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VISUAL PERFORMANCE OF TUNNEL LIGHTING ALONG THE JAKARTA OUTER RING ROAD

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Abstract

Traffic jam is a trade mark of the street of Jakarta and the government has done their best to overcome this. One way to overcome traffic jam is to build tunnel or underpass. To provide safe traffic, the underpass should be equipped with street mark, traffic signs, and lighting. Nevertheless, base on our early survey, underpass or tunnel lighting had not been designed optimally. This research is conducted to find the visual performance of underpass in Jakarta, to measure the lighting and finally to evaluate and to recommend the lighting system if needed. The research method is to measure the luminance and illumination on the surface of street under the underpass along the Jakarta outer ring road, such as underpass Pasar Rebo at TB. Simatupang, underpass Ampera/Trakindo, underpass Rambutan and underpass Cijantung. According to SNI standard, underpass luminance in Indonesia is 2 cd/m^2 and the illuminance is 20 lux. Beside that, CIE standard state that there is a differences in tunnel lighting according to its zone and there is also differences between day and night lighting in the tunnel.The findings of this research are the underpass lighting has not meet the SNI nor the CIE standard (some underpass has less or bigger than standard luminance and illuminance) and the luminance and illuminance are homogen along the underpass. These are the effect of poor lighting design and lack of lighting maintenance. We hope the result of this research will contribute to tunnel lighting design as well as recommendation to Dinas Perindustrian dan Energi and PT Jasa Marga as the manager of street and tunnel lighting in Jakarta.

Keywords: Tunnel, illuminance, luminance, tunnel lighting, SNI and CIE standard.

INTRODUCTION

Tunnel is one of the infrastructure built to provide better traffic flow and safe for driving. Dense traffic causes congestion and longer the time to the destination. The tunnel was made to divert traffic through an intersection in order to bypass other traffic with elevation engineering. Elevation difference between the public road and tunnel allows both lines intersecting the horizontal section at different vertical levels so that each traffic lane does not interfere with each other [1]. During the day, levels of natural light in the tunnel is inversely proportional to its length, i.e. the longer tunnel is, the lesser level of natural light in the tunnel. The width of tunnel opening, height of tunnel, the orientation of the openings, and the reflection coefficient of the surface in the tunnel are factors that affect the level of natural light in the tunnel [1]. Outside the tunnel, natural light intensity is very high, where as inside the tunnel the natural light intensity is very low, so it is necessary to design the lighting inside the tunnel during the day. Meanwhile at night, artificial lighting system is used as the primary light source since the natural lighting is not available.

Local government/municipalities and PT. Jasa Marga Tbk, are responsible for maintenance of tunnel lighting as part of public road lighting (Penerangan Jalan Umum - PJU). PJU is a form of service to the community in order to improve the security and safety of street users, tunnels, and the environment. Based on preliminary observations in several tunnels in Jakarta, we found that (a) some lights in the tunnel were off so it does not meet the standard lighting level, (b) there is excessive levels of illumination in some

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tunnels during the day and (c) the influence of luminance caused by multiple reflection from the road surface, walls and roof of the tunnel were not considered. These will cause the motorists who enter the tunnel to see a glare. Lack or excess lighting and luminance levels can be dangerous because it would distract the motorist and the worst consequence is traffic accident.

MATERIALS AND METHOD

The tunnel is covered structures road, generally below the elevation of the road at ground level [2]. The word tunnel and underpass in Bahasa Indonesia has one equivalent word, e.i. "terowongan". The word "terowongan" means the structure of a long underpass and its physical configuration does not limit the driver to see objects in the structure. Usually artificial lighting is not necessary during the day because the length of the underpass is generally less than 25 m [3]. Tunnel interpretes as covering roads, both natural and artificial, in which natural light is blocked such that the driver can not see anything[3]. The tunnel can be divided into "long tunnel" and "short tunnel" is based on the clarity of vision. Short tunnel is a tunnel that is clearly visible the other end of tunnel from a point right in front of the tunnel entrance, when no vehicles pass. Usually the length of short tunnel is limited to 75 meters [1]. During the day, the short tunnel does not require artificial lighting because the entry of sunlight during the day from both sides of the short tunnel, plus the effect of bright light silhouettes the other end of the tunnel, generally guarantee a satisfactory visibility. Examples of tunnel lighting can be seen in Figure 1.

