STUDIES ON EFFICIENT LIGHTING DESIGN FOR STREETS AND HIGHWAYS

A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENT FOR DEGREE OF

MASTER OF ENGINEERING

IN

ILLUMINATION ENGINEERING

(ELECTRICAL ENGINEERING)

SUBMITTED BY

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This foregoing thesis is hereby approved as a creditable study in the area of Illumination Engineering, carried out and presented by Arghya Ghosh, in a manner of satisfactory warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned do not necessarily endorse or approved the thesis only for the purpose for which it has been submitted.

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I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Illumination Engineering studies.

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This is to certify that Mr Arghya Ghosh, a student of M.E. in Illumination Engineering, Electrical Engineering Department, Jadavpur University, has worked as an Intern in the Lighting Advisory Bureau of this Organisation from 1st June, 2018, to 31st March, 2019.

He carried out a project on "Efficient Lighting Design in Outdoor Application" under the guidance of Ms Uma Lanka, Associate Vice President – Design. During the tenure of his training with us, he has been sincere, hardworking and diligent in carrying out the assignment entrusted to him.

We wish him all success in his future endeavor.

For CROMPTON GREAVES CONSUMER ELECTRICALS LIMITED

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ACKNOWLEDGEMENT

I take this opportunity to express my deep sense of gratitude and indebtedness to Prof. (Dr.) Saswati Mazumdar, Professor of Illumination Engineering, Electrical Engineering Department, Jadavpur University, for her constant guidance, support, encouragement and supervision. I would like to thank her for providing me her valuable time and helpful suggestions.

I am very thankful to Ms. Uma Lanka, vice president of Crompton Greaves Consumer Electrical Limited for providing me the opportunity to carry out my project work in their company and for her continuous help and guidance. I am thankful to Mr. Phaneendra Babu Repalle and Mr. Sumit Kar and Mr. Sagar Bose and Mr. Prasenjit Roy, Head of the Designers of Crompton Greaves Consumer Electricals Limited and for their continuous help.

I would be glad to express my thanks to Prof. (Dr.) Biswanath Roy, Professor of Illumination Engineering, Electrical Engineering Department, Jadavpur University for his valuable suggestions and encouragement to carrying out this project work.

I would like to thank Prof. Suddhasatwa Chakraborty, Assistant Professor, Electrical Engineering Department, Jadavpur University and Prof. Sangita Sahana, Assistant Professor, Electrical Engineering Department, Jadavpur University, for their guidance and suggestions.

Again I would like acknowledge my sincere thanks to Prof. (Dr.) Kesab Bhattacharyya, Head of Electrical Engineering Department, Jadavpur University for providing me the opportunity to carry out my project work in illumination engineering laboratory, Jadavpur University.

I am also thanks to Mr. Gairik Saha, and Mr. Pradip Pal of the Illumination Engineering Laboratory for their co-operation during my entire course. Last but not least, my special thanks to Prof. Partha Ghosh and my friends who helped me in completing thesis successful.

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ABSTRACT

The necessity to illuminate our outdoor night time environment is to meet certain social goals, such as increasing safety and security, enhancing economic development, as well as highlighting historic areas or landmarks of cities or towns. Night time lighting has become a necessity to facilitate using roadways and downtown areas.

Outdoor lighting is used for a variety of purposes in our modern society. For work or recreation, it enables people to see essential detail in order that they may undertake their activities at night. It is used for advertising or display to promote products or services or to call attention to commercial premises by means of area lighting or signs. However most outdoor lighting is not so pleasing and sometimes even repulsive and accidents and crime still occurs. Furthermore excessive light is bad for the environment and it requires energy which causes light pollution.

Outdoor lighting projects such as Road Lighting, Highway Lighting have been included. The designs have been simulated by using lighting software and the quality criteria as recommended in different lighting standard have been achieved. Care is taken so that each of the design is energy efficient and avoids light pollution.

There are many lighting software to use as lighting design aids e.g., Dialux, AGI32, Calculux, CGlux, Photolux etc. The accuracy and perfection of the lighting simulation and its calculation results vary differently on those lighting Softwares. In this project all the lighting designs were simulated by using this AGI32 lighting software.

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Chapter 1

Road Lighting

1.1 Introduction

The India has a huge road network connecting its major cities and neighboring countries. It also has a large municipal and urban road network. Road lighting has always been an effective tool to promote security in urban, rural areas and to increase the quality of life by artificially extending the hours in which it is light so that activity can take place. Driving outside of daylight hours is more dangerous so, street lighting also improves safety for drivers, riders and pedestrians. It is not only a functional requirement which provides safety and security to motorists and residents it also helps us in creating an identity and image. Fixed lighting of public ways for both vehicles and pedestrians can create a night time environment in which people can see comfortably, and can quickly and accurately identify objects on the roadway being travelled. Roadway lighting can improve traffic safety, achieve efficient traffic movement, and promote the general use of the facility during darkness and under a wide variety of weather conditions. At the same time city lighting if not proper planned well can lead to energy waste, which is very precious. Currently, in the whole world, enormous electric energy is consumed by the street lights, which are automatically turn on when it becomes dark and automatically turn off when it becomes bright. These roadway systems should use low-glare luminaires that produce very little intensity between 70° and 90° from nadir and no intensity at 90° or above. A reduction in intensity at these high angles (70° to 90°) will reduce light pollution, minimize spill light and optimize the use of energy by placing the light where it is needed. High-angel intensity (70° and up) does little or nothing to produce illumination on a horizontal roadway surface.

1.2 Objectives of Road Lighting

The main function of road lighting is to make road traffic possible at night with an acceptable degree of safety and comfort. This holds not only for vehicle drivers but for other road users as well. Apart from these functions road lighting may also contribute to amenity and the quality of life more in particular to the aesthetic aspects of the night time scenery. The main objectives of providing and maintaining road lighting are to:

- Improve road safety (pedestrian and vehicle)
- Reduce the incidence of night time crime

- Improve the perception of street safety and security
- Increase leisure and commercial activity after dark
- Encourage walking, cycling and use of public transport
- Improve the effectiveness of other community safety measures such as closed circuit television (CCTV) and Automatic Number Plate recognition (ANPR)
- Create a quality environment for local people, business and tourism
- Economic and aesthetic enhancement of cities

1.3 Design Criteria

Before considering the lighting design parameters for road we need to know the basic lighting parameter which plays the dominant role in the seeing process illuminance or luminance. It is luminance in case of road lighting.

A surface is made visible by virtue of light being reflected from it and entering the eye of the observer. The greater amount of light entering the eye, the stronger will be the visual sensation experienced. Brightness will depend on the amount of light radiated by the surface per unit of bright area and per unit of solid angle in the direction of the observer. This is the luminance (L) at an element of the surface, which can be expressed as:

$$L = q \times E$$

Where, q = Luminance coefficient. This is measure the amount of light reflected by the surface in the direction of the observer.

E = Illuminance at an element of the surface

Since the brightness is finally determined by the luminance, not the illuminance. There are two types of lighting design methodologies:

1. Illuminance Methodology
2. Luminance Methodology

Illuminance Methodology:

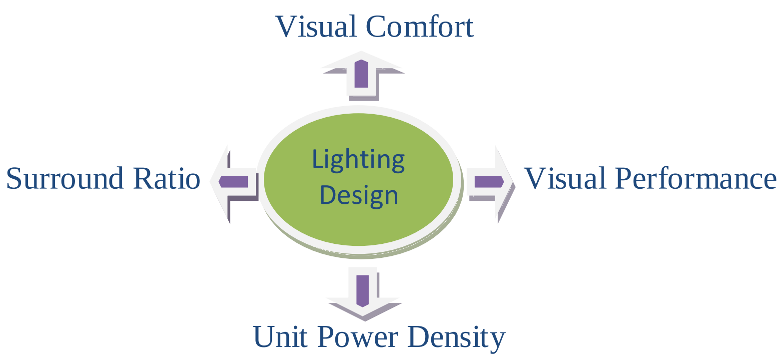
The illuminance methodology is used to determine the total amount of luminous flux reaching in particular locations and assess how uniformly the luminous flux is horizontally distributed over the road surfaces. The design factors used in illuminance design are average maintained horizontal illuminance (E_{avg}) and the uniformity ratio (E_{min}/E_{avg}).

Luminance Methodology:

Luminance methodology is used to simulate driver visibility by assessing the quality of light reflected by the pavement surface as well as road surface to motorist’s eye from contributing luminaires. Road lighting design is based on luminance method in international practices. Compared to illuminance, the luminance methodology is considerably complicated as luminance depends on observer's position, viewing direction, nature of road surface, luminaire position etc.. The lighting design factors include average maintained luminance (L_{avg}), minimum luminance (L_{min}), maximum luminance (L_{max}), maximum veiling luminance (L_v), overall uniformity (L_{min}/L_{avg}) and longitudinal uniformity (L_{min}/L_{max}). For a good road lighting design we need to maintain certain lighting design parameters.

Lighting Parameters:

1. Visual Performance
2. Visual Comfort
3. Surround Ratio
4. Unit Power Density



1.3.1 Visual Performance

The three basic road lighting parameters which influence the degree of visual performance of the road users are:

- The average road surface luminance (L_{avg})
- The overall uniformity ratio (U_o)
- The threshold increment (TI)

Average Road Surface Luminance: The maintained average luminance of the road surface over the carriageway (cd/m^2). It is dependent on,

- Light distribution of the luminaires
- Luminous flux of the lamps
- Reflection properties of the road surface
- Geometry of installation

An object is said to processed by the luminance contrast (C_0) defined by

$$C_0 = \left|\frac{L_0 - L_b}{L_b}\right|$$

Where, L_o = Luminance of the object itself

L_b = Luminance of the background

If an object is darker than its background then it is called negative contrast & if the object is brighter than its background then it is called positive contrast. Road lighting mainly produces negative contrast. It is true that under a fixed road lighting condition visual performance improves with increase road surface luminance or illuminance. So the average road surface luminance or illuminance is a very important parameter.

Overall Uniformity: Good average lighting level is not only sufficient for a good visual performance; it also requires the second lighting parameter which is called overall uniformity (U_o). It is the ratio of the minimum to average luminance or illuminance of the road surface. A good overall uniformity ensures that all sports on the road are sufficiently visible.

Disability Glare: Disability glare is caused by light being scattered in the eye. This produces a veil of light over the image of the scene being viewed, which reduces contrasts. Mathematically, this can be shown as follows from the definition of contrast:

$$C_0 = \left|\frac{L_0 - L_b}{L_b}\right|$$

Where,

C_0 is the initial contrast, without veiling luminance,
L_0 is the luminance of the object,
L_b is the luminance of the background.

The equation for C_0 is stated in its usually quoted form; that is, with modulus signs which imply that whether L_o is larger or smaller than L_b is immaterial. However, there is same value of C_0 a target in negative contrast $(L_o - L_b) < 0$ is better seen than one in positive contrast $(L_o - L_b) > 0$.
The equation can then be stated as,

$$C_1 = \frac{L_0 - L_b}{L_b}$$

If there is veiling luminance, L_v, present this will be added on to both L_o and L_b, so the contrast, C_v, will now be:

$$C_v = \frac{(L_0 + L_v) - (L_b + L_v)}{L_b + L_v}$$

$$C_v = \frac{(L_0 - L_b)}{L_b + L_v}$$

$$C_v = \frac{(L_0 - L_b)}{(L_b)} \text{ X } \frac{(L_b)}{(L_b + L_v)}$$

$$C_v = C_1 \text{ X } \frac{(L_b)}{(L_b + L_v)}$$

It is obvious that $|C_v|$ is less than $|C_1|$. The threshold increment is the percentage by which the luminance of the object has to be increased to achieve a contrast equal to that obtained without any veiling luminance.

Glare depends on the illumination produced by the luminaire on the eye of the observer. The light from the glare source scattered in the direction of the retina will cause a bright veil to be superimposed on the sharp image of the scene in front of the observer. This veil can be considered as having a certain luminance,

$$L_{veiling} = K \sum_{i=1}^{n} \frac{E_{eye,i}}{\theta_i^{\ 2}}$$

Where,

$E_{eye,i}$ = Illuminance on the eye (in a plane perpendicular to the line of sight) Caused by the ith glare source (lux);

θ_i = Angle between viewing direction and direction of light incidence on the eye of the i^{th} glare source (degrees).

K = age factor (usually taken as 10)

The equivalent veiling luminance and the adaptation state of the eye, which under road lighting conditions is determined by the average road luminan (L_{avg}).

According to CIE, for the luminance range 0.5 cd/m^2 < L_b < 5 cd/m^2. This value can be calculate from equivalent veiling luminance (L_v) and the average road surface luminance (L_{avg}) by using this formula,

$$TI = 65 * \frac{L_{veiling}}{(L_{avg})^{0.8}}$$

Where,

TI = Relative Threshold Increment (percent)

L_v = Equivalent veiling luminance (cd/m^2)

L_{avg} = Average road surface luminance (cd/m^2)

CIE Recommended Threshold Increment value classifications are shown in below table 1.1:

Threshold Increment (TI)	Glare Level
>15	Disagreeable
10	Acceptable
<10	Good

1.3.2 Visual Comfort

Visual comfort is one of the most essential parts of road safety. The three basic road lighting parameters which influence the degree of visual comfort of the road users are:

- The average road surface luminance (L_{avg})
- The longitudinal uniformity ratio (U_l)
- The glare control mark (G)

Average Road Surface Luminance:

The degree of visual comfort by a road user is very much dependent upon the value of the average road surface luminance. Higher the value creates more comfort. Thus, a lighting parameter of major importance in connection with the visual comfort aspect of road lighting is the average road surface luminance.

Longitudinal Uniformity:

A good longitudinal uniformity ensures that comfortable driving condition without “zebra effect” (continuously repeated sequence of alternate bright and dark transverse bands on the road surface). It is the ratio of the minimum to maximum road surface luminance on a line parallel to the axis of the road & passing through the observer position.

Discomfort Glare:

Glare that causes discomfort without necessarily impairing the visibility is called as discomfort glare. This type of glare can be reduced by selecting good luminaire used in the road lighting installation. In road lighting discomfort glare is described by “glare control mark (G)”.

Glare control mark (G) = SLI + 0.97log L_{avg} + 4.41 log h – 1.46 log p

Where, SLI = Specific luminaire index
L_{avg} = Average road surface luminance (cd/m^2)
h = vertical distance between eye level and the luminaire mounting height.
P = Number of luminaires per kilometer.

1.3.3 Surround Ratio

The function of the Surround Ratio (SR) is to ensure that sufficient light falls on the surrounds to provide a bright background for objects towards the edge of the carriageway to be revealed. It also helps the driver to anticipate the movement of pedestrians about to cross the road. It is important in curved roads where the surround forms the greater part of the background against which objects are seen. The surround ratio is formally defined as the ratio of the average illuminance which area adjacent to the edge of both side of the carriageway to the average illumination on the width of the carriageway.

