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Chapter 6
Luminance contrast distribution analysis in selected pedestrian crossings configurations

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Dedicated lighting fittings for pedestrian crossings have increased the sense of security. Despite this, accidents often occur at nighttime. The paper contains legal and normative requirements regarding illumination of pedestrian crossings. The results of the calculation of luminance contrast at selected configurations of pedestrian crossings meeting the lighting requirements are shown.

Index terms: lighting design, lighting of roads, lighting of pedestrian crossings, luminance contrast

Introduction

According to EuroStat data [1], in Poland there are 9 fatalities per 100 road accidents, which is the highest number in Europe. This number decreases year by year, but the situation is quite different on Polish pedestrian crossings. From 2012 to 2017, there were 95,000 incidents involving pedestrians, of which 37,000 occurred at pedestrian crossings. Over the years, a concerning increase in the number of injuries and victims in incidents at crossings has been noted. It is therefore justified to install additional lighting fixtures within pedestrian crossings. The article points out that the existing requirements in this area should be adjusted to take into account luminance distribution.

Normative and technical requirements

All important requirements for road lighting are contained in the PN-EN 13201 standard [2]. The first part of this document contains a division into road lighting classes (Table 6.1), while the second part contains the operational requirements for road lighting.

In July 2018, the Ministry of Infrastructure and the National Road Safety Council recommended the use of the following document in designing "Guidelines for organizing safe pedestrian traffic. Guidelines for proper lighting of pedestrian crossings" [3]. An additional PC lighting class was established in the guidelines for dedicated lighting at pedestrian crossings. This solution consists in setting additional lighting fixtures as shown in Figure 6.1.

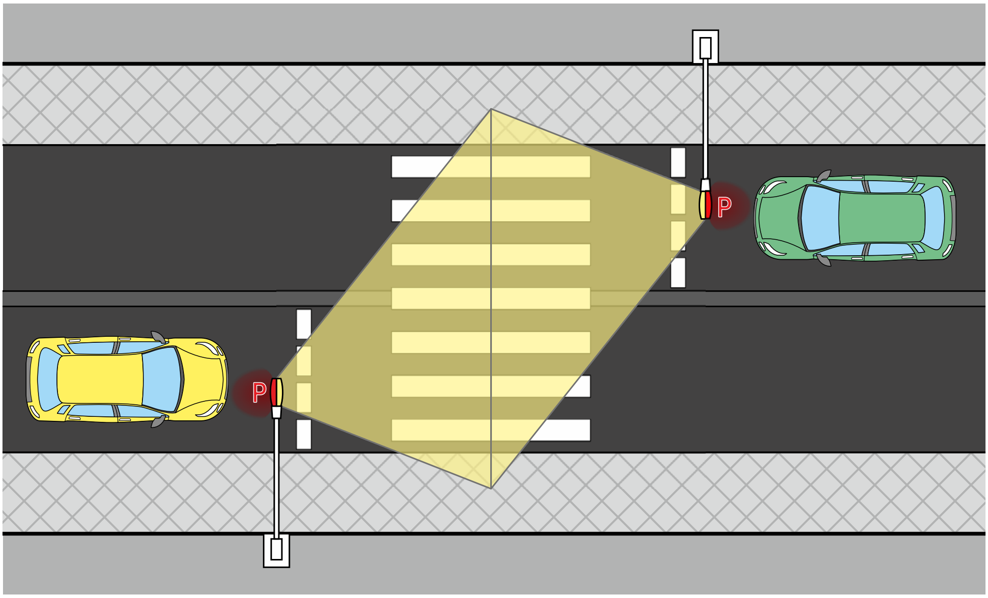

FIGURE 6.1. **Example of dedicated pedestrian crossing lighting solution [3]**

It is necessary to use lighting fittings with asymmetrical light distributions shown in Figure 6.2. The PC class determines the values of vertical and horizontal lighting intensity within the pedestrian crossing, depending on the lighting class of the road in which the dedicated pedestrian crossing lighting is designed. Tables 6.2 and 6.3 contain the requirements of PC classes for various classes M or C, while Figure 6.3 shows the geometry of measuring the horizontal illuminance E_h and vertical illuminance E_v. The indications of the guidelines [3] coincide with the requirements of PN-EN 13201 and supplement the standard. The General Directorate for National Roads and Motorways, citing the requirements of the Czech Ministry of Transport regarding pedestrian crossing lighting [4], published guidelines for pedestrian crossing lighting [5] which are similar to the indications described below.