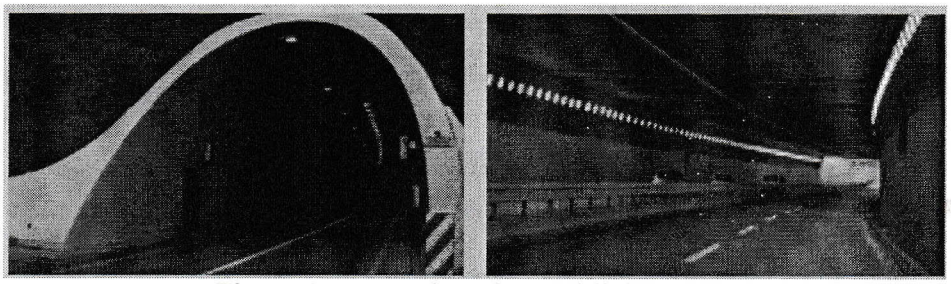

Figure 1. Examples of tunnel lighting [4]

The basic purpose of the tunnel lighting is to provide sufficient visibility and convenient for motorist so that they can pass through the tunnel safely, both in day time and at night time [1]. To achieve these objectives, there are several things to be considered [5]:

1. Lighting should provide sufficient illuminance level and uniformly for the driver along the tunnel both in dry and wet conditions.
2. The angle of the light the lamp relative to the driver's eyesight should provide a high level of vision to the road markings in all weather conditions.
3. The bottom of the tunnel must have adequate lighting levels
4. Lighting should not cause glare
5. The lighting should not flicker

In addition to those things, the human eye's ability to adapt changes in light levels should be considered as well. The human eye's can not adapt from bright to dark as quickly as to adapt changes from dark to bright. This is called the black-hole conditions. By paying attention to the this matter, the level of lighting in a long tunnel is divided into five different zones, i.e. access zone, threshold zone, transition zone, interior zone and exit zone, as shown in Figure 2.

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The level of lighting in the tunnel, express in the values of the average horizontal road at minimum condition. The wall reflection of 70% or more and the use of luminaires (lighting fixtures) which illuminate the road and wall, will contribute a horizontal lighting levels such that the visibility will be satisfactory or good enough. In this condition, the horizontal illumination level will also provide sufficient vertical lighting levels. Tunnel lighting depends on the length, geometry and traffic density as shown in Table 1.

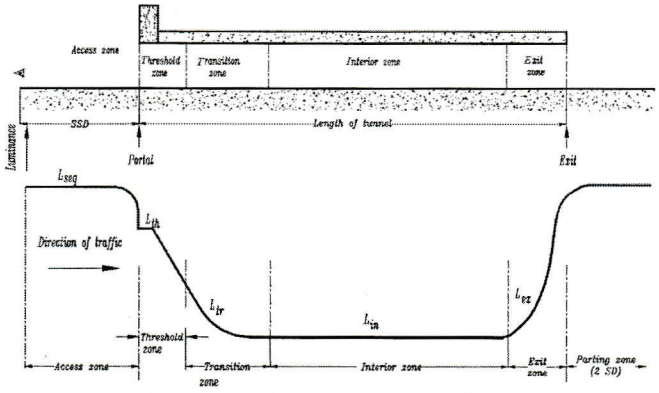

Figure 2. Five Zone Tunnel [1]

Table 1. Tunnel lighting according to the length , geometry and traffic density [4]

Length of tunnel	<25m	25-75m					75-125m						>125m
Is exit fully visible when viewed from stopping distance in front of tunnel?	-	yes	yes	no	no	no	yes	yes	no	no	no	no	-
Is daylight penetration good or poor?	-	-	-	good	good	poor	-	-	good	good	good	poor	-
Is wall reflectance high (>0.4) or low (<0.2)?	-	-	-	high	low	-	-	-	high	high	low	-	-
Is traffic heavy (or does it include cyclists or pedestrians) or light?	-	light	heavy	light	-	-	light	heavy	light	heavy	-	-	-
Lighting required	●	●	◐	●	◐	◐	◐	○	◐	○	○	○	○