1.3.4 Unit Power Density

In road lighting, energy use involvement depends on two components:

- The power demand of the equipment
- The equipment itself hours of use

The lighting industry has worked hard to develop equipment that has reduced the demand for electricity for lighting and produce more efficient light sources. Significant savings in energy consumption and therefore cost of providing lighting without reducing standards can be achieved by applying an energy efficient design approach to lighting installation. To meet this basic requirement it is necessary to evaluate the equipments, techniques and services available for both existing and proposed installations. There are some following parameters to achieving energy efficient lighting should be considered:

- Use most suitable efficient light source
- Use most efficient light output of the luminaire
- Maintain minimum lighting design parameters to achieved required lux level
- Use the control of switching operations and try to make full use of daylight.

To calculate the unit power density,

$$UPD = \frac{Total\ installed\ power\ (P)}{Area\ of\ the\ roadway\ (A)}$$

$$= \frac{No\ of\ luminaire\ X\ watt\ per\ luminaire\ X\ 1.15}{Span\ X\ Width}$$

Where,

1.15 is multiplied due to curve portion of the road where the pole span reduced from the normal span.

NOTE: Shoulders are not included in the area of the roadway.

1.4 Lighting Installations

The most common spacing arrangements are single sided, staggered, opposite sided and twin central. According to the geometry of road layout, we can choose lighting design pole arrangement. The different types of pole arrangements are shown below.

1. Single sided arrangement
2. Staggered arrangement
3. Opposite sided arrangement
4. Twin central arrangement
5. Twin central and opposite sided arrangement
6. Catenary arrangement

1.4.1 Single Sided Arrangement:

In this type of installation all the luminaires are located on one side of the road as shown in the figure 1.1. It is used mainly when the width of the road is equal to or less then the mounting height of the luminaires. The luminance of the road surface on the luminaire side is inevitably higher than on the opposite side. This type of arrangement is normally used for a two-way traffic road consisting of one carriageway.

1.4.2 Staggered Arrangement:

In a staggered arrangement the luminaires are located on either side of the road as shown in the figure 1.1. It is used mainly when the width of the road is between 1 and 1.5 times the mounting height of the luminaires. Careful attention should be paid to the uniformity of the luminance on the road surface – alternate bright and dark patches can produce an unpleasant zigzag effect. This type of installation is normally used for a two-way traffic road consisting of one carriageway.

1.4.3 Opposite Sided Arrangement:

In this type of installation the luminaires located opposite to one another as shown in the figure 1.1. It is used mainly when the width of the road is greater than 1.5 times the mounting height of the lumianires. An opposite sided arrangement is normally used for a two-way traffic road consisting of one carriageway.

1.4.4 Twin Central Arrangement:

In a twin central installation the lumianires are located above the central reservation only as shown in figure 1.1. Therefore, this type of installation can be considered as a single sided arrangement for each individual carriageway. This type of installation is normally used for road with dual carriageways.

1.4.5 Twin Central and Opposite Sided Arrangement:

Twin brackets on a single pole, located on the central reservation, are combined with the opposite sided arrangement as shown in figure 1.1. This can be considered as opposite sided arrangement for each individual carriageway. This type of installation is normally used for very wide roads with dual-carriageways.

1.4.6 Catenary Arrangement:

In this type of installation the luminaires, normally spaced 10m to 20m apart, and are suspended axially from longitudinal cables over the central reserve as shown in the figure 1.1. The supporting columns are widely spaced (roughly 60m to 90m).
The catenary system offers:

- Excellent visual guidance
- Excellent uniformity
- Less glare than with other systems (because the luminaires are viewed axially)
- Greater visibility which is particularly noticeable in bad weather.

This type of installation is normally used for roads with dual-carriageways.

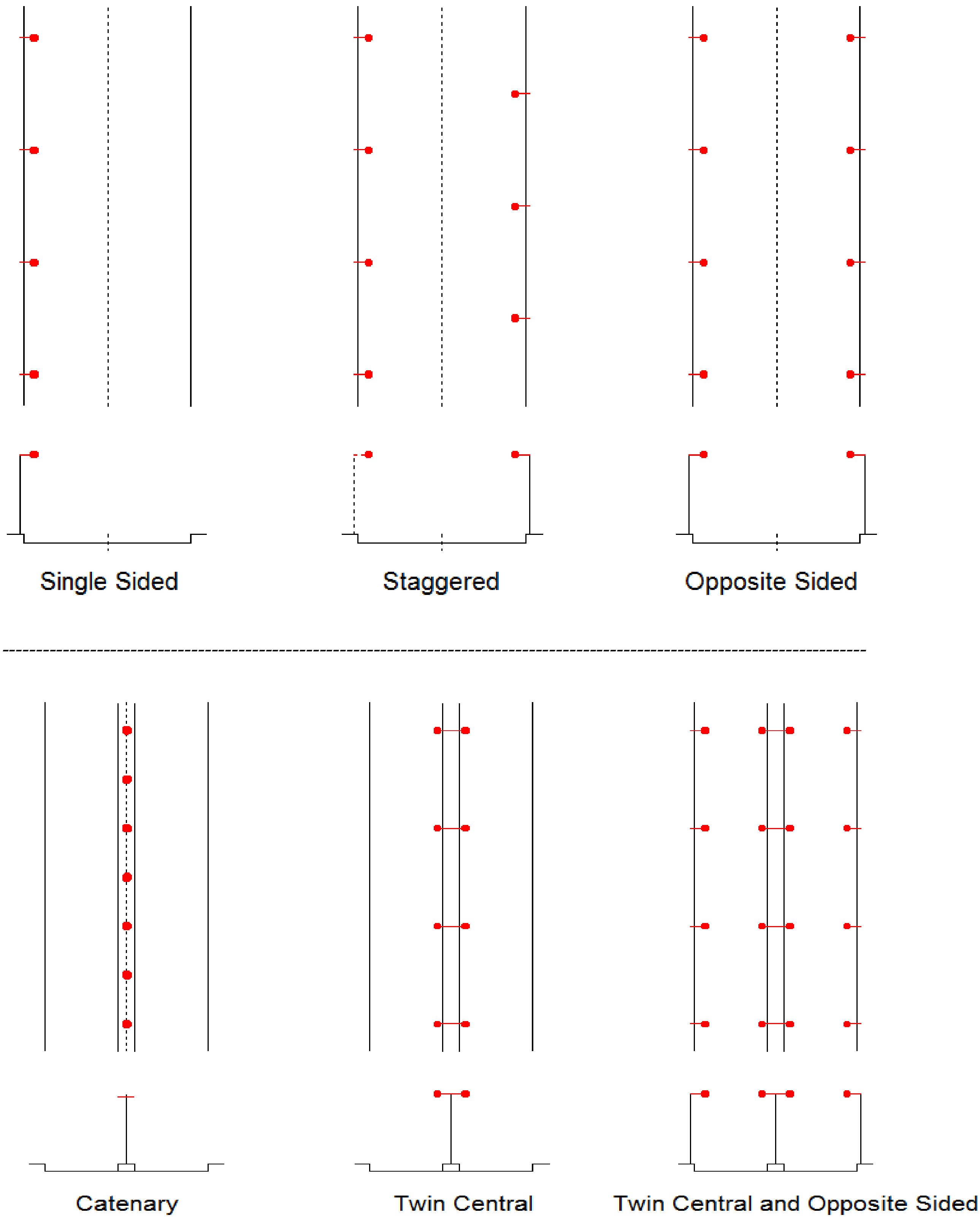


Figure 1.1: Different Types of Pole Spacing Arrangements.

1.5 Different Road Lighting Standards

There are different road lighting standards such as Illuminating Engineering Society of North America (IESNA), International Commission on Illumination (CIE) and IS: 1944 (Parts I and II) – 1970.

1.5.1 IESNA Classifications

According to Illuminating Engineering Society of North America (IESNA) the Road ways, Areas and Pavements are classified as given below.

1.5.1.1 Roadway Classifications

Freeway: A divided major roadway with full control of access and with no crossings at grade. This definition applies to toll as well as non toll roads as follows:

- **Freeway A:** Roadways with visual complexity and high traffic volumes. Usually this type of freeway is found in major metropolitan areas in or near the central core and operates through much of the early evening hours of darkness at or near design capacity.
- **Freeway B:** All other divided roadways with full control of access where lighting is needed.

Expressway: A divided major roadway for through traffic with partial control of access and generally with interchanges at major crossroads. Expressways for noncommercial traffic within park areas are generally known as parkways.

Urban Principal Arterials: The urban major roadway system that serve the major centers of activities of urbanized areas containing the corridors with the highest traffic volume.

Urban Minor Arterials: The roadway system that interconnects with and augments the urban principal arterial system. It accommodated trips of moderate length at a somewhat lower level of travel mobility than do principal arterials.

Major: The part of the roadway system that serves as the principal network for through traffic flow. The routes connect areas of principal traffic generation and important rural highways entering the city.

Collector: The roadways serving traffic between major and local roadways. These are roadways used mainly for traffic movements within residential, commercial, and industrial areas.

Local: Roadways used primarily for direct access to residential, commercial, industrial, or other abutting property. They do not include roadways carrying through traffic. Long local roadways are generally divided into short sections by a system of collector roadway systems.

Alley: Narrow public ways within a block, generally used for vehicular access to the rear of abutting properties.

Sidewalk: Paved or otherwise improved areas for pedestrian use, located within public street rights-of-way that also contain roadways for vehicular traffic.

Pedestrian Walkway: A public walk for pedestrian traffic, not necessarily within the right-of-way for a vehicular traffic roadway. Included are skywalks (pedestrian overpasses), sub walks (pedestrian tunnels); walkways giving access to parks or block interiors, and midblock street crossings.

Bikeway: Any road, street, path, or way that is specifically designated as being open to bicycle travel, regardless of whether such facilities are designed for the exclusive use of bicycles or are to be shared with other transportation modes.

- **Type A:** Designated bicycle lane. A portion of roadway or shoulder that has been designated for use by bicyclists. It is distinguished from the portion of the roadway for motor vehicle traffic by a paint stripe, curb, or other similar device.
- **Type B:** Bicycle trail. A separate trail or path from which motor vehicles are prohibited and which is for the exclusive use of bicyclists or the shared use of bicyclists and pedestrians. Where such a trail or path forms a part of a highway, it is separated from the roadways for motor vehicle traffic by an open space or barrier.

1.5.1.2 Area Classifications

Certain land uses, such as office and industrial parks, may fit into any of the classifications below. The classification elected should be consistent with the expected night pedestrian activity.

Commercial: A business area of a municipality where ordinarily there are many pedestrians during night hours. This definition applies to densely developed business areas outside, as well as within, the central part of a municipality. The area contains land use that frequently attracts a heavy volume of nighttime vehicular and pedestrian traffic.

Intermediate: Those areas of a municipality characterized by frequent moderately heavy nighttime pedestrian activity, as in blocks having libraries, community recreation centers, large apartment buildings, industrial buildings, or neighborhood retail stores.

Residential: A residential development, or a mixture of residential and small commercial establishments, characterized by few pedestrians and a low parking demand at night. This definition includes areas with single-family homes, town houses, and small apartment buildings.

1.5.1.3 Pavement Classifications

The calculation of pavement luminance requires information about the surface reflectance characteristics of the pavement. Studies have shown that most common pavements can be grouped into a limited number of standard road surfaces having specified reflectance data given by reduced luminance coefficient tables (r tables). In this section, pavement reflectance characteristics follow the established CIE document. A description of road surface classifications is as shown below:

Class R1: This type of pavement has a mostly diffuse mode of reflectance. R1 pavements include Portland cement concrete road surfaces and asphalt road surface with a minimum of 15% of the aggregates composed of artificial brightener aggregates. Mean luminance coefficient, Q_0 value for this type of pavement is 0.10.

Class R2: This pavement has a mixed (diffuse and specular) mode of reflectance. R2 pavements include asphalt road surface with an aggregate composed of minimum 60% gravel with a size greater than 10 millimeters and 10% to 15% artificial brightener in aggregate mix. Q_0 value for this type of pavement is 0.07.

Table 1.2: Maintained Luminance Values (L_{avg}) in Candelas per Square Meter

Road And Area Classification		Average Luminance (L_{avg}) cd/m^2	Luminance Uniformity		Veiling Luminance Ratio (maximum) L_v to L_{avg}
			L_{avg} to L_{min}	L_{max} to L_{min}	
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
Express Way	Commercial	1.0	3.0 to 1	5 to 1	0.3 to 1
	Intermediate	0.8	3.0 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	6 to 1	
	Residential	0.6	3.5 to 1	8 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	

Class R3: This pavement has a slightly specular mode of reflectance. R3 pavements include asphalt road surface, both regular and carpet seal, with dark aggregates and exhibit a rough texture after some months of use. Class R3 pavement represents typical asphalt highways and as used on most highway project. Q_0 value for this type of pavement is 0.07.

Class R4: This type of pavement has a mostly specular mode of reflectance. R4 includes asphalt road surfaces with very smooth texture. Q_0 value for this type of pavement is 0.08.

Recommended Maintained Average Luminance values and Illuminance Uniformity Ratio are shown in the table 1.2 and table 1.3

Table 1.3: Illminance Uniformity Ratio Values (E_{avg} /E_{min})

Road And Area Classification		**Pavement Classification**			**Illuminance Uniformity Ratio (E_{avg} to E_{min})**
		R1	**R2 and R3**	**R4**	
Freeway class A		6	9	8	3 to 1
Freeway class B		4	6	5	
Express Way	Commercial	10	14	13	3 to 1
	Intermediate	8	12	10	
	Residential	6	8	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	

1.5.2 CIE - 115:2010 Road Lighting Recommendation:

1.5.2.1 Road Lighting For The Motorist:

- Headlights provide some of the visual cues required at night, but become progressively ineffective as speed, number of vehicles, or complexity of the night-time scene increases. Moreover, they are glaring to oncoming traffic, especially where no road lighting is installed. This problem is further aggravated on two-way roads where vehicles travelling in opposite directions are in close proximity.
- The distance required to bring a vehicle to a stop safely can exceed the distance at which headlights can adequately reveal the object, depending on recognition, reaction and braking times, and factors such as the speed of the vehicle and whether the road surface is wet or dry. Good quality road lighting can provide the visibility required at this distance, so that evasive action can be taken in good time, without resort to an abrupt man oeuvre.
- The lighting requirements for motorized traffic can be most easily fulfilled under dry conditions. Where appropriate, the design should take wet road conditions into consideration. Under wet conditions the road luminance becomes less uniform. Poor uniformity leads to increased susceptibility to glare as well as the production of glare from the shiny surface reflections of wet areas, as the road surface tends to behave in a more specular way, rather than as a diffuse reflector.
- The result is that in wet conditions the average luminance in most cases increases whereas the uniformity of the luminance is severely degraded. The visibility on a large proportion of the road is adversely affected.
- The approach generally used when selecting quality criteria for lighting roads for motor traffic is based on the luminance concept. In the application of the luminance concept, the aim is to provide a bright road surface against which objects are seen in silhouette. It uses, therefore, average luminance level and uniformity of road surface luminance, as well as glare control, as quality criteria.
- The approach of providing a good level and uniformity of road luminance with adequate glare control has been widely adopted in national and international recommendations.
- It is important that the changes in the average lighting level do not affect the other quality criteria outside the limits given in the system of M, C or P lighting classes. Reducing the light output from every lamp by the same amount using dimming techniques will not affect luminance or illuminance uniformity, or the object contrast, but the threshold contrast increases.

