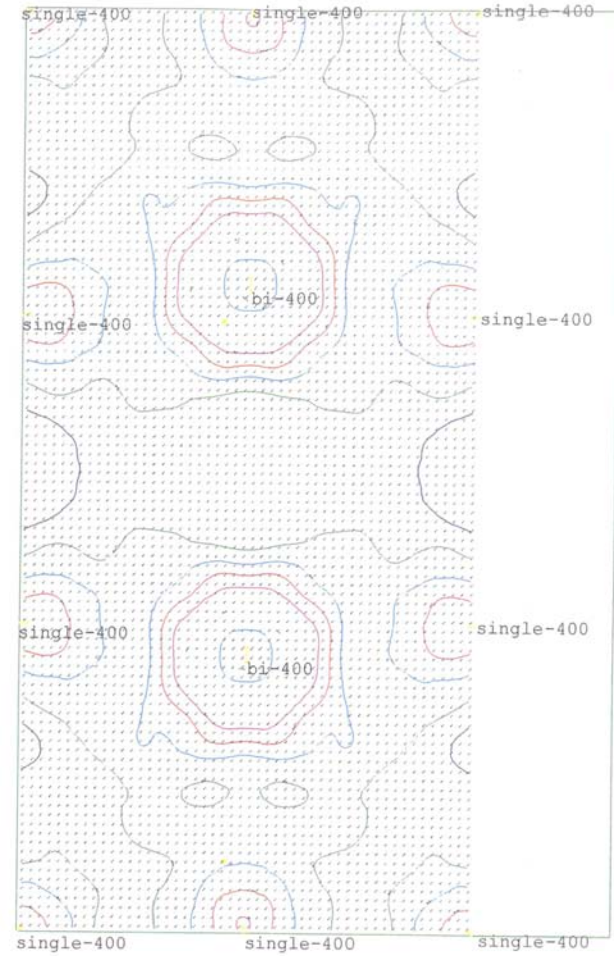
CONFIGURATION 6: CONCRETE

-- red	4.1 cd/m^2	-- turquoise	3.6 cd/m^2
-- purple	2.5 cd/m^2	-- yellow	5.1 cd/m^2
-- green	3.0 cd/m^2	-- pink	4.6 cd/m^2



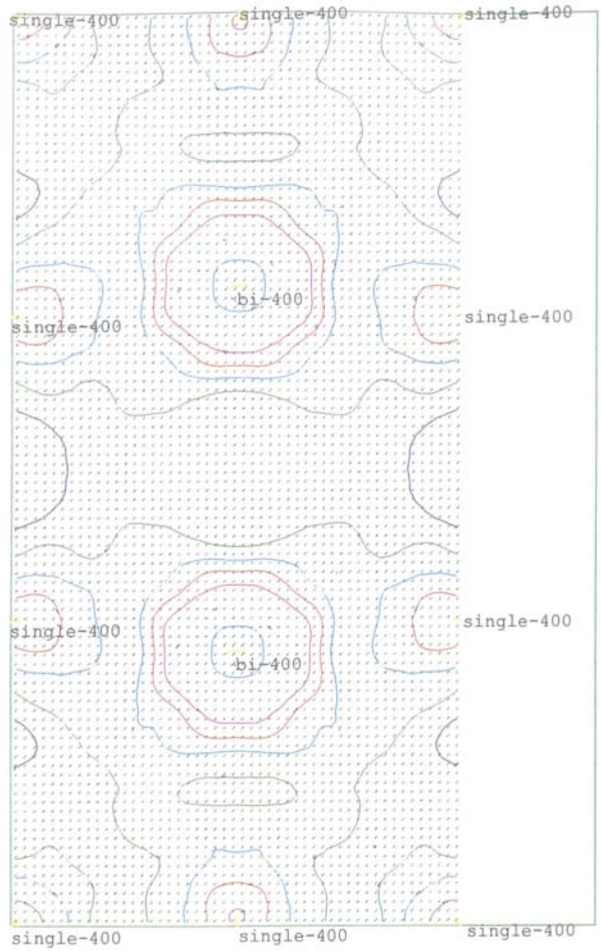
CONFIGURATION 7: CONCRETE

-- red	5.1 cd/m^2	-- turquoise	4.2 cd/m^2
-- purple	2.5 cd/m^2	-- yellow	6.8 cd/m^2
-- green	3.4 cd/m^2	-- pink	5.9 cd/m^2