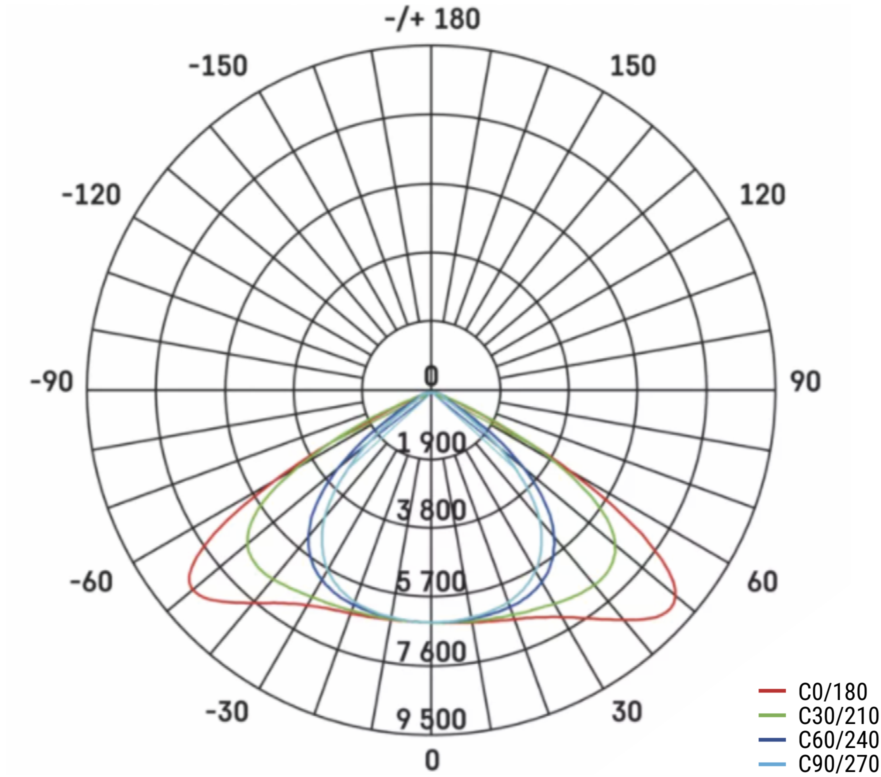

FIGURE 6.2. Example of light distribution of luminaires for pedestrian crossing in the PC class [3]

TABLE 6.1. Road lighting classes and their applications in accordance with PN-EN 13201 [2]

Lighting classes	Class application
M	The main road users are motor vehicle drivers. There may be communication routes. Medium and high speed.
C	Conflict areas (simultaneous occurrence possible): motor vehicles, pedestrians, cyclists; used for areas with variable road geometry or increased collision probability.
P	The main road users are pedestrians and cyclists. Used for lighting sidewalks and bicycle paths. Permitted movement of motor vehicle drivers at low speeds – residential streets.
EV	Additional class: used when the visibility of vertical surfaces must be ensured.
HS	Additional class: pedestrian traffic mainly on pedestrian roads, parking lanes, traffic surfaces lying separately or along the road, housing estate roads.
PC	Additional class used when the main purpose of lighting is to identify people, objects and road surfaces.