1.5.2.1.1 Requirements For Motorized Traffic

- The M lighting classes are intended for drivers of motorized vehicles on traffic routes, and in some countries also on residential roads, allowing medium to high driving speeds.
- The lighting classes M1 to M6 are defined by the lighting criteria given for each class in Table 1.5.
- The application of these classes depends on the geometry of the relevant area and on the traffic and time dependant circumstances.
- The appropriate lighting class has to be selected according to the function of the road, the design speed, the overall layout, the traffic volume and composition, and the environmental conditions.
- For the determination of the M lighting class to be applied the appropriate weighting values for the different parameters have to be selected and added to find the sum of the weighting values (V_{WS}). The number of the lighting class M is then calculated as:

$$\text{Number of lighting class } M = 6 - V_{WS}$$

- Careful selection of appropriate weighting values in Table 1.4 will yield class numbers between 1 and 6. If the result is not a whole number, use the next lower whole number.

Table 1.4: Parameters For The Selection of M Lighting Class.

Parameter	**Options**	**Weighting Values**
Speed	Very high (v > 80 km/h)	1
	High (60 < v ≤ 80 km/h)	0.5
	Moderate (30 < v ≤ 60 km/h)	0
Traffic volumes (in both directions)	Very high(> 25000 vehicles/day)	1
	High (15000 to 25000 vehicles/day)	0.5
	Moderate (7000 to 15000 vehicles/day)	0
	Low (4000 to 7000 vehicles/day)	-0.5
	Very low (< 4000 vehicles/day)	-1
Traffic composition	Mixed with high percentage of non motorized	1
	Mixed	0.5
	Only motorized	0
Separation of carriageway	Not separated	1
	Separated	0
Junction density	High	1
	Moderate	0
Parked vehicles	Present	0.5
	Not present	0
Ambient luminance	High	0.5
	Moderate	0
	Low	-0.5
Visual guidance/traffic control	Poor	0.5
	Moderate or good	0
Complexity of the visual field	Normal	0
	Higher than normal	0.5

- The lighting criteria used are the maintained average road surface luminance (L_{avg}), the overall (U_o) and longitudinal (U_l) uniformity of the luminance, the surround ratio (SR), and the threshold increment (f_{TI}).

- These values apply to roads, which are sufficiently long so that the luminance concept can be used, outside conflict areas and/or outside areas with measures of traffic calming. The surround ratio is considered for roads with adjacent footpath/cycle path.

Table 1.5: Lighting Classes for Motorized Traffic, Based on Road Surface Luminance.

Lighting Class	**Road Surface**				**Threshold Increment**	
	Dry			**Wet**	**TI (%),f_{TI}**	**SR**
	L_{avg}	**U_0**	**U_L**	**U_0**		
M1	2	0.4	0.7	0.15	10	0.5
M2	1.5	0.4	0.7	0.15	10	0.5
M3	1	0.4	0.6	0.15	15	0.5
M4	0.75	0.4	0.6	0.15	15	0.5
M5	0.5	0.35	0.4	0.15	15	0.5
M6	0.3	0.35	0.4	0.15	20	0.5

The uniformity expression for CIE is just reciprocal of IESNA, IESNA recommended uniformity ratio is L_{avg} to L_{min} and for CIE, it is L_{min} to L_{avg}.

1.5.2.2 Road Lighting For Pedestrians

The road lighting should enable pedestrians to discern obstacles or other hazards in their path and be aware of the movements of other pedestrians, friendly or otherwise, who may be in close proximity. For this, the lighting on both horizontal and vertical surfaces, as well as the control of glare and the colour rendering, is important. Environmental issues should be taken into account.

1.5.2.2.1 Lighting of Horizontal Surfaces

- To ensure that the pedestrian can move over the road and footpath surfaces in safety, the horizontal illuminance, E_h, must be adequate.
- Horizontal illuminance is measured at ground level in terms of average and minimum values.

1.5.2.2.2 Lighting of Vertical Surfaces

- Adequate lighting of vertical surfaces is necessary for facial recognition, which may also enable an act of aggression to be anticipated. The quantification of this presents a difficulty because of the multiplicity of planes at each measurement point which have to be taken into account. An attempt to overcome this has been made by considering the illuminance on an infinitesimal vertical half cylinder situated at head height (1.5 m). This measure, the semi cylindrical illuminance, E_{sc}, has been introduced in CIE 136 -2000, as an adjunct to horizontal illuminance. For its measurement a special adaptation is required to the mounting of the photoelectric detector which is used to measure planar illuminance.

1.5.2.2.3 Lighting Levels For Pedestrian

- The parameters relevant for the selection of an appropriate P lighting class for a given pedestrian or low speed traffic area are summarized in Table 6. The lighting classes P1 to P6 are defined by the lighting criteria given for each class in Table 1.7. They are intended for pedestrians and pedal cyclists on footways, cycle ways, and other road areas lying separately or along the carriageway of a traffic route, and for residential roads, pedestrian streets, parking places, etc.
- The application of these classes depends on the geometry of the relevant area and the traffic and time dependant circumstances.
- For the determination of the P lighting class to be applied, the appropriate weighting values in Table 1.6 for the different parameters have to be selected and added to find the sum of the weighting values (V_{WS}). The number of the lighting class P is then calculated as:

$$\text{Number of lighting class P} = 6 - V_{WS}$$

- Careful selection of appropriate weighting values will yield class numbers between 1 and 6. If the result is not a whole number, use the next lower whole number.

Table 1.6: Parameters for the Selection of P Lighting Class.

Parameter	**Options**	**Weighting Values**
Speed	Low	1
	Very low (walking speed)	0
Traffic volumes (in both directions)	Very high(> 25000 vehicles/day)	1
	High (15000 to 25000 vehicles/day)	0.5
	Moderate (7000 to 15000 vehicles/day)	0
	Low (4000 to 7000 vehicles/day)	-0.5
	Very low (< 4000 vehicles/day)	-1
Traffic composition	Pedestrians, cyclists and motorized traffic	2
	Pedestrians and motorized traffic	1
	Pedestrians and cyclists only	1
	Pedestrians only	0
	Cyclists only	0
Parked vehicles	Present	0.5
	Not present	0
Ambient luminance	High	1
	Moderate	0
	Low	-1
Facial recognition	Necessary	Additional requirements
	Not Necessary	No Additional requirements

Table 1.7: Lighting Classes for Pedestrian and Low Speed Traffic Areas.

Lighting class	Average horizontal illuminance $E_{h, avg}$ In lux	Minimum horizontal illuminance $E_{h, min}$ In lux	Additional requirement if facial recognition is necessary	
			Minimum vertical illuminance $E_{v, min}$ In lux	Minimum semi-cylindrical illuminance $E_{sc, min}$ In lux
P1	15	3.0	5.0	3.0
P2	10	2.0	3.0	2.0
P3	7.5	1.5	2.5	1.5
P4	5.0	1.0	1.5	1.0
P5	3.0	0.6	1.0	0.6
P6	2.0	0.4	0.6	0.4

1.5.2.3 Road Lighting For Conflict Areas

- Conflict areas occur whenever vehicle streams intersect each other or run into areas frequented by pedestrians, cyclists, or other road users, or when there is a change in road geometry, such as a reduced number of lanes or a reduced lane or carriageway width. Their existence results in an increased potential for collisions between vehicles, between vehicles and pedestrians, cyclists, or other road users, or between vehicles and fixed objects. Parking areas and toll-stations are also regarded as conflict areas.
- The lighting should reveal the existence of the conflict area, the position of the kerbs and road markings, the directions of the roads, the presence of pedestrians, other road users, and obstructions, and the movement of vehicles in the vicinity of the conflict area. Where no lighting is otherwise provided on a road leading to or leaving the conflict area, the selected lighting class should be installed for a stretch long enough to provide about 5 seconds of driving distance at the expected traffic speed.
- For the determination of the C lighting class to be applied the appropriate weighting values in Table 1.8 for the different parameters have to be selected and added to find the sum of the weighting values (V_{WS}). The number of the lighting class C is then calculated as:

$$\text{Number of lighting class } C = 6 - V_{WS}$$

- Careful selection of appropriate weighting values will yield class numbers between 0 and 5. If the result is not a whole number, use the next lower whole number.
- For conflict areas, luminance is the recommended design criterion. However, where viewing distances are short and other factors prevent the use of luminance criteria, illuminance may be used on a part of the conflict area, or the entire area if the luminance criteria cannot be applied to the whole area. The correspondence between luminance and average horizontal illuminance depends on the lightness of the road surface, as represented by the Q_0 value of that surface. Table 1.9 gives the relationship between the M and C classes for three examples of Q_0 values.

Table 1.8: Parameters for the Selection of C Lighting Class.

Parameter	**Options**	**Weighting Values**
Speed	Very high	3
	High	2
	Moderate	1
	low	0
Traffic volumes (in both directions)	Very high(> 25000 vehicles/day)	1
	High (15000 to 25000 vehicles/day)	0.5
	Moderate (7000 to 15000 vehicles/day)	0
	Low (4000 to 7000 vehicles/day)	-0.5
	Very low (< 4000 vehicles/day)	-1
Traffic composition	Mixed with high percentage of non motorized	2
	Mixed	1
	Only motorized	0
Separation of carriageway	Not separated	1
	Separated	0
Ambient luminance	High	1
	Moderate	0
	Low	-1
Visual guidance/traffic control	Poor	0.5
	Moderate or good	0

Table 1.9: M and C Lighting Classes of Comparable Lighting Level for Different Values of Q_0 for the Road Surface.

Lighting class M			**M1**	**M2**	**M3**	**M4**	**M5**	**M6**
Average Luminance L in cd/m^2			2.0	1.5	1	0.75	0.50	0.30
Lighting class C if $q_0=0.05\ cd.m^{-2}.lx^{-1}$			C0	C1	C2	C3	C4	C5
Average Illuminance E in lx			50	30	20	15	10	7.5
Lighting class C if $q_0=0.07\ cd.m^{-2}.lx^{-1}$		C0	C1	C2	C3	C4	C5	
Average Illuminance E in lx		50	30	20	15	10	7.5	
Lighting class C if $q_0=0.09\ cd.m^{-2}.lx^{-1}$	C0	C1	C2	C3	C4	C5		
Average Illuminance E in lx	50	30	20	15	10	7.5		

- Table 4 gives comparable M and C classes for various values of Q_0 for the road surface. Row 1 gives the M classes from which the luminance class used for the most important road leading to the conflict area is selected. The equivalent illuminance C class is then taken from column 1, depending on the Q_0 value. The actual C class to be used in the conflict area is recommended to be one step higher than the equivalent class so determined.
  (E.g. if the most important road leading to the conflict area is M4 and $Q_0 = 0.07\ cd\cdot m^{-2}\cdot lx^{-1}$, the equivalent class is C4 and the conflict area is recommended to be lit to class C3.)

- Where luminance is used as a criterion for the conflict area lighting, it is necessary to calculate threshold increment TI (symbol f_{TI}), for relevant observer positions and viewing directions in the conflict area, which requires knowledge of veiling luminances and adaptation luminances for the particular observer positions and viewing directions.

- The lighting classes C0 to C5 are defined by the lighting criteria given for each class in Table 1.10.

Table 1.10: Lighting Classes for Conflict Areas.

Lighting Class	Average Illuminance over whole of Used Surface E_{avg} (lux)	Overall Illuminance Uniformity (U_0)	Threshold Increment F_{TI} in %	
			High & Moderate Speed	Low & Very Low Speed
C0	50	0.4	10	15
C1	30	0.4	10	15
C2	20	0.4	10	15
C3	15	0.4	15	20
C4	10	0.4	15	20
C5	7.5	0.4	15	25

1.5.3 IS: 1944 (Parts I and II) -1970

1.5.3.1 Terms Relating to the Lighting Installation

- **Lighting Installation:** The whole of the equipment provided for lighting the Roadway comprising the lamps, luminaires, means of support and electrical and other auxiliaries.
- **Lighting System:** An array of luminaires having a characteristic light distribution, sited in a manner concordant with this distribution. (Lighting systems are commonly designated by the name of the characteristic light distribution, for example, cut-off, semi-cut-off, etc).
- **Luminaire:** A housing for one or more lamps, comprising a body and any refractor, reflector, diffuser or enclosure associated with the lamp(s).
- **Outreach:** The distance measured horizontally between the centre of the pole and the centre of a luminaire (see p in fig 1.1).
- **Overhang**: The distance measured horizontally between the centre of a luminaire mounted on a bracket and the adjacent edge of the carriageway (see s in fig 1.1).
- **Mounting Height:** The vertical distance between the centre of the luminaire and the surface of the carriageway (see h in fig 1.1).
- **Spacing:** The distance measured between two successive luminaires along the centre line of the carriageway in an installation (see d in fig 1.1).

- **Span:** The distance measured between two successive luminaires along one side of the carriageway in an installation.
- **Width of Carriageway:** The distance between kerb lines measured at right angles to the length of the carriageway (see l in fig 1.1).
- **Arrangement:** The patterns according to which luminaires are sited on plan, for example, single sided, staggered, opposite sided, twin central.
- **Geometry (of a Lighting System)**: The inter-related linear dimensions and characteristics of the system, namely, the spacing, mounting height, width overhand and arrangement.