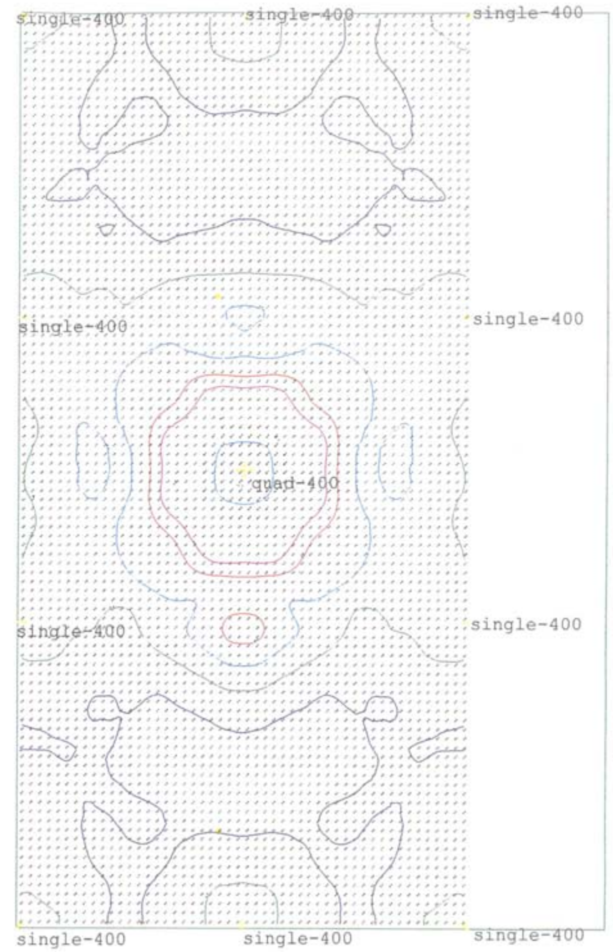
CONFIGURATION 8: CONCRETE

-- red	3.9 cd/m^2	-- turquoise	3.4 cd/m^2
-- purple	2.3 cd/m^2	-- yellow	4.9 cd/m^2
-- green	2.8 cd/m^2	-- pink	4.4 cd/m^2