● No day time lighting ◐ 50% of normal threshold zone lighting level ○ normal threshold zone lighting level

Tunnel lighting in the daytime is different from night time. However, the lighting of the tunnel is determined by the following factors [6]:

1. Lighting Control
   Luminance produced by lighting in the tunnel must meet the standards of the percentage of the access zone luminance. Access zone luminance will change according to sunlight conditions outside the tunnel. This led to the emergence of automatic switching facility which set the level of artificial lighting along the tunnel so that the ratio of the luminance of the access zone and threshold zone is not changed.
2. Glare
   Glare can reduce visibility so that glare should be minimized. Glare is called Threshold Increment (TI), and it must be less than 15 percent for all zones except exit zone when the sun shines.
3. Uniformity
   The road surface and tunnel walls must have good uniformity illumination so that both can help to detect obstacles in the path of the vehicle in the tunnel. Road surface and wall of height 2 meter should have a ratio of the overall luminance (Lmin / Lav) is greater than 0.4. Average luminance on the wall should not be lower than the average

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luminance on the adjacent road, without eliminating the curb of the road. Luminance ratios longitudinally along the center line of each lane (Lmin/Lmax) should be greater than 0.6. The high uniformity is not recommended for long distance, because it can lead to driver's fatigue and loss of contrast.

4. Flicker
   Luminaire installed on lines that criss-cross along the tunnel can produce a flicker in the eyes of the driver. Flicker is caused by light from the luminaire itself and by the reflection of light on shining luminaire surfaces, such as: the bonnet of a vehicle and the back of another car being followed. Flicker that disturbs the driver, depend on the following three factors [4]: luminance difference in a single cycle, the number of luminance change that occur per second (flicker frequency) and the total time of flicker occurrence.

The problem of tunnel lighting at night is simpler because it is derived from artificial lighting only. There are 2 things to consider [1]:

1. If the tunnel is part of illuminated highway, then the quality of light in the tunnel must be at least equal to the quality of light beyond the tunnel, thus forming a uniform lighting level. The lighting level is equal to lighting level in the tunnel during the day
2. If the tunnel is not part of the illuminated highway, the luminance on the surface of the highway is at least of 1 cd/m2.

There are 2 ways of setting the arrangement of the lights in the tunnel to reach the appropriate lighting levels [4]:

1. Ceiling mounting, the installation of luminaires along the roof/ceiling of the tunnel, can be mounted on 1 line or 2 lines.
2. Wall mounting, the installation of luminaires along the walls of the tunnel, usually mounted in the second line on left and right tunnel.

Some types of lamps are recommended to be used as lighting in the tunnel are [7,8,9,14]: Fluorescent lamps, low pressure sodium lamps, high pressure sodium lamp, high voltage mercury lamp, LED (Light Emitting Diode) and electrodeless lamps (Induction lamps) [10]. LED lights are less advisable for tunnel lighting, because the installation is complex, and has not be consistent in color light, lamp life and efficacy. [10]. Nevertheles, nowadays there are LED lamps that are used as Public Lighted Road (Penerangan Jalan Umum - PJU) with good performance [11,12]. However, LED lamps will not have a good performance, if planning, design and installation phases are not done optimally. This can be found on the PJU at Jl. Antasari Jakarta, the excessive use of LED lamps that have illumination level far exceed the ISO standards and have glare [13].