TABLE 6.2. Operating requirements of PC classes for the road in class M [3]

Road lighting		**Pedestrian crossing lighting**					
Values before and after the pedestrian crossing		PC classes	Measuring planes				Point A, B, C, D, E, F
M classes	L_m		Vertical		Horizontal		
	[cd/m²]		E_{vm}	$U_{0\,V}$	E_{hm}	$U_{0\,h}$	$E_{v\,min\,(A,\,B\ldots)}$
			[lx]	[–]	[lx]	[–]	[lx]
M1	2.00	No need for dedicated solutions					
M2	1.50	**PC1**	75	0.35	75	0.4	5.0
M3	1.00	**PC2**	50	0.35	50	0.4	4.0
M4	0.75	**PC3**	35	0.35	35	0.4	4.0
M5	0.50	**PC4**	25	0.35	25	0.4	3.0
M6	0.30	**PC5**	15	0.35	15	0.4	2.0

TABLE 6.3. Operating requirements of PC classes for the road in class C [3]

Road lighting		**Pedestrian crossing lighting**					
Values before and after the pedestrian crossing		PC classes	Measuring planes				Point A, B, C, D, E, F
C classes	E_m		Vertical		Horizontal		
	[lx]		E_{vm}	$U_{0\,V}$	E_{hm}	$U_{0\,h}$	$E_{v\,min}$
			[lx]	[–]	[lx]	[–]	[lx]
C0	50	No need for dedicated solutions					
C1	30	**PC1**	75	0.35	75	0.4	5.0
C2	20	**PC2**	50	0.35	50	0.4	4.0
C3	15	**PC3**	35	0.35	35	0.4	4.0
C4	10	**PC4**	25	0.35	25	0.4	3.0
C5	7.5	**PC5**	15	0.35	15	0.4	2.0