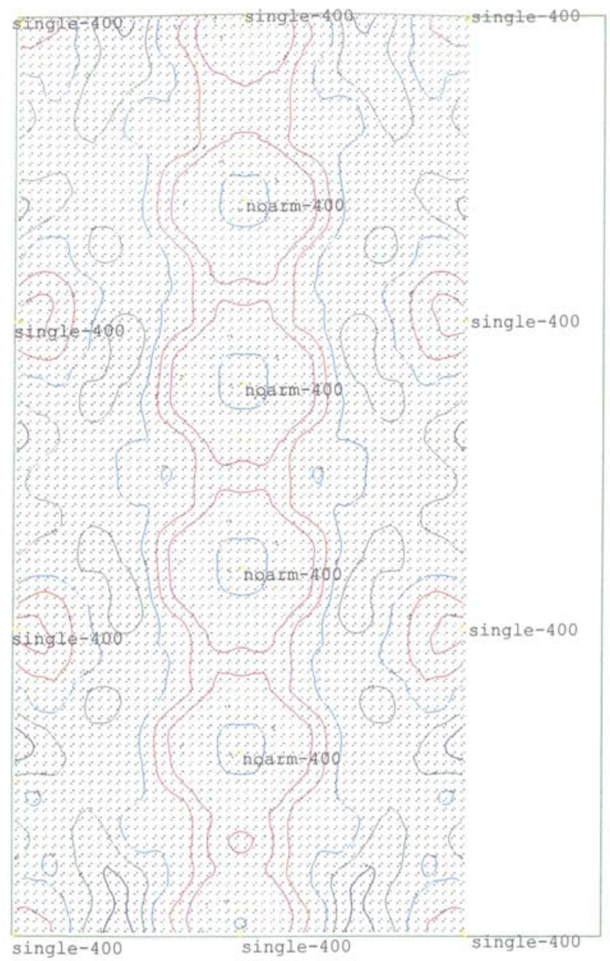
CONFIGURATION 9: CONCRETE

-- red 3.9 cd/m^2 -- turquoise 3.4 cd/m^2
-- purple 2.3 cd/m^2 -- yellow 4.9 cd/m^2
-- green 2.8 cd/m^2 -- pink 4.4 cd/m^2



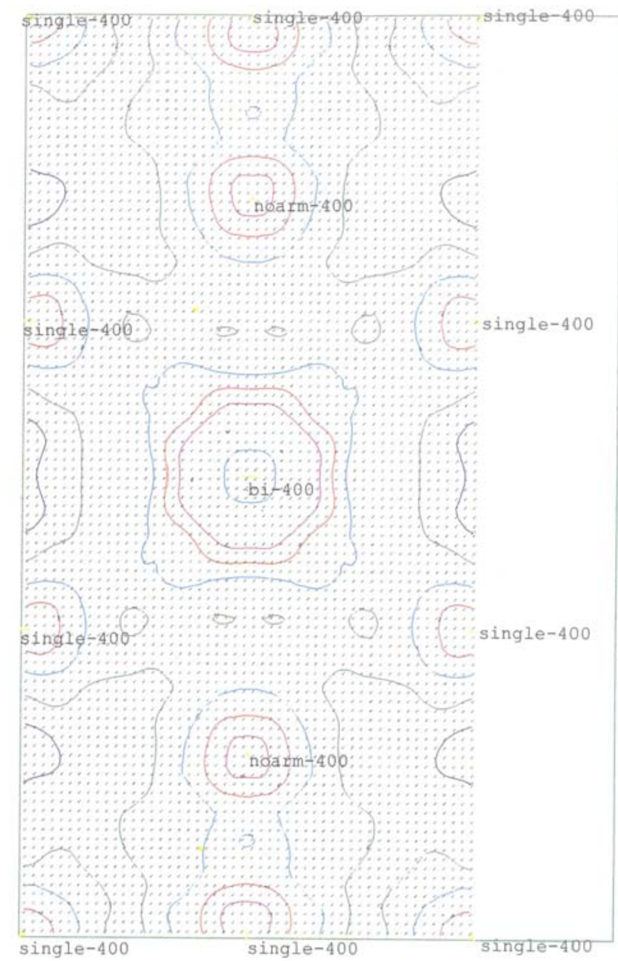
CONFIGURATION 10: CONCRETE

-- red 5.8 cd/m^2 -- turquoise 4.6 cd/m^2
-- purple 2.1 cd/m^2 -- yellow 8.2 cd/m^2
-- green 3.4 cd/m^2 -- pink 7.0 cd/m^2