The purpose of this study was to determine the visual performance of tunnel lighting along the Jakarta Outer Ring Road which includes Cibubur tunnel, Pasar Rebo/ TB. Simatupang tunnel, Ampera/Trakindo tunnel and Cijantung-Rambutan tunnel. The benefit of research is to provide input to the Department of Industry and Energy Jakarta and PT. Jasa Marga Tbk, on visual performance of several tunnels in Jakarta. Hopefully the research results can be used as a reference to repair the tunnel lighting, so safety and security for users of public roads can be assured. The data were collected from physical measurements in the surface of the road along the tunnel, i.e. measurement of the illuminance and luminance of tunnel lighting. The equipments required in the measurement are: Luxmeter to measure lighting level (illuminance) in lux, Luminance meter to measure luminance in Candela/m^2, Otomatic Distance Meter to measure distance between points of

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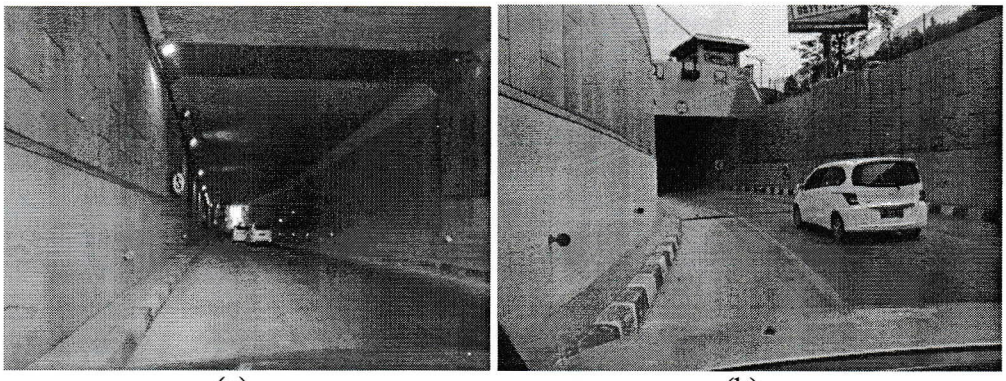
measurement and the dimension of tunnel. A digital camera to take pictures of the tunnel and types of lamp as well as to capture data related to luminance.

RESULTS AND DISCUSSION

Cibubur Tunnel/Underpass.

Cibubur tunnel is the latest tunnel operated in Jakarta which was inaugurated by the Minister of Public Works, Djoko Kirmanto on 25 Otober 2013 (Viva.co.id., 2013). The tunnel connects the highway toll gate Transyogi and Cibubur. The vehicles from Transyogi toll road can directly enter toll road Jagorawi, without pass through the Cibubur Junction mall. Vehicles come from the Cullinan, Cikeas or Jonggol areas across the Transyogi toll road usually congested around the Cibubur Juction mall. Congestion caused by the interfere of Jakarta traffic going to and from Cibubur Cimanggis. This tunnel is a part of Cibubur access road which has total length of 1199.657 m. The tunnel it self is 135.78 m length and 7 m width. It consists only one way traffic, which has width of 4 m. There are left road side (2 m wide) and right road side (1 m wide). Both sides are equipped with a coverred waterways which are 1 m wide. (see fig. 3). The tunnel consists of one lane, to the Cibubur toll booths towards Jagorawi toll road. There are some curves inside this tunnel so it requires some traffic signs to direct motorists.

Lighting in the tunnel come from lamps mounted on the top left of the tunnel. These mounted lights are on continuously for 24 hours to provide light to motorists, but it appears that no difference in the light intensity level for all zone in the tunnel. According to fig. 2, tunnel lighting during the day in the threshold zone has light intensity level greater than in other zones. In the next zone, the transition zone, the light intensity level gradually decline to light intensity level in the interior zone and finally, at the exit zone, light intensity level is climb up. It is necessary to provide an adaption zone to the motorists' eyes from the sun with a high light intensity level to the low light intensity level in the tunnel. In contrast to day time lighting, night time lighting in the threshold zone and exit zone has a lower light intensity level than the interior zone.



(a) (b)

Figure 3. Cibubur Tunnel (a) interior zones and (b) to access zone

Pasar Rebo Tunnel.