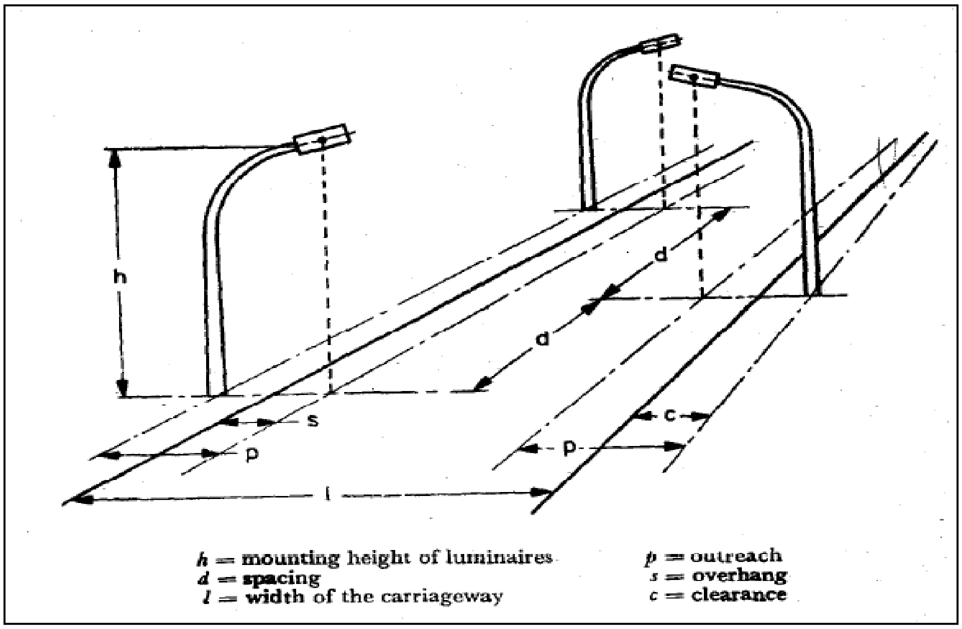


Fig 1.1: Street Lighting

1.5.3.2 Photometric Terms

- **Luminous Flux:** The total amount of visible radiation coming out from a light source. The unit of the luminous flux is the lumen (lm).
- **Downward Flux:** The luminous flux emitted by a luminaire in all direction below the horizontal.
- **Luminous Intensity:** The luminous flux emitted by a luminaire, per solid angle in a particular direction. The unit of luminous intensity is candela (cd).
- **Illumination:** The luminous flux incident on a surface per unit area. The unit of illumination is the lumen per square meter (lux).
- **Luminance:** The luminous intensity per unit projected area of a surface. The usual unit is candela per square meter (cd/m^2).
- **Luminosity:** It is a visual sensation which correlates approximately with the photometric quantity “luminance”.

- **Light Distribution:** the distribution of luminous intensity from a luminaire in various directions in space.
- **Beam:** The portion of the light output of the luminaire contained by the solids angle subtended at the effective centre of the luminaire containing the maximum intensity, but no intensity less than 90 percent of the maximum intensity.
- **Iso Candela Curve:** A curve traced on an imaginary sphere with a source at its centre and joining all the points corresponding to those directions in which the luminous intensity is the same or a plane projection of this curve.
- **Polar curve**: Curve of light distribution using polar co-ordinates.

1.5.3.3 Classification of Lighting

Lighting for streets is classified into the following groups:

Group A: For main roads. This is sub-divided into two categories:

- **Group A1:** For very important routes with rapid and dense traffic where the only considerations are the safety and speed of the traffic and the comfort of the drivers.
- **Group A2:** For other main roads with considerable mixed traffic like main city streets, arterial roads and thoroughfares.

Group B: For secondary roads which do not require lighting up to Group A standard. This is also divided into two categories:

- **Group B1:** For secondary roads with considerable traffic, such as principal local traffic routes, shopping streets, etc.
- **Group B2:** For secondary roads with light traffic.

Group C: Lighting for residential and unclassified roads not included in the previous groups.

Group D: Lighting for bridges and flyovers.

Group E: Lighting for town and city centers.

Group F: Lighting for roads with special requirements, such as roads near airfields, railways and docks.

1.5.3.4 Mounting Height

The minimum mounting height should be chosen taking into account the power of the sources, the light distribution of the luminaires and the geometry of the installation. The mounting height should be greater as the lamps are more powerful to avoid excessive glare; and also greater as the roadway is wider to obtain adequate transverse uniformity. As a general rule heights of 9 to 10 meters are suitable for Group A roads and 7.5 to 9 meters for Group B roads. Heights of less than 7.5 meters are undesirable except in certain special cases, such as the lighting of residential roads or roads bordered by trees.

1.5.3.5 Spacing

To preserve longitudinal uniformity the spacing should generally be not greater than the values given below:

Type of Luminaire	Maximum Spacing/Height Ratio
Cut off	3
Semi-cut-off	3.5
Non-cut-off	4

1.5.3.6 Recommended Values of Illumination

According to the IS: 1944 (Parts I and II) -1970, the recommended light levels for road lighting are shown in the following table 1.11

Classification of Lighting Installation	Type of Road	Average Illumination on Road Surface (Lux)	Overall Uniformity Ratio (E_{min}/E_{avg})	Transverse Uniformity Ratio (E_{min}/E_{max})
Group A1	Important traffic routes carrying fast traffic	30	0.4	0.33
Group A2	Other main roads carrying mixed traffic like main city streets, arterial roads and throughway roads	15	0.4	0.33
Group B1	Secondary roads with considerable traffic like principal local traffic routes and shopping	8	0.3	0.20
Group B2	Secondary roads with light traffic	4	0.3	0.20
Note: Transverse uniformity: Ratio of E_{min} and E_{max} across the road.				

Table 1.11 Classification of Lighting Installation and Levels of Illumination

For Group A lighting, the level and uniformity of illumination should be as high as possible and the glare strictly reduced.

For Group B lighting, greater tolerances on uniformity and glare may be admitted which may be justified by the character of the roads and by the presence of facades.

1.5.3.7 Luminaires

The luminaire has a double role of protecting the light source from the weather and redistributing its luminous flux.
In the choice of the luminaire the following points should be considered:

- Nature and power of the source or sources.
- Nature of the tied arrangements and the light distribution which they provide.
- Light output ratio.
- Whether the luminaire is open or closed type;
- Resistance to heat, soiling and corrosion.
- Protection against collection of dust and insects.
- Resistance to atmospheric conditions.
- Ease of installation and maintenance.
- Presence or absence of auxiliaries.
- Fixing arrangements, the weight and area exposed to wind pressure.

The influence of all these factors varies according to local circumstances. There is, however, one essential characteristic of luminaires the choice of which directly influences the quality of the lighting, that is, the general form of its distribution curves of luminous intensity particularly in directions near the usual directions of vision.
Three fundamental forms of light distribution are considered according to the degree of glare which is acceptable:

1) Cut-off luminaires,
2) Semi-cut-off luminaires, and
3) Non-cut-off luminaires

1.5.3.7.1 Cut-off Luminaire

A luminaire whose light distribution is characterized by a rapid reduction of luminous intensity in the region between about 80° and the horizontal. The intensity at the horizontal should not exceed 10 cd per 1000 lm of flux from the light sources and the intensity at 80° is of the order of 30 cd per 1000 lm. The direction of the maximum intensity may vary but should be below 65°.

The principal advantage of the cut-off system is the reduction of glare.

1.5.3.7.2 Semi-Cut-off Luminaire

A luminaire whose light distribution is characterized by a less severe reduction in the intensity in the region 80° to 90°. The intensity at the horizontal should not exceed 50 cd per 1000 lm of flux from the light sources and the intensity at 80° is of the order of 100 cd per 1000 lm. The direction of the maximum intensity may vary but should be below 75°.

The principal advantage of the semi-cut-off system is a greater flexibility in sitting.

1.5.3.7.3 Non-Cut-off Luminaire

A Luminaire whose luminous intensity in directions making an angle equal to or greater than 80° from the downward vertical is not reduced materially and the intensity of which at the horizontal may exceed the values specified for the semi-cut-off distribution, but should not nevertheless exceed 1000 cd. Non-cut-off luminaires are permissible only when a certain amount of glare may be accepted and when the luminaires are of large size and of reduced brightness.

In certain cases they have some advantages in increasing the illumination on facades.

1.6 Photometric Specification

1.6.1 Key Element

This is a key element of street light luminaires, as it will determine the lighting quality on the road surface. Photometric specification may include the following:

a) Type of distribution
b) Luminaire efficacy and
c) Need for optic or lamp position adjustment.

1.6.2 Lighting Control Elements

a) Reflector
b) Refractor
c) Diffuser
d) Filter
e) Screening

These elements (eventually used in combination) define the light distribution.

1.6.3 Luminaire Photometric Principle

a) **Throw:** it is represents an angle (γ_{max}) of emission of light along the road.
b) **Spread:** it is represents an angle (γ_{90}) of emission of light across the road.
c) **Control:** it is control of glare from the luminaire. It is represented by number.

The Throw is defined by the angle (γ_{max}) that the beam axis makes with the downward vertical. The beam axis is determined by the direction midway between the 2 directions of 90 percent I_{max} in the vertical plane of maximum intensity. Fig. 1.2 shows the polar intensity curve through the plane of maximum luminous intensity, indicating the angle γ_{max} used for determination of the Throw.

Three degrees of Throw are de fined a follows:

$\gamma_{max} < 60°$: short throw;
$60° \leq \gamma_{max} \leq 70°$: intermediate throw; and
$\gamma_{max} \geq 70°$: long throw.

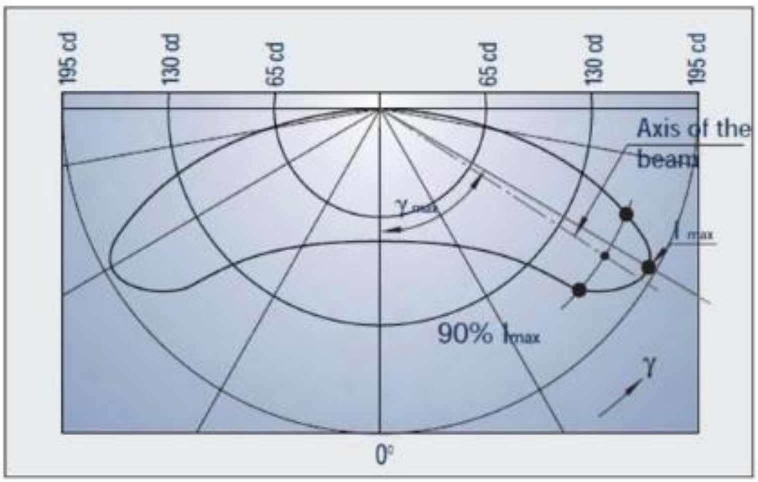


Fig 1.2: Polar intensity curve showing Throw

The spread is defined by the position of the line, running parallel to the road axis that touches the far side of the 90 percent I_{max}. Contour on the road. The position of this line is defined by the angle γ_{90}. Fig. 1.3 shows the degree of throw and spread as defined by CIE, where h is the mounting height.

The three degrees of spread are defined a follows:

$\gamma_{90} < 45°$: narrow spread
$45° \leq \gamma_{90} \leq 55°$: average spread
$\gamma_{90} \geq 5°$: broad spread .

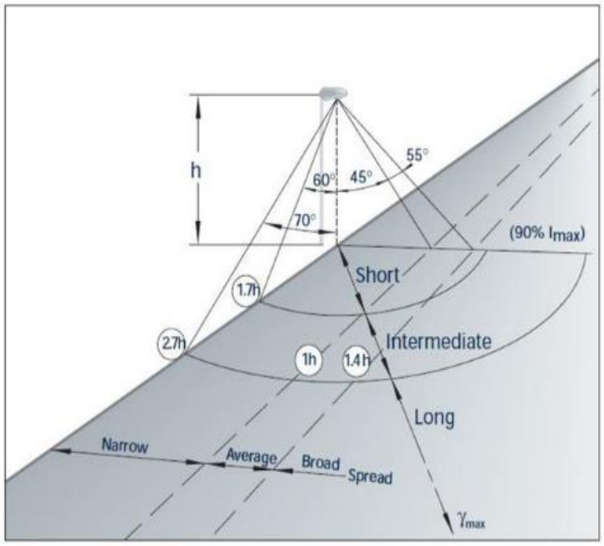


Fig 1.3: Degree of Throw and Spread Defined by CIE

The control is defined by the specific luminaire index (SLI) of the luminaire. This is the part of the glare control mark G.

Three degrees of controls are recognized:

SLI < 2 = limited control;
2 ≤ SLI ≤4 = moderate control; and
SLI > 4 = tight control.

Summary of CIE Classification for Photometric Properties of Luminaire is given in Table 1.12

Sl. No.	Throw		Spread		Control	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Short	γ max < 60°	Narrow	γ90 < 45°	Limited	SLI < 2
ii)	Intermediate	60° ≤ γ max ≤ 70°	Average	45° ≤ γ 90 ≤ 55°	Moderate	2 ≤ SLI ≤ 4
iii)	Long	γ max ≥70°	Broad	γ90 ≥ 55°	Tight	SLI > 4

Table 1.12: Photometric Values of Luminaires.

1.7 Luminaires and Lamps Selection Criteria

1.7.1 Luninaires Selection Criteria

a) Mechanical;
b) Electrical;
c) Required lamp types;
d) Ambient operation temperature;
e) Required IP rating;
f) Air resistance, with/without bowl, with/without gear unit;

g) Component exchangeability, accessories;
h) Mounting functionality; and
i) Material requirement

1.7.2 Lamps Selection Criteria

a) Color temperature (T_c)
b) Color rendering index (CRI)
c) Lumen output
d) Lamp efficacy
e) Lumen depreciation
f) Lamp life

For road lighting generally high efficacy (100, 115, 125 lm/w), light emitting diode (LED) and high pressure sodium vapour lamps (150, 250, 400 W) are being used. But now a day for better optimization of energy efficient lighting design and better colour appearance (CRI > 80) and for better light distribution of luminaire at junctions and city centers, light emitting diode (LED) are also being used to make a energy efficient and better colour appearance and better light distribution.

1.8 Optical Characteristics

a) Type of distribution;
b) Multiple optics;
c) Luminaire efficiency;
d) Standard tilt angle; and
e) Need for optic or lamp position adjustment.

1.9 Lighting Measurements

1.9.1 CIE Method

The CIE (1976a) recommends that where the luminaire spacing does not exceed 50 m, there should be 10 evenly spaced transverse rows of calculation points over its length, while for luminaire spacing greater than 50 m, the number of transverse rows should be such that the distance between two successive rows does not exceed 5m (See Fig. 1.4).

The calculation grid as proposed by CIE (1976a): S = Spacing; d = longitudinal spacing between calculation points; n = no. of transverse rows. For, $S \leq 50$ m, $n = 10$; $S > 50$ m, n = smallest integer giving $d \leq 5$ m.

Finally the CIE also recommends that there should be 5 points across each traffic lane, with 1 point positioned on the centre line of each lane. It is stated' that where the uniformity is good, $U_o \geq 0.4$, subsequent calculations may be based on 3 points instead of 5.