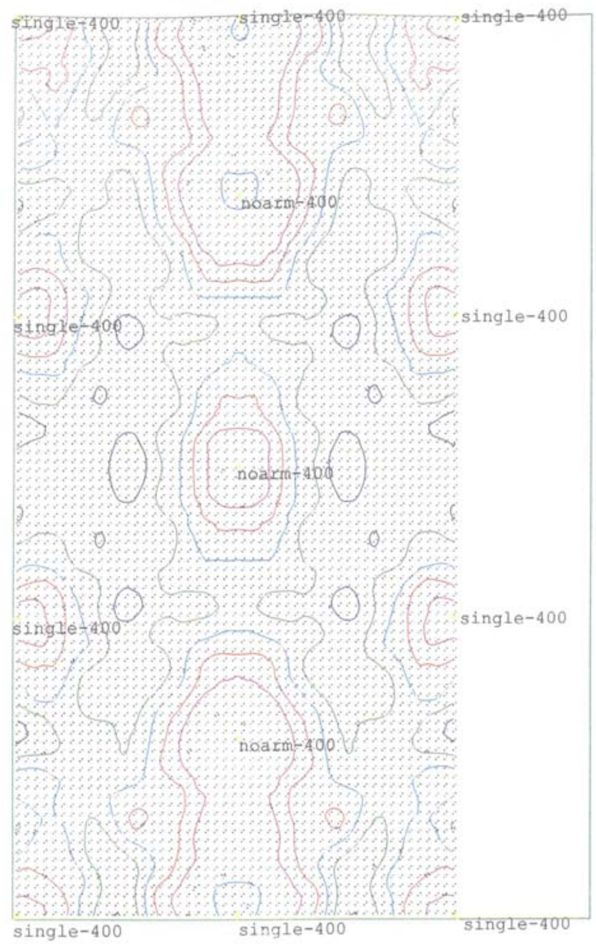
CONFIGURATION 11: CONCRETE

-- red	3.6 cd/m^2	-- turquoise	5.3 cd/m^2
-- purple	2.5 cd/m^2	-- yellow	4.3 cd/m^2
-- green	2.9 cd/m^2	-- pink	3.9 cd/m^2



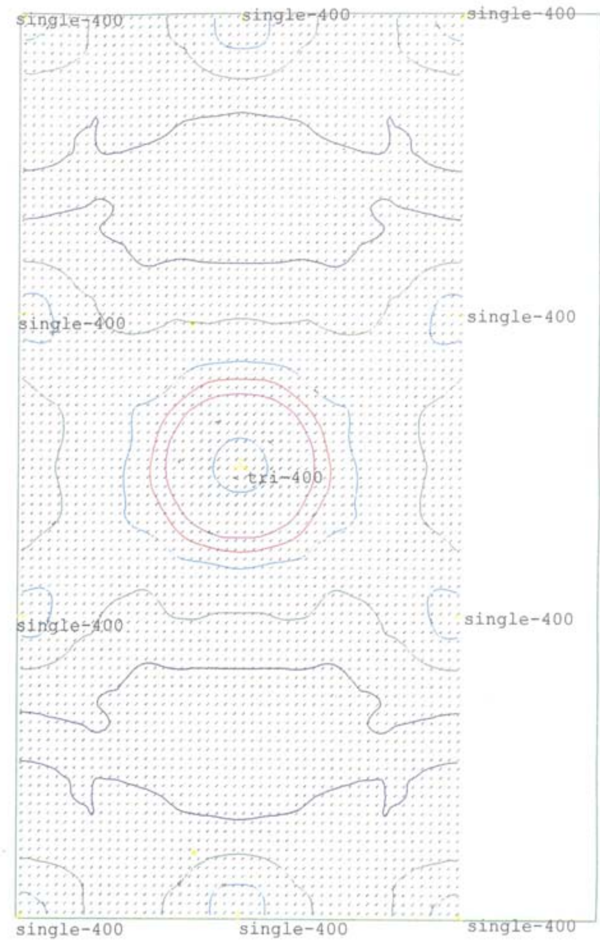
CONFIGURATION 12: CONCRETE

-- red	5.2 cd/m^2	-- turquoise	6.4 cd/m^2
-- purple	2.7 cd/m^2	-- yellow	6.9 cd/m^2
-- green	3.5 cd/m^2	-- pink	6.1 cd/m^2



CONFIGURATION 13 CONCRETE

-- red	3.3 cd/m^2	-- turquoise	4.9 cd/m^2
-- purple	2.4 cd/m^2	-- yellow	3.9 cd/m^2
-- green	2.7 cd/m^2	-- pink	3.6 cd/m^2



CONFIGURATION 14 CONCRETE

-- red	4.6 cd/m^2	-- turquoise	9.1 cd/m^2
-- purple	2.0 cd/m^2	-- yellow	6.4 cd/m^2
-- green	2.9 cd/m^2	-- pink	5.5 cd/m^2