This tunnel is also known as TB Simatupang tunnel because it lies on the TB Simatupang road. The atmosphere of the tunnel at night time and day time (accessed from Merdeka.com/Arie Basuki) shown in Figure 4. The Pasar Rebo tunnel is a two-way divided tunnel, e.i. to Kampung Rambutan and to Cijantung (see Figure 4a). So actually this tunnel is a one lane tunnel because there is only one direction of traffic in each tunnel. The tunnel consists of three lanes and equip with a 1 m roadside on both side of the road

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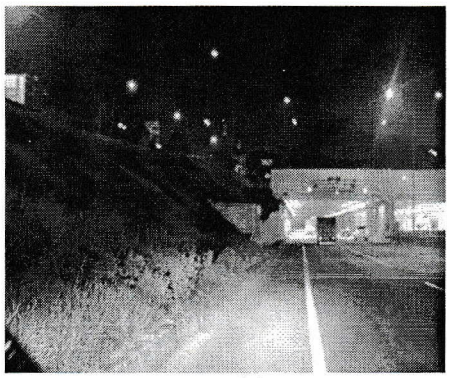
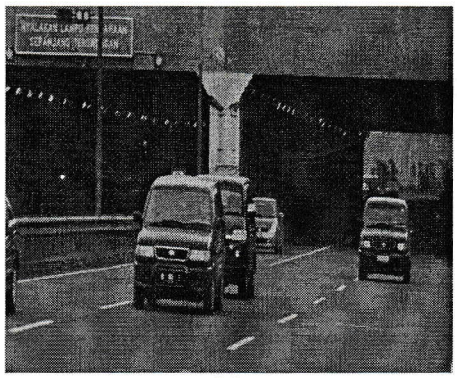
and uncovered waterways about 30 cm width. There are 66 lamps along the tunnel, 61 of them are High Pressure Sodium (HPS) lamps with a yellow color (CCT is 2000 K) and the rest are LED lamps with white color (CCT is 5000 K). The tunnel length is about 250 m, approximately 10.5 m wide and 5 m high. Lamps fitted with the same distance in all zones, e.i. 4 meters.

The result of illuminance measurement in this tunnel varies between 53 lux to 163 lux and uniformity value is 0.32. Illuminance and uniformity of TB Simatupang tunnel are larger than SNI standard, which is 20 lux. With uniformity values greater than 0.2 indicates a large difference between the minimum and maximum illuminance. This is due to improper installation of lamps, the lamps are installed alternately by means of luminaires installed in the upper wall of the tunnel (system ressesed) which shone downwardly and luminaires mounted (surface mounting system) on the wall which shone to the middle of the road. Overall system installation of lamps in TB Simatupang tunnel is called asymmetrical lighting wall mounting system (Thorn, 2004). The illuminance level on the road before and after the tunnel is less than 8 lux which is under ISO standard (11-20 lux). The illuminance level outside and inside the tunnel at night time shoud be the same. The big difference between the illumince level on the road leading to the tunnel and outing from the tunnel will cause visual discomfort to the driver's eyes.

During the day, the black hole phenomena will occur because there is no different in illuminance level in each zone of the tunnel, so that the eyes of motorists do not have the opportunity to adapt the difference illumination level between outside and inside the tunnel. Type of HPS lamps and LED lamps mounted alternately on TB Simatupang tunnel, causing the impression that mixed color between yellow and white (see Figure 5.8a). We recommend one type installation of lamps in the tunnel, so that the color impression is uniform, namely yellow (warm) or white (daylight or cool daylight). If there are two different color lamps, it shows a lack of planning in chosing lamps for the tunnel. But if there is a desire from the manager of the tunnel (in this case is Jasa Marga) to change the HPS lamps to LED lamps which have higher efficacy and longer lifetime (i.e. more than 50,000 hours), as well as better rendering color (i.e. 83%), then it should select the lamps tha have the same color impression or the same color temperature [15].