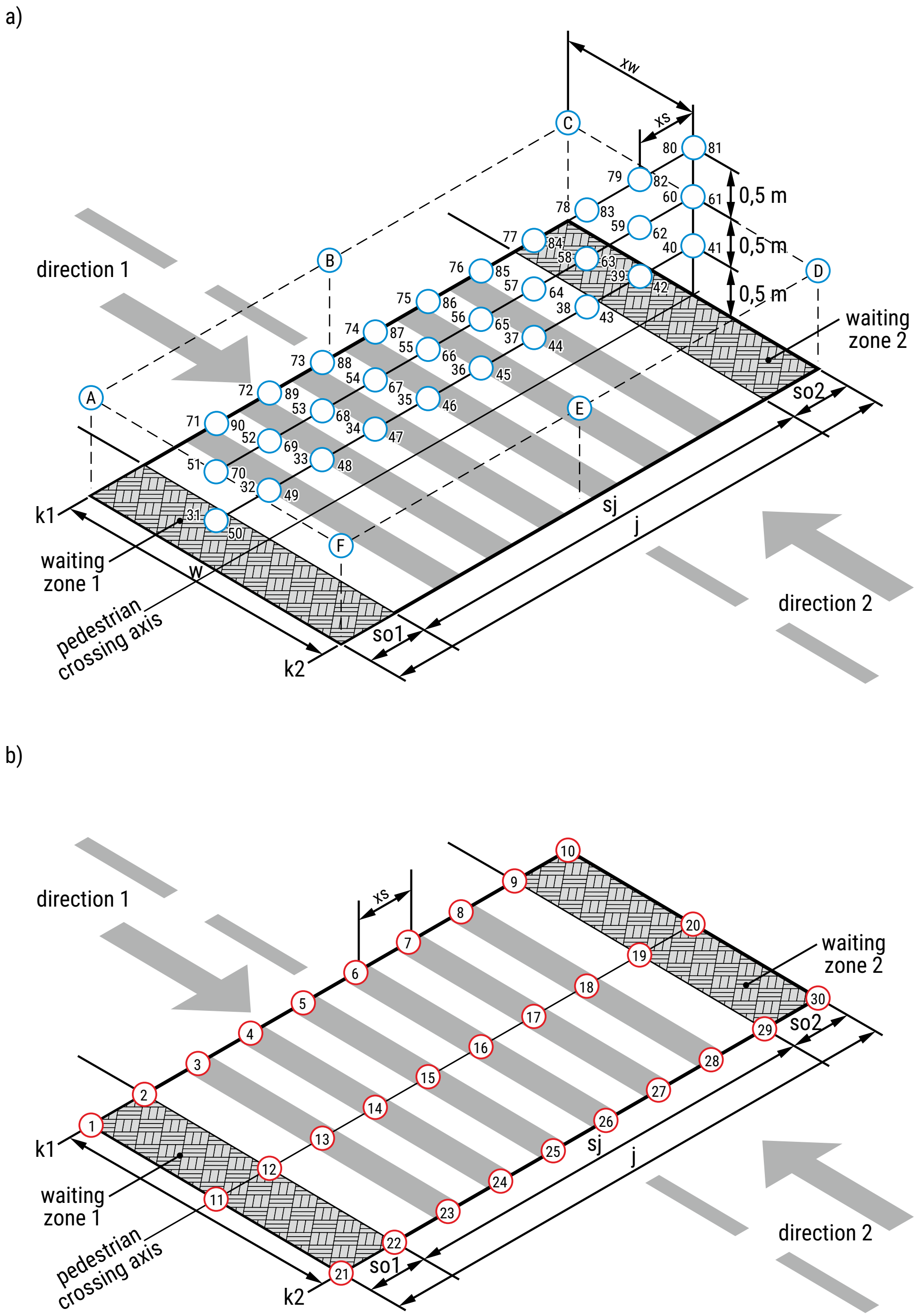

FIGURE 6.3. Geometry of illuminance measurement: a) vertical, b) horizontal

luminance in lighting of pedestrian crossings

A common feature of the presented requirements and guidelines for lighting pedestrian crossings are only the quantitative and qualitative parameters of lighting intensity. There is no analysis of the luminance of objects (mainly pedestrian luminance) that may be at the crossings. Luminance, or more precisely the luminance contrast C between the observed object and the background (1) allows to detect objects [6]:

$$C = \frac{L_o - L_T}{L_T} \rightarrow L_0 = \frac{\rho \cdot E_v}{\pi} \rightarrow C = \frac{\left(\frac{\rho \cdot E_v}{\pi} - L_T\right)}{L_T}, \qquad (6.1)$$

where:
C – luminance contrast,
ρ – total reflection coefficient of the objects,
E_v – vertical illuminance [lx],
L_o – object luminance [cd/m^2],
L_T – background luminance [cd/m^2].

FIGURE 6.4. Measurement of the luminance distribution of the observed environment [6]

When analyzing the results of the measurement of the luminance distribution visible in Figure 6.4, it can be stated, that there are situations when it is difficult or even impossible to detect the object despite lighting the area according to the requirements [2, 5]. In the event that the luminance contrast C is close to one, there is a high probability of not noticing the object on the road. Obtaining sufficiently high luminance contrast values across the entire width of the pedestrian crossing requires a different view of the lighting problem. The situation can be solved by using a lighting system that could dynamically modify the distribution of light using for this purpose optical systems with advanced structures [7, 8].

Numerical calculations in DIALux software

In order to check in which lighting situations the above described phenomenon may occur, simulation calculations were performed using DIALux software. Road lighting was designed (Fig. 6.5) along with the infrastructure with parameters included in Table 6.4. Various configurations of the location of the pedestrian crossing with respect to the road lighting poles and the possibility of pedestrian movement in the axis of the crossing and at its edges were considered. The pedestrian crossing was considered with the location:

- directly behind the lighting pole,
- between lighting columns,
- directly in front of the lighting column.