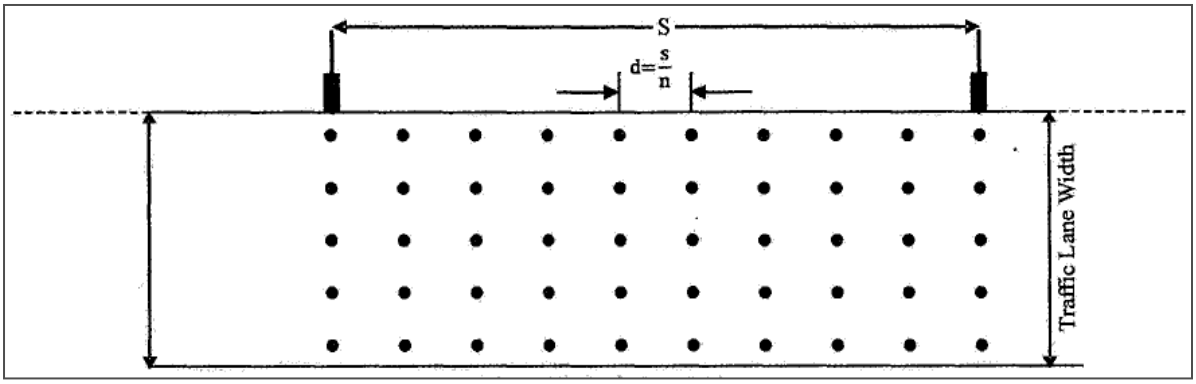


Fig 1.4: Calculation Grid

1.9.2 Field Measurements

For practical on-site measurements, the 9 point method is most acceptable. Fig. 1.5 illustrates the layout of a 9 point measuring grid of the kind sometimes used when checking new road lighting installations. The formula above the figure gives the weighting procedure that should be followed when calculating the average lighting level. Where extreme accuracy is required, the CIE recommends using as many measuring points as specified earlier.

$$\text{Eav} = \frac{P1 + P3 + P7 + P9}{16} + \frac{\text{P2} + \text{P4} + \text{P6} + \text{P8}}{8} + \frac{\text{P5}}{4}$$

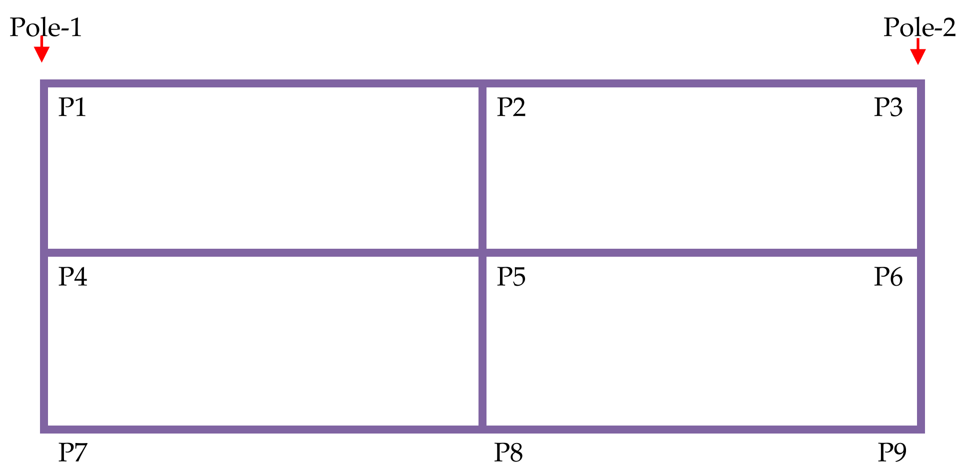


Fig 1.5: Regular Nine-point Measuring Grid

1.9.3 Derivation of 9 Point Method

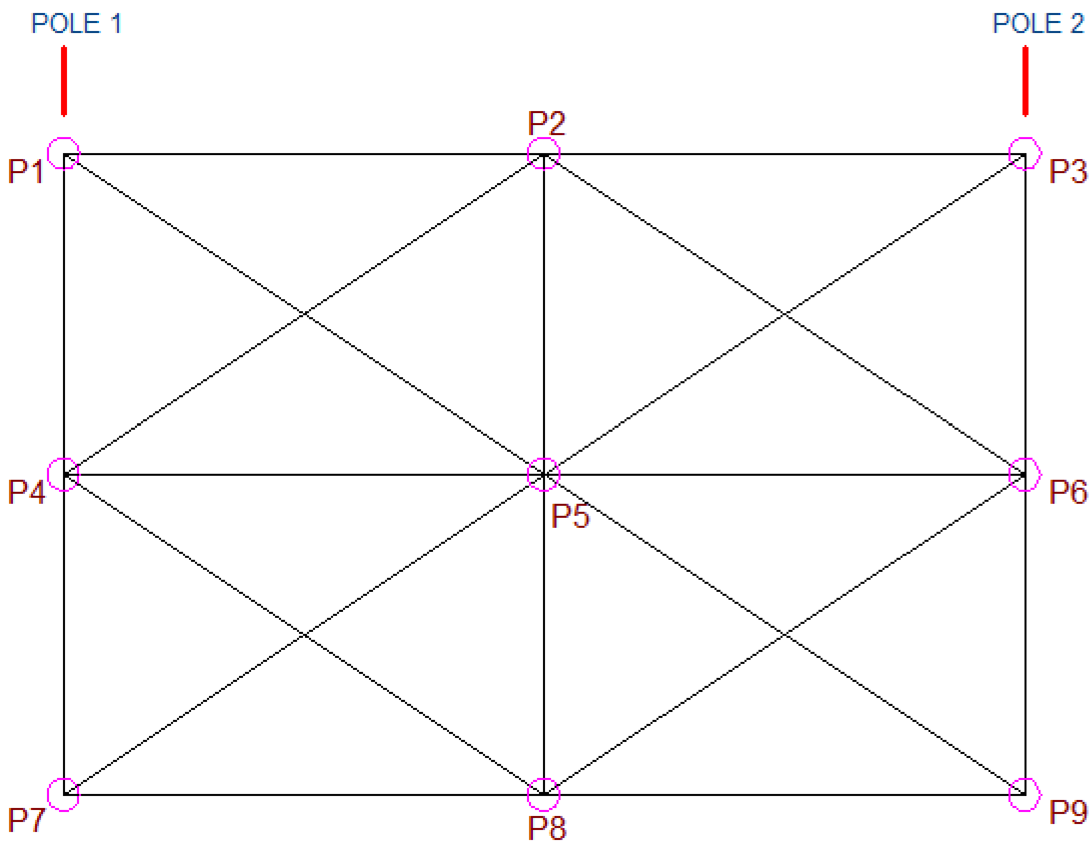


Fig 1.6: Measuring Grid Point between Two Poles.

$$\text{Eav} = \frac{\frac{P1+P2+P4+P5}{4}+\frac{P2+P3+P5+P6}{4}+\frac{P4+P5+P7+P8}{4}+\frac{P5+P6+P8+P9}{4}}{4}$$

$$= \frac{\frac{1\,(P1+P3+P7+P9)+2\,(P2+P4+P6+P8)+4\,(P5)}{4}}{4}$$

$$= \frac{1\,(\mathrm{P1}+\mathrm{P3}+\mathrm{P7}+\mathrm{P9})+2\,(\mathrm{P2}+\mathrm{P4}+\mathrm{P6}+\mathrm{P8})+4\,(\mathrm{P5})}{16}$$

$$\text{Eav} = \frac{P1+P3+P7+P9}{16}+\frac{\mathrm{P2}+\mathrm{P4}+\mathrm{P6}+\mathrm{P8}}{8}+\frac{\mathrm{P5}}{4}$$

1.10 Case Study

The layout of the carriageway is 21.5m wide as shown in the simulated lighting design. The lighting design has been simulated by using AGI32 lighting software as shown in the fig 1.6 & fig 1.7.

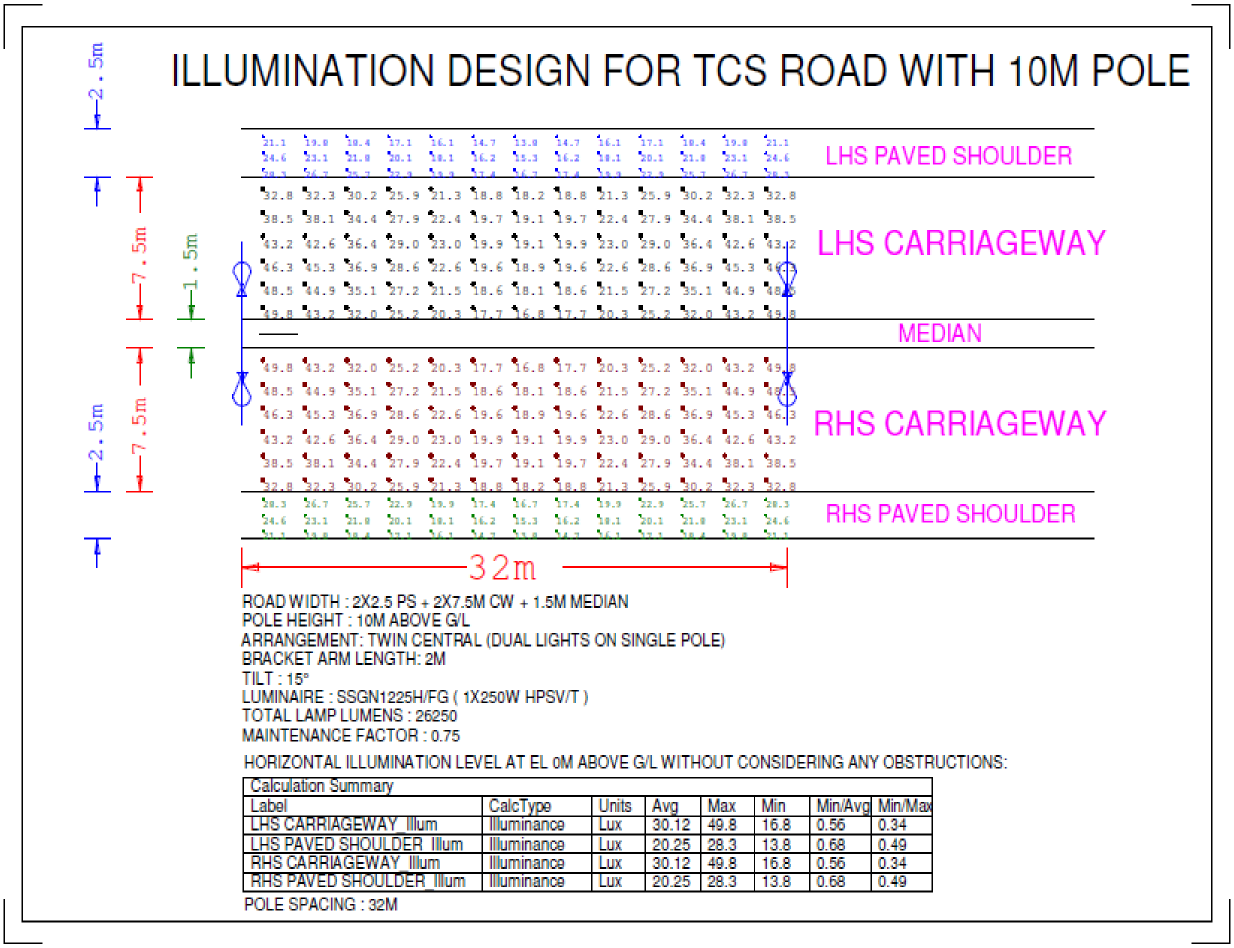
In the fig 1.6 design has been carried out with 10m pole by using luminaire SSGN1225H/FG (1X250W HPSV/T) having IP 66 protection with maintenance factor 0.75 and in the fig 1.7 design has been carried out with 10m pole by using luminaire LSTN1-150-CDL-A-HE (150W LED STREET LIGHT) having IP 66 protection with maintenance factor 0.75.

Twin Central arrangement has been selected because the dimension of the road is 2X2.5M PS + 2X7.5M CW + 1.5M MEDIAN. So, the required lux level is achieved on both side of the road by using single pole (double lights on single pole) which is placed in Median of the road. Lighting level of the carriageway is under Group A1 which comes into Group A Road according to the IS: 1944 (Parts I and II) -1970.

According to the IS: 1944 (Parts I and II) -1970, the average road surface illuminance should be at least 30 lux, overall uniformity (E_{min}/E_{avg}) should be at least 0.40 and Overall E_{min}/E_{max} should be at least 0.33.

In fig 1.6, for carriageway, average illuminance 30.12 lux with E_{min}/E_{avg} = 0.56 and E_{min}/E_{max} = 0.34 is achieved with 32m pole span and In fig 1.6, for carriageway, average illuminance 30.34 lux with E_{min}/E_{avg} = 0.63 and E_{min}/E_{max} = 0.43 is achieved with 36m pole span.

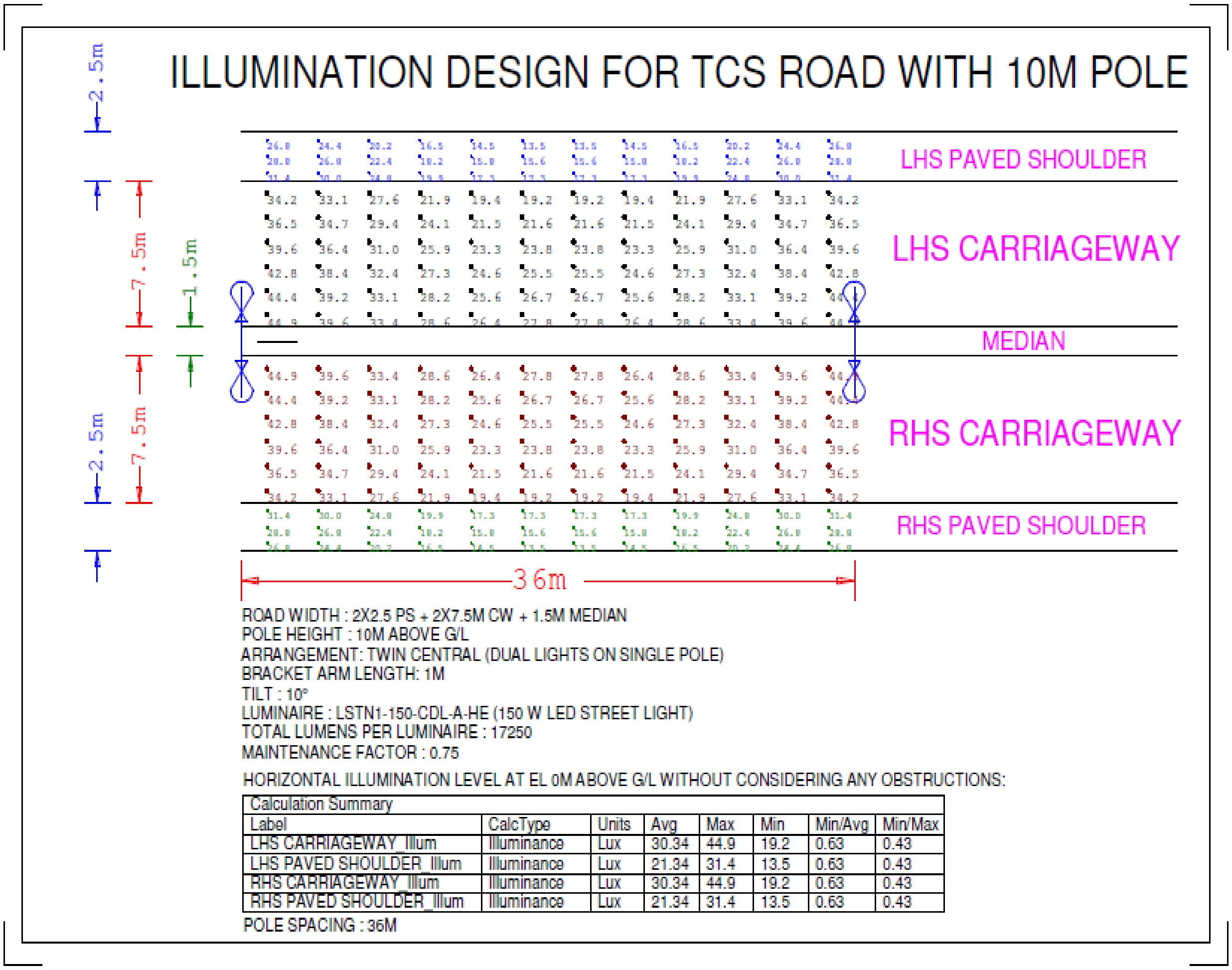
Both (Conventional & LED) the designs are achieved required lux level and uniformity but in Conventional is used 250 W HPSV and then pole span is 32M and, when used 150W LED STREET LIGHT with the same dimension of road then pole span is 36M.



Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
LHS CARRIAGEWAY_Illum	Illuminance	Lux	30.12	49.8	16.8	0.56	0.34
LHS PAVED SHOULDER_Illum	Illuminance	Lux	20.25	28.3	13.8	0.68	0.49
RHS CARRIAGEWAY_Illum	Illuminance	Lux	30.12	49.8	16.8	0.56	0.34
RHS PAVED SHOULDER_Illum	Illuminance	Lux	20.25	28.3	13.8	0.68	0.49

Fig 1.6: Road Lighting Design for 21.5M Width with Conventional



Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
LHS CARRIAGEWAY_Illum	Illuminance	Lux	30.34	44.9	19.2	0.63	0.43
LHS PAVED SHOULDER_Illum	Illuminance	Lux	21.34	31.4	13.5	0.63	0.43
RHS CARRIAGEWAY_Illum	Illuminance	Lux	30.34	44.9	19.2	0.63	0.43
RHS PAVED SHOULDER_Illum	Illuminance	Lux	21.34	31.4	13.5	0.63	0.43

Fig 1.7: Road Lighting Design for 21.5M Width with LED

1.11 Conclusion

The lighting design for the 21.5M wide road has been simulated successfully by using AGI32 lighting software.

For example road chainage is 750M. So in fig 1.6 is used 250W HPSV Street light and arrangement is Twin Central (Dual lights on single pole) and span is 32M.

So, total number of pole,

$$= \frac{Chainage}{Span} + 1$$

$$= \frac{750}{32} + 1$$

= 24 numbers (Approx)

And total number of luminaires,

= 24X2

= 48 numbers

To calculate the unit power density,

$$UPD = \frac{Total\ installed\ power\ (P)}{Area\ of\ the\ roadway\ (A)}$$

$$= \frac{No\ of\ luminaire\ X\ watt\ per\ luminaire\ X\ 1.15}{Span\ X\ Width}$$

$$= \frac{48\ \text{X}\ 250\ \text{X}\ 1.15}{32\ \text{X}\ (7.5 + 7.5)}$$

= 28.75 W/m^2

NOTE: Shoulders are not included in the area of the roadway.

In fig 1.7 is used 150W LED Street light and arrangement is Twin Central (Dual lights on single pole) and span is 36M.

So, total number of pole,

$$= \frac{Chainage}{Span} + 1$$

$$= \frac{750}{36} + 1$$

= 22 numbers (Approx)

And total number of luminaires,

= 22X2

= 44 numbers

To calculate the unit power density,

$$UPD = \frac{Total\ installed\ power\ (P)}{Area\ of\ the\ roadway\ (A)}$$

$$= \frac{No\ of\ luminaire\ X\ watt\ per\ luminaire\ X\ 1.15}{Span\ X\ Width}$$

$$= \frac{44 \text{ X } 150 \text{ X } 1.15}{36 \text{ X } (7.5 + 7.5)}$$

$$= 14.05 \text{ W/m}^2$$

NOTE: Shoulders are not included in the area of the roadway.

Table 1.13: Comparison of Conventional and LED

Type of Lighting Fixture	Total Qty of Poles	Total Qty of Luminaires	UPD (W/m^2)
Conventional	24	48	28.75
LED	22	44	14.05

Table 1.13 shows that the comparison between Conventional luminaire & LED luminaire lighting design of 21.5M road width to match the the requirements of the lighting design parameters. uses of LED Street light will save more energy and the total quantity of poles and total quantity of luminaires will be reduce and pole span will be maximum and also uniformity will be better than conventional luminaire. So LED Street light is more efficient lighting design over HPSV Street light.

Chapter 2

Highway Lighting

2.1 Introduction

The lighting designer shall design the project highway in a manner that will ensure safe operation of the Project Highway as a “partially access controlled highway”. The concept of providing ‘forgiving highway’ to the road user shall be kept in mind while planning and designing the project highway.

2.2 Acceptable Standard

The lighting designer shall follow latest version of the following Indian Standards, Specifications, Codes of Practice, Guidelines, etc;

a) Technical circulars issued by the ministry of shipping, Road Transport & Highways (MOSRTH) which are either published by Indian Roads Congress(IRC) and are available on the website of MOSRTH.
b) Indian Road Congress (IRC) Codes and Standards
c) Indian Standard IS: 1944

Where Indian Standards are either not available, or if available, are not adequate, the lighting designer shall be permitted to adopt international standards and specifications as followed in United States of America, United Kingdom, European Union, Japan, Germany or Australia.

2.3 General Considerations for Planning, Design and Construction

The Project Highway shall be planned as a "partially access controlled highway" where access to the highway shall be provided only at pre determined locations. In doing so, the Concessionaire shall take measures to overcome the physical and operational constraints and plan, design and construct the Project Highway using appropriate methods, management techniques and technologies. The objective therefore is to construct a 4-lane highway for all road users as an active infrastructure facility for people for their safety and services and as a catalyst in development of economy based on an inclusive approach.

General considerations shall, without being limited to, be as follows:-

a) The Constraints

The physical constraints in the existing highway are in the form of limitation of right of way; unregulated access, inadequate service roads and underpasses, numerous at-grade junctions, lack of physical separation between local and through traffic etc. The operation constraints arise out of the necessity or possibility of closing a portion of the road for construction and or diverting the traffic to temporary diversions, thereby reducing the capacity and safety of the existing highway. The solutions evolved by the Concessionaire shall be such that these operational constraints are overcome through appropriate planning, design and construction method, techniques and technologies and by adopting suitable traffic management measures.

b) Safety of Design

All designs shall be safe to ensure that the Project Highway or any part thereof (for example embankment, pavement, retaining structures, bridges, culverts, etc) does not collapse (global stability) nor its serviceability/performance (for example settlement, roughness, undulations, deflections, etc) deteriorates below acceptable level.

c) Durability

The Project Highway shall not only be safe but also durable. This would mean that the deteriorating effects of climate and environment (for example wetting and drying, freezing and thawing, if applicable, temperature differences, aggressive environment leading to corrosion, etc.) in addition to the traffic shall be duly considered in design and construction to make the Project Highway durable.

d) Mitigating Disruptive Effects of Construction

The planning, design and construction of the highway shall be such that the construction of Project Highway does not have adverse impact on the environment and does not disrupt the lives and business activities of the people living close to the Project Highway.

2.4 Built-Up-Area & Non Built-Up-Area

Built-up-area shall mean sections of the Project Highway that are situated within the municipal limits. Sections of 200 m or more in non-municipal areas where permanent structures are built on one or both sides of the Project Highway on at least 50 percent of the total length comprising such section shall also be treated as built up area.

Rural areas are synonymous to non-built-up areas and urban areas are synonymous to built-up areas.

2.5 Grade Separated Structures

1. The structures through which the traffic flows at different levels are called Grade Separated Structures.
2. A grade separated structure which is provided for crossing of vehicles under the Project Highway is called as Vehicular Underpass (VUP).
3. A grade separated structure which is provided for crossing of vehicles over the Project Highway is called as Vehicular Overpass (VOP).
4. A structure provided below the Project Highway to cross the pedestrians is called Pedestrian Underpass (PUP).
    - A PUP may not be necessary within a distance of 2 km from Vehicular underpasses/overpasses and Light Vehicular Underpasses.
    - The pedestrian crossings (PUP) shall have provision for movement of physically challenged persons.
    - Pedestrian underpass shall also be provided within a distance of 200 m from a school or hospital or factory/industrial area.
5. A structure provided below the Project Highway to cross the catties is called Cattle Underpass (CUP).
    - A CUP may not be necessary within a distance of 2 km from Vehicular underpasses/overpasses and Light Vehicular Underpasses.
6. A pedestrian/cattle underpass through which light vehicles of height upto 3 m can also pass is called Light Vehicular Underpass (LVUP).
7. Flyover is synonymous to VUP/VOP/LVUP/PUP/CUP.
8. A structure provided above the Project Highway to cross pedestrians is called Foot Over Bridge.
    - A Foot Over Bridge may not be necessary within a distance of 2 km from Vehicular underpasses/overpasses and Light Vehicular Underpasses.
    - The pedestrian crossings (FOB) shall have provision for movement of physically challenged persons.
    - Foot Over Bridge shall also be provided within a distance of 200 m from a school or hospital or factory/industrial area.
9. A structure provided over the railway lines to carry the Project Highway is called Road Over Bridge (ROB).
10. A structure provided below the railway lines to carry the Project Highway is called Road Under Bridge (RUB).
11. A Trumpet interchange is a grade separator structure provided at major T-junction facilitating uninterrupted flow of traffic in each direction.
12. A Cloverleaf is a grade separator structure provided at a major cross road junction facilitating uninterrupted flow of traffic in each direction

2.6 Geometric Design and General Features

2.6.1 Design Speed

- The design speeds given in Table 2.1 shall be adopted for various terrain classifications (Terrain is classified by the general slope of the ground across the highway alignment).

Nature of Terrain	Cross Slope of the Ground	Design Speed (km/h)	
		Ruling	Minimum
Plain and rolling	Up to 25 percent	100	80
Mountainous and Sleep	More than 25 percent	60	40

Table 2.1: Design Speed

- In general, the ruling design speed shall be adopted for the various geometric design features of the road. Minimum design speed shall be adopted only where site conditions are restrictive and adequate land width is not available.

2.6.2 Right-of-Way

A minimum Right of Way (ROW) of 60 m should be available for development of a 4-lane highway.

2.6.3 Lane Width of Carriageway

The standard lane width of project highway shall be 3.5 m.

2.6.4 Median

- The median shall be either raised or depressed. The width of median is the distance between inside edges of carriageway. The type of median shall depend upon the availability of Right of Way. The minimum width of median, subject to availability of Right of Way, for various locations shall be as in Table 2.2. Including Kerb shyness of 0.50 m on either side, in the existing 4-lane reaches also, the minimum kerb shyness of 0.5 m shall be maintained. This additional width for kerb shyness shall be catered by augmenting the carriageways toward the shoulder side.

Type of Selection	Minimum Width of Median (m)		
	Plain and Rolling Terrain		Mountainous and Steep Terrain
	Raised	Depressed Median	Raised
Open country with isolated built-up area	5.0	7.0	2.50
Built-up area	2.50	Not Applicable	2.50
Approach to grade separated structures	5.0	Not Applicable	2.50

Table 2.2: Width of Median

- The median shall have suitably designed drainage system so that water does not stagnate in the median. All median drains shall be of Cement Concrete.
- In case of depressed median, a minimum 0.6 m width adjacent to carriageway in either direction shall be paved.
- As far as possible, the median shall be of uniform width in a particular section of the highway. However, where changes are unavoidable, a transition of 1 in 50 shall be provided.
- In the case of depressed median, metal beam type (thrie beam - one side) crash barriers or Wire rope barrier shall be provided on either side of the median. However, in case the width of median is more than 9 m, no crash barrier is required to be provided in the median.
- The median in built up area shall be paved. In such locations, crash barriers and suitable antiglare measures such as plastic screens shall be provided at the center of median to reduce headlight glare from opposite traffic. The total height of screen including the height of the barrier shall be 1 .5 m and spacing shall be such as to effectively cut the glare.

2.6.5 Shoulders

Paved shoulder is the portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles for emergency use, and for lateral support of the base and surface courses. A paved shoulder refers to the part of the highway that is adjacent of the regularly traveled portion of the highway and is on the same level as the highway. Paved shoulders also better accommodate bicyclists by providing an area for them to ride on that is off of the mainline of the roadway.

The shoulder width on the outer side (left side of carriageway) shall be as given in Tables 2.3 and 2.4.

Type of Section	Width of Shoulder (m)		
	Paved	Earthen	Total
Open country with isolated built-up area	1.5	2.0	3.5
Built-up area	2.0	-	2.0
Approaches to grade separated structures	2.0	-	2.0
Approaches to bridges	1.5	2.0	3.5

Table 2.3: Width of Shoulders in Plan and Rolling Terrain

Type of Section		Width of Shoulder (m)		
		Paved	Earthen	Total
Open country with isolated built-up area	Hill Side	1.5 m	-	1.5 m
	Valley Side	1.5 m	1.0 m	2.5 m
Built-up area and approaches to grade separated structures/ bridges	Hill Side	0.25 m + 1.5 m (Raised)	-	1.75 m
	Valley Side	0.25 m + 1.5 m (Raised)	-	1.75 m

Table 2.4: Width of Shoulders in Mountainous and Steep Terrain (Hilly Area)

The type of shoulder shall be as below:

a) In the built-up section and approaches to the grade separated structures, the shoulder shall be paved in full width
b) Earthen shoulders shall be covered with 150 mm thick layer of granular material.
c) The composition and specification of the paved shoulder shall be same as of the main carriageway

2.6.6 Roadway Width

The width of roadway shall depend upon the width of carriageway, shoulders and the median.

On horizontal curves with radius up to 300 m, width of pavement and roadway in each carriageway shall be increased as per table 2.5.

Radius of Curve	Extra Width
75-100 m	0.9 m
101-300 m	0.6 m

Table 2.5: Extra Width of Pavement and Roadway in Each Carriageway

2.6.7 Geometric Design

2.6.7.1 Sight Distance

The safe stopping sight distance and desirable minimum sight distance for divided carriageway for various design speeds are given in Table 2.6.