(a)



(b)

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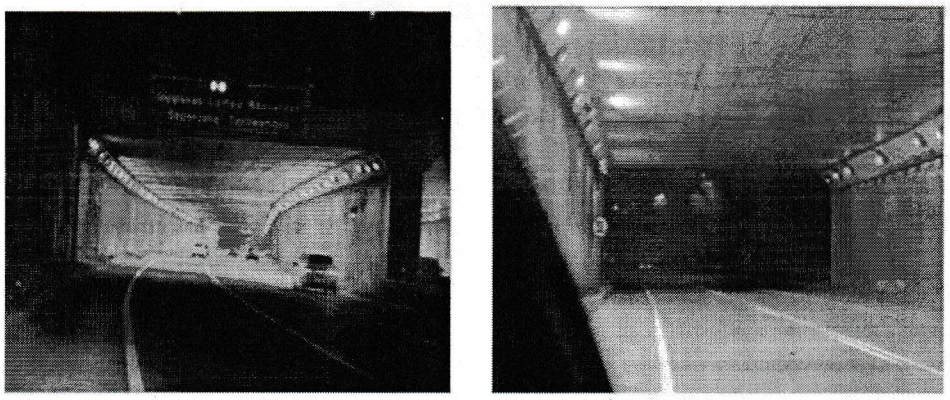
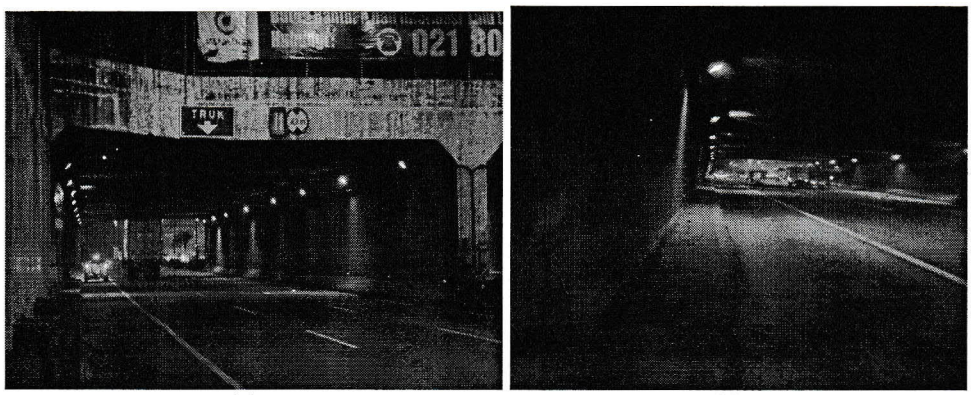


(c) (d)

Figure 4. Pasa Rebo Tunnel
(a) Devided tunnel separated by a wall (tunnel at night).
(b) Tunnel at the day
(c) Access zone and threshold zone
(d) Exit zone and 3 lanes of the road

Cijantung Tunnel/Underpass

The tunnel is located at the Jakarta Outer Ring Road (JORR) between the Cijantung and Kampung Rambutan road. This tunnel can be referred as underpass, has length of 60 m, width of 13.5 m, and consists of 3 lanes, roadside and sidewalks curbside (see Figure 5). As in Pasar Rebo tunnel, this underpass is consist of two directions traffic, but are separated by a dividing wall. Tunnel heght is 4.2 m. Level of lighting in the tunnel is unnuiform because the distances between the mounted lamps are too far. These conditions cause inconvenience for motorists'eyes, especially at night. This underpass in considered as short tunnels so it does not require division of zones. The tunnel is said to be short when someone standing at the end of the tunnel can still be seen clearly at the other end of the tunnel. The tunnel lighting can be made equal between zones while maintaining the quality of lighting such as illuminance and uniformity levels.



(a) (b)

Figure 5. Cijantung Tunnel/underpass.
(a) Not-uniform lighting tunnel (b) Short Tunnel (underpass).

CONCLUSIONS

1. The surveyed tunnel or underpass have not met the visual performance aspect of a tunnel lighting, which are illuminance, luminance and uniformity levels.

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2. Both, Pasar Rebo tunnel and the Cibubur tunnel, have the same illuminance level during night time and day time. Tunnel illuminance level during the day must be greater than night time, because of the high influence of sunlight.
3. The use of two different types of lamps with has different color temperature, give the mix color impression for motorists' eyes, which also less level of aesthetics.
4. Energy savings can be made with the use of LED lamp or induction lamp, instead of High Pressure Sodium lamps.
5. To meet the quality aspects of lighting in a tunnel during day time and night time, the automation of the lighting system in the tunnel can be developed.

ACKNOWLEDGEMENTS

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