FIGURE 6.5. View of the road lighting project in the DIALux software

TABLE 6.4. Parameters of the road designed in the DIALux software

Parameter	Value
Road class according to PN-EN 13201	M3
Average road luminance	L_m = 1.00 [cd/m^2]
Uniformity	$U_0 \geq 0.40$ $U_l \geq 0.60$
Road width	7 [m]
Road surface	R3, q_0=0.07
f_{TI}	≤ 15%

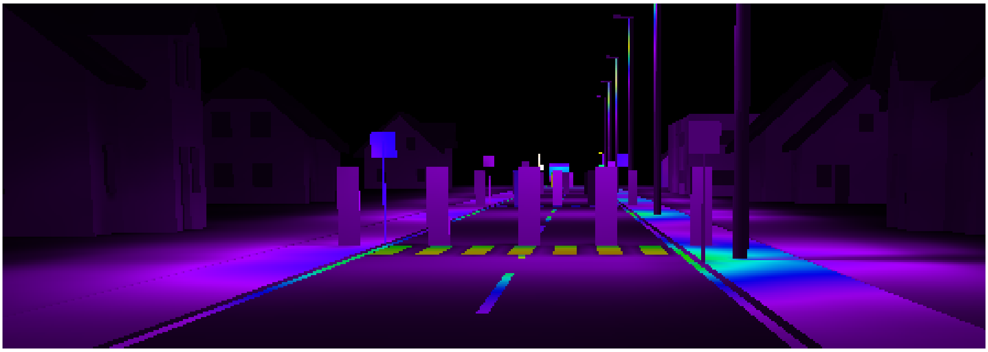

FIGURE 6.6. **Luminance distribution from the driver's perspective**

In the DIALux software, pedestrians are represented as a cuboid for which the value of the coefficient of reflection of the surface of the side walls was changed successively by 0.1; 0.4; 0.8, which in practice may mean a different color of clothing for pedestrians. Based on the results of the simulation, the average luminance of the cuboid wall seen from the driver's side was calculated, and the background luminance value to determine the luminance contrast. In each case, the illuminance value of the silhouette of the pedestrian model did not change.

The analysis of the results leads to the conclusion that for different values of the reflection coefficient, the luminance contrast value can differ significantly from 1. In this case, there is an insufficient luminance contrast difference, which can lead to a distorted perception of the object on the road. The contrast itself should be analyzed as an absolute value calculated according to the formula (1). Luminance contrast *C*, both negative and positive, is only acceptable in selected pedestrian configurations relative to pedestrian crossing positions [9].

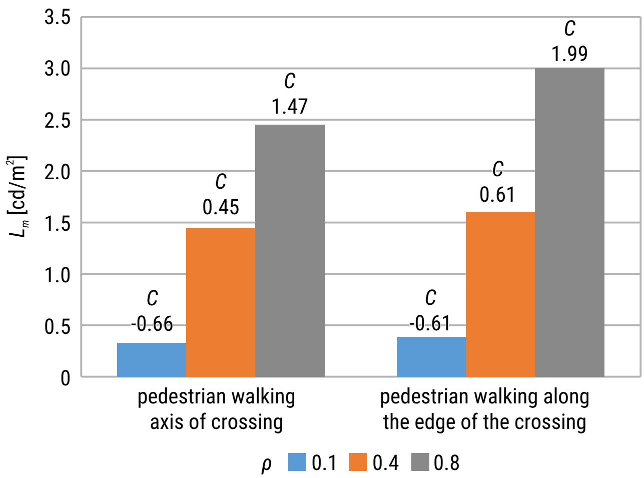

FIGURE 6.7. **Value of the average luminance of the pedestrian model and calculated luminance contrasts, pedestrian crossing directly behind the lighting column**

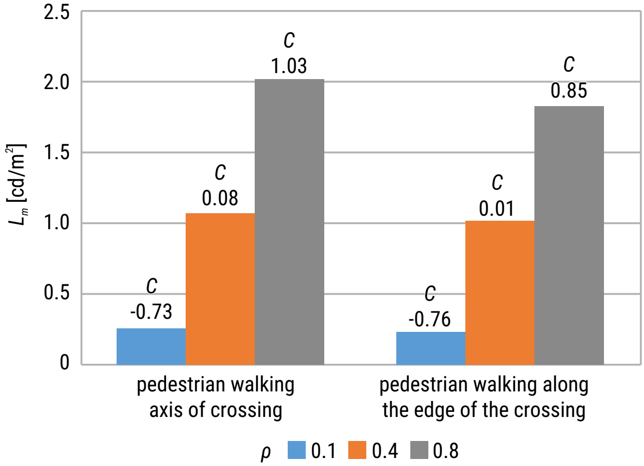

FIGURE 6.8. The value of the average luminance of the pedestrian model and calculated luminance contrasts, pedestrian crossing between lighting columns.