A minimum of safe stopping sight distance shall be available throughout.

Design Speed (km/h)	Safe Stopping Sight Distance (M)	Desirable Minimum Sight Distance (m)
100	180	360
80	130	260
60	90	180
40	45	90

Table 2.6: Safe Sight Distance

2.6.7.2 Vertical Alignment

- The vertical alignment should provide for a smooth longitudinal profile. Grade changes shall not be too frequent as to cause kinks and visual discontinuities in the profile. In this regard, directions given in IRC: 73 should be kept in view.
- **Gradients:**
  The ruling and limiting gradients are given in Table 2.7.
  Ruling Gradients shall be adopted as far as possible. Limiting Gradient shall be adopted in difficult situations and for short lengths.

Nature of Terrain	Ruling Gradient	Limiting Gradient
Plain and Rolling	2.5%	3.3%
Mountainous	5.0%	6.0%
Steep	6.0%	7.0%

Table 2.7: Gradients

2.6.8 Lateral and Vertical Clearance at Underpasses

Wherever the Project Highway is proposed to be taken above/over a cross road minimum clearances at underpasses shall be as follows:

Lateral Clearance:

It can be defined as the clearance b/w the body of the vehicle (moving on the outermost lane) to any of the way side installation (like sign post, signal tree, etc.).

1) Full roadway width of the cross road shall be carried through the vehicular underpass. The lateral clearance shall not be less than 1 2 m (7 m carriageway + 2 X 2.5 m shoulder width on either side).
2) For Light Vehicular Underpass the lateral clearance shall not be less than 10.5 m including 1 .5 m wide raised footpath on either side.
3) For pedestrian and Cattle underpasses the lateral clearance shall not be less than 7 m.
4) Guard rails/crash barriers shall be provided for protection of vehicles from colliding with the abutments and piers and the deck of the structures.

Vertical Clearance:

Vertical clearance at underpasses shall not be less than the values given below:

1) Vehicular Underpass	5.5 m
2) Light Vehicular Underpass	3.5 m
3) Pedestrian And Cattle Underpass	3.0 m (to be increased to 4.5 m, in case certain categories of animals such as elephant/camel are expected to cross the Project Highway frequently.

Wherever existing slab/box culverts and bridges allow a vertical clearance of more than 2 m, these can be used in dry season for pedestrian and cattle crossing by providing necessary flooring.

Fig 2.1A: Railway Underpass

2.6.9 Lateral and Vertical Clearance at Overpasses

Wherever any structure is provided over the Project Highway; the minimum clearances at overpasses shall be as follows:

Lateral Clearance:

Full roadway width shall be carried through the overpass structure. Provision shall also be made for future widening of the Project Highway to 6-lane with service roads. The abutments and piers shall be provided with suitable protection against collision of vehicles. Crash barriers shall be provided on abutment side and on sides of piers for this purpose. The ends of crash barriers shall be turned away from the line of approaching traffic.

Vertical Clearance:

A minimum 5.5 m vertical clearance shall be provided at all points of the carriageway of the Project Highway.

2.6.10 Access to Project Highway

2.6.10.1 Access

Access to the Project Highway shall be partially controlled. In general, access to the Project Highway shall be provided at the following locations:

- i) Intersection with National Highways
- ii) Intersection with State Highways
- iii) Intersection with Major District Roads
- iv) Intersection with village road and other district roads, subject to a minimum Distance of 3 km from the nearest intersection.

2.6.10.2 Service Road

In open country with isolated built up area, the service road shall have 7 m wide carriageway and 1.5 m wide earthen shoulder on either side. In built up area, the service road shall have 7.5 m wide carriageway (including kerb shyness of 0.25 m on either side) with raised footpath/separator on either side as shown in Fig. 2.1.

For the stretches where total length of a bridge is less than 60 m and the service road is required to be provided on both sides of the stream, then the service road shall continue across the stream and suitably designed 2-lane bridge structure shall be provided. In cases involving bridges of 60 m length or more, separate bridge structures may not be provided and service road shall be merged with the Project Highway at 50 m distance before the bridge structure.

Wherever service roads are provided, provision shall be made for proper entry and exit ramps between the main highway and the service roads through properly designed acceleration and deceleration length, duly keeping in view future widening of main highway to six-lanes. The layout for entry/exit at service road shall be as per Figs. 2.2 and 2.3.

A minimum design speed of 40 km/h shall be adopted for service roads.

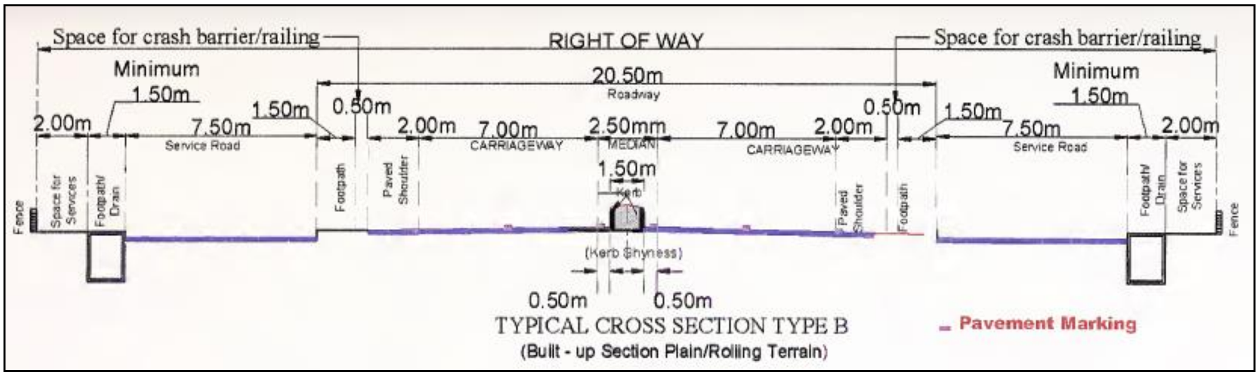


Fig 2.1: 4 lane divided highway with service roads and with raised median

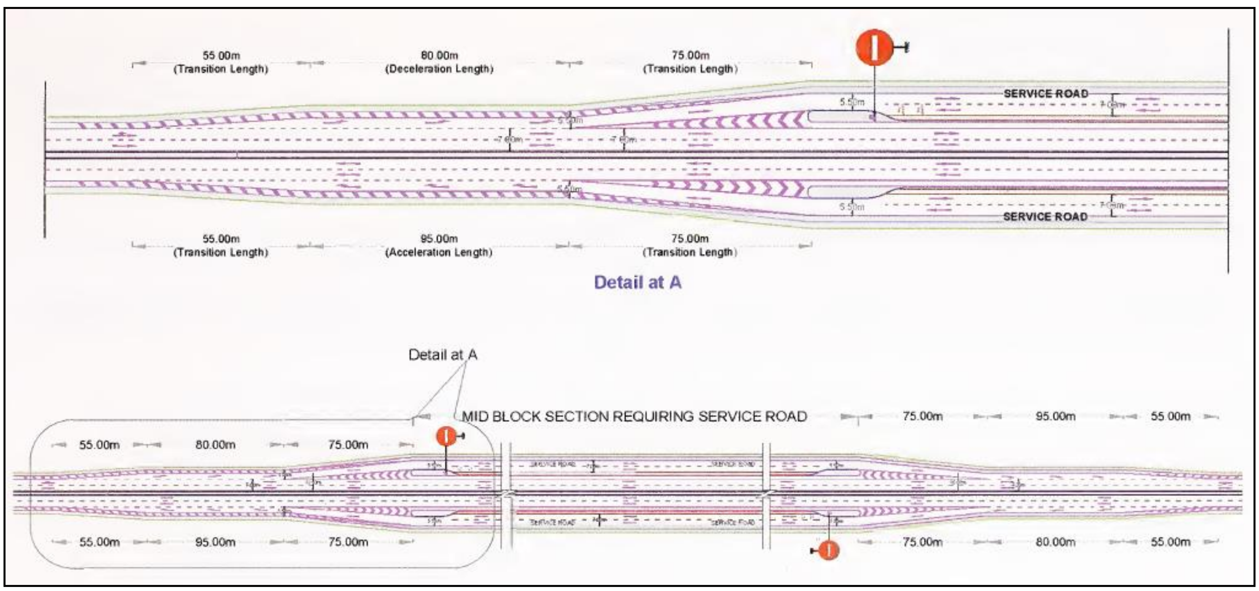


Fig 2.2: Entry/Exit arrangement with service road

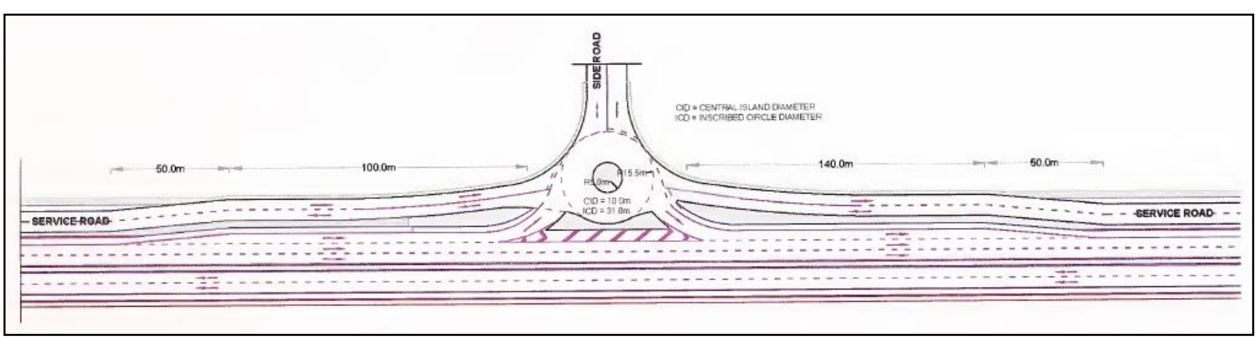


Fig 2.3: Entry/Exit arrangement with a side road (service road continuing)

Fig 2.3B: Main Carriageway and Service Road

2.6.10.3 Slip Road

Slip Road is a small road which is provided to enter or exit a highway section as shown in Fig. 2.4.

Fig 2.4: Slip Road

2.6.10.4 Acceleration and Deceleration Lanes:

The following requirements shall apply:

- i) Length: Designed for a speed differential of 60 km/h
- ii) Width: 5.5 m (minimum)
- iii) Taper at merge: 1 in 15 beyond design length

The acceleration and declaration lanes and transition length will be considered as incidental to the project and shall not be counted towards service road length.

2.6.11 Separator, Footpath and Drain in Built-Up Areas

Raised Footpath of minimum 1 .5 m width with kerb on either side (200 mm above road surface), drain pipes across at minimum 10 m intervals and finished with CC paving blocks along with Metal Beam Barrier (Thrie Beam - one side) as shown in the above Fig. 2.1.

Drain-cum-footpath shall be provided at the edge of the service road (ROW side).

The raised footpath shall be depressed at suitable intervals to provide for convenient use of physically challenged persons.

2.6.12 Typical Cross-Sections

Typical cross-sections of Project Highway are given in Figs. 2.2 to 2.10 for various locations as below:

Fig. 2.2 shows typical cross-section Type-A1 for 4-lane divided highway in open country with isolated built-up area in plain/rolling terrain, without service roads and with depressed median.

Fig. 2.3 shows typical cross-section Type-A2 for 4-lane divided highway in open country in plain/rolling terrain with service roads on both sides and with depressed median.

Fig. 2.4 shows typical cross-section Type-A3 for 4-lane divided highway in open country with isolated built-up area in plain/rolling terrain, without service roads and with raised median.

Fig. 2.5 shows typical cross-section Type-A4 for 4-lane divided highway in open country in plain/rolling terrain with service roads on both sides and with raised median.

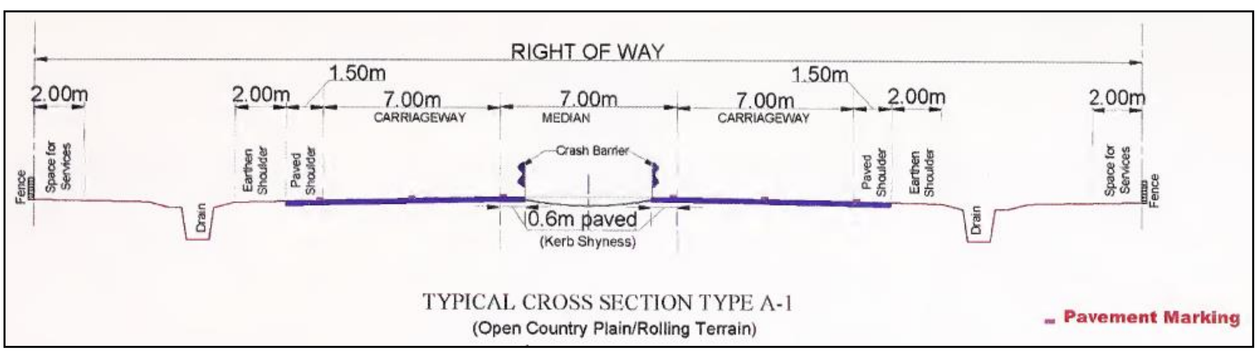


Fig 2.2: 4 Lane Divide Highway without Service Roads and with Depressed Median

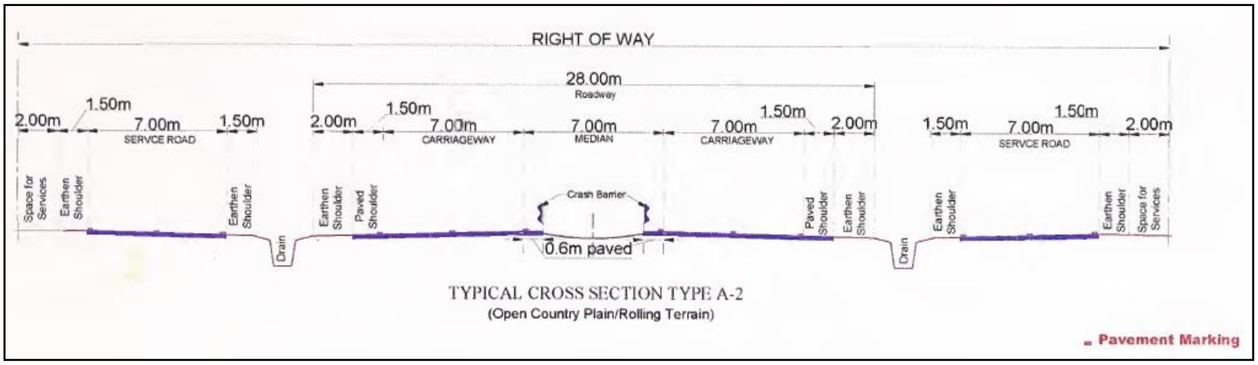


Fig 2.3: 4 Lane Divide Highway with Service Roads and with Depressed Median

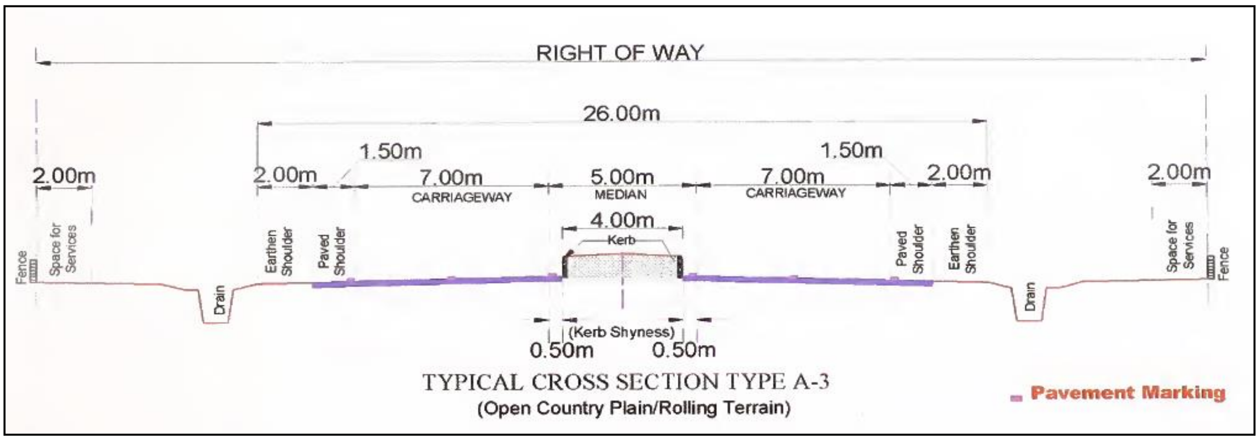


Fig 2.4: 4 Lane Divide Highway without Service Roads and with Raised Median

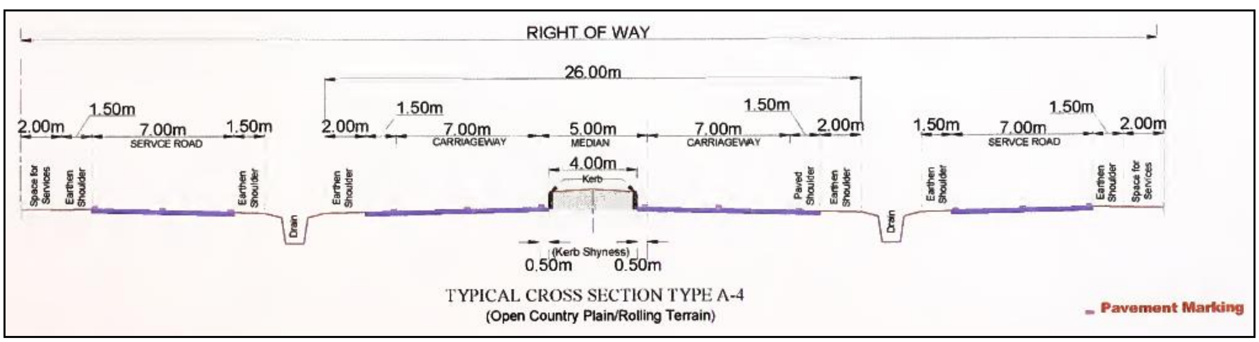


Fig 2.5: 4 Lane Divide Highway with Service Roads and with Raised Median

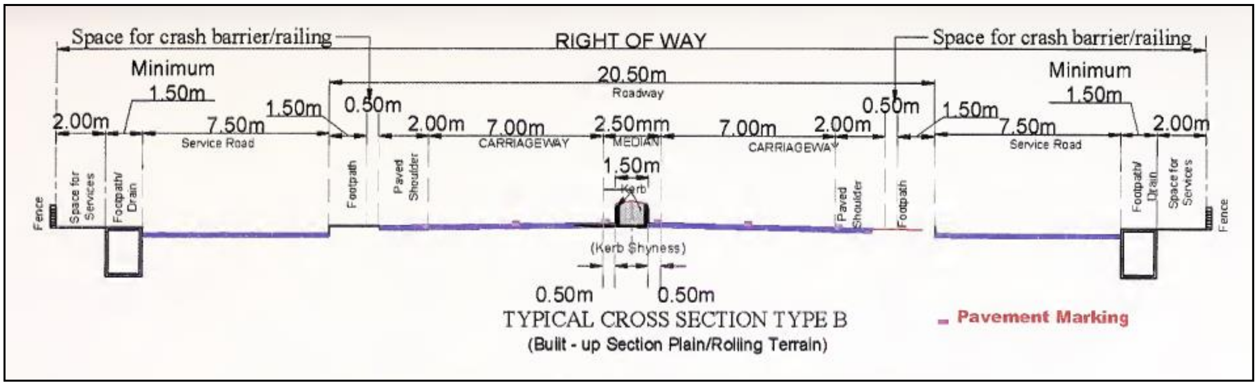


Fig 2.6: 4 Lane Divide Highway with Service Roads and with Raised Median

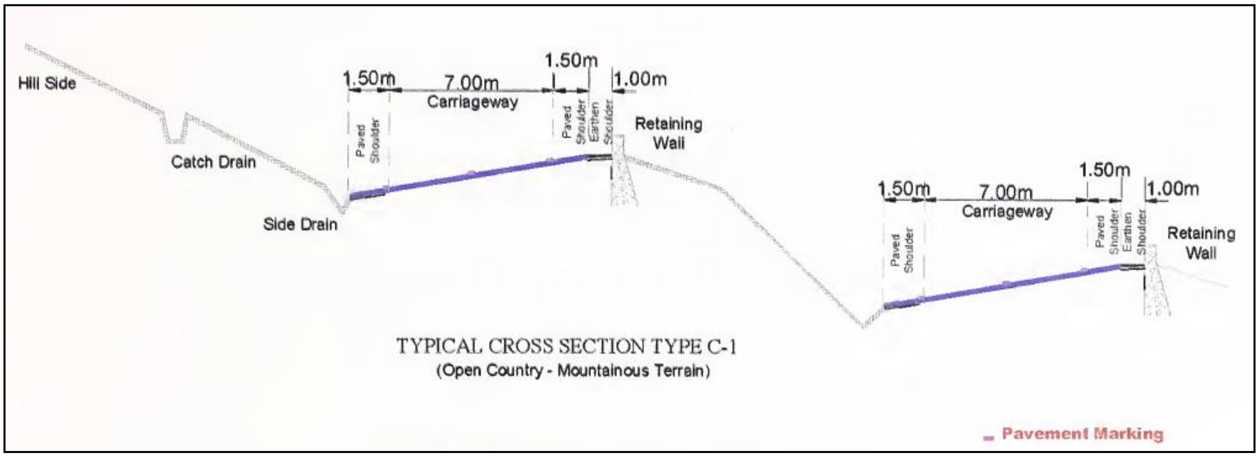


Fig 2.7: 4 Lane Divide Highway on Different Contours

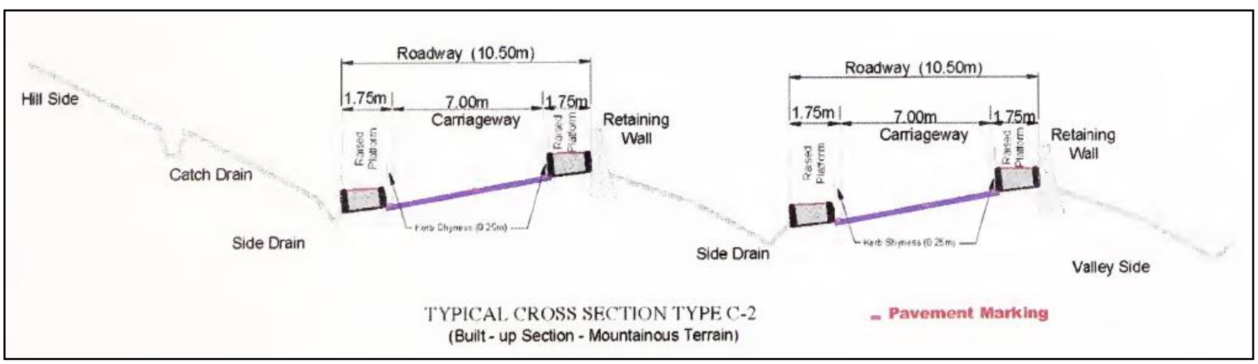


Fig 2.8: 4 Lane Divide Highway on Different Contours

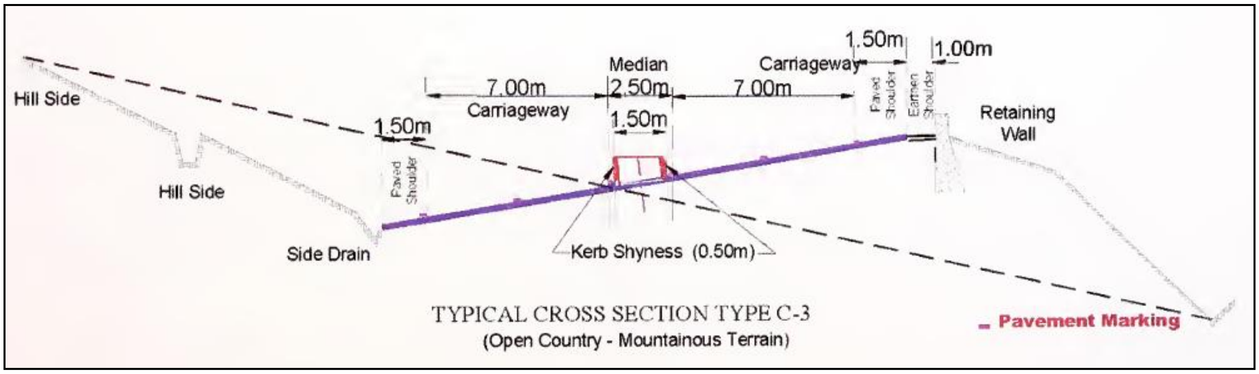


Fig 2.9: 4 Lane Divide Highway at same level with Raised Median

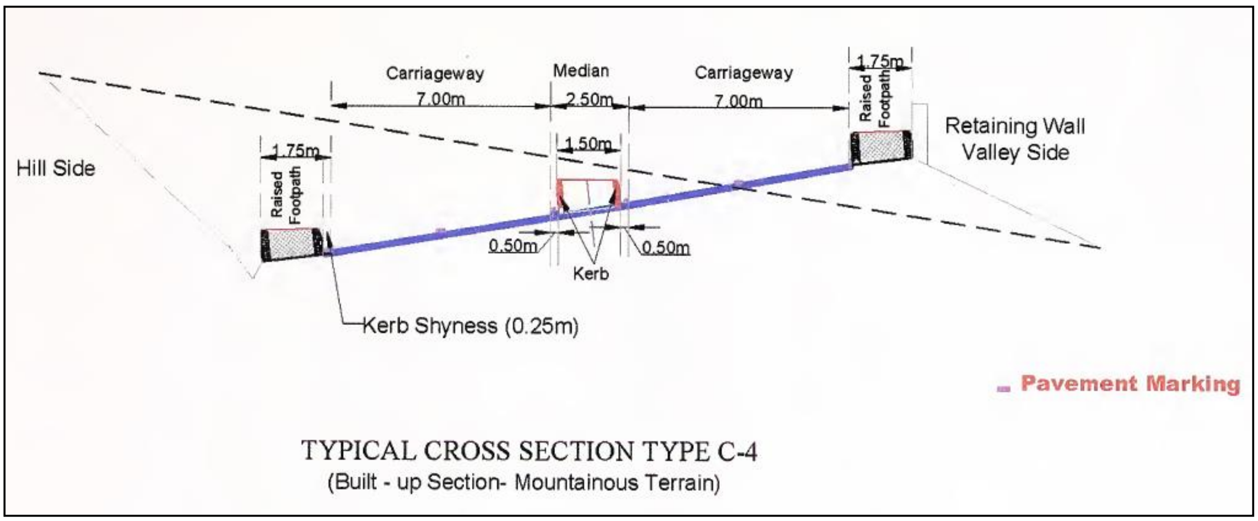


Fig 2.10: 4 Lane Divide Highway at same level with Raised Median

Fig. 2.6 shows typical cross-section Type-B for 4-lane divided highway in built-up section in plain and rolling terrain with service roads on both sides and with raised median.

Fig. 2.7 shows typical cross-section Type-C1 for 4-lane divided highway on different contours in open country with isolated built-up area in mountainous terrain.

Fig. 2.8 shows typical cross-section Type-C2 for 4-lane divided highway on different contours in built-up section in mountainous terrain.

Fig. 2.9 shows typical cross-section Type-C3 for 4-lane divided highway at same level in open country with isolated built-up area in mountainous terrain.

Fig. 2.10 shows typical cross-section Type-C4 for 4-lane divided highway at same level in built-up section in mountainous terrain.

2.7 Intersections and Grade Separators

The intersections to be provided shall be one of the following types:

1) At-grade Intersections
2) Grade separated Intersections without ramps
3) Interchanges

The existing intersections, which are deficient with respect to the minimum requirements, shall be improved to the prescribed standards. Additional land, if any, required for improving the existing intersections shall be provided by the Authority.

The types and locations of new Intersections, Interchanges and Grade-separated Intersections without ramps shall be based on requirements stipulated in IRC:SP:41, IRC:5, IRC:92, MORTH Specifications for Road and Bridge Works.

2.7.1 At-Grade Intersections

- The type of intersections to be adopted shall be decided on the basis of parameters like number of intersecting legs, traffic volume/speed, type of traffic control etc. Properly designed intersections shall be provided at all at-grade crossings. Rotary shall not be provided on the Project highway.
- **1)** The intersections shall be designed having regard to flow, speed, composition, distribution and future growth of traffic. Design shall be specific to each site with due regard to physical conditions of the site available. The design of different elements of intersection shall be done as per IRC: SP: 41 "Guidelines on Design of At-grade Intersections in Rural and Urban Areas" including other criteria given in this Manual. MORTH - Type Designs for Intersection on National Highways may also be referred to, wherever required to develop suitable layout and design of At-grade Intersections.

  2) At multi leg intersections, the points of conflict should be studied carefully and possibilities of realigning one or more of the intersecting legs and combining some movements to reduce the conflicting movements shall be examined. The object shall be to simplify the design and appropriate control devices added to ensure more efficient and safe operation.

  3) The channelising islands shall start from the edge of the paved shoulder. This principle shall also apply in case of MORTH - Type Designs for Intersections on National Highways.