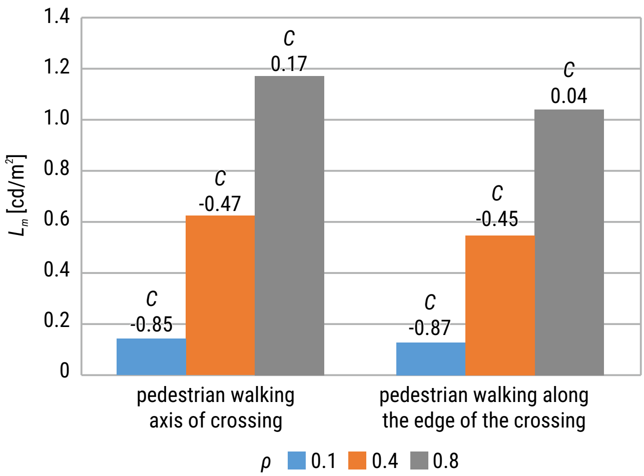

FIGURE 6.9. The value of the average luminance of the pedestrian model and the calculated luminance contrasts, pedestrian crossing in front of the lighting column

In the considered case, a dedicated pedestrian crossing lighting system recommended by regulatory requirements was also analyzed [2, 3, 5]. Figure 6.10 presents an increase in the luminance contrast value using a dedicated lighting system, however, when the pedestrian reflection coefficient is 0.1, the contrast value is $C \leq 1$. This situation proves that the requirements of the standards, taking into account only the distribution of illuminance, may be insufficient and require an additional assessment of the luminance arrangement.

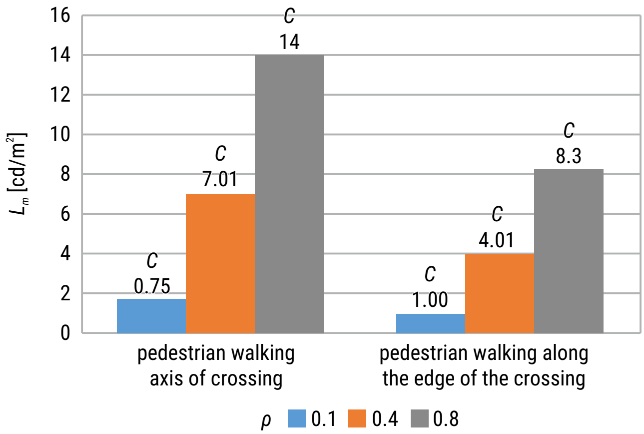

FIGURE 6.10. **The value of the average luminance of the pedestrian model and calculated luminance contrasts, pedestrian crossing with a dedicated lighting system**

Conclusion

The use of road lighting is an obligation arising from standards and legal provisions. Current requirements allow for the use of dedicated lighting systems for pedestrian crossings to see the pedestrian as early as possible. Specific values of illumination within the pedestrian crossing must be met, depending on the lighting class of the road on which the crossing is located. Unfortunately, the presented analyses may face the problem of the correct process of visibility on the road. The current requirements do not address the aspect of luminance contrast in relation to pedestrian crossings. High luminance contrast ensures the ability to correctly observe the field of view. In extremely unfavorable lighting conditions it may happen that the luminance of the surroundings and the pedestrian luminance are similar, which may result in an accident. Adverse conditions do not necessarily mean an unlit road. It is therefore necessary to create a lighting system that could analyze the luminance contrast within the pedestrian crossing. In addition, it should allow for dynamic change in light beam distribution. This feature can allow for proper lighting of pedestrians walking not only within the crossing axis, but also in any of its areas.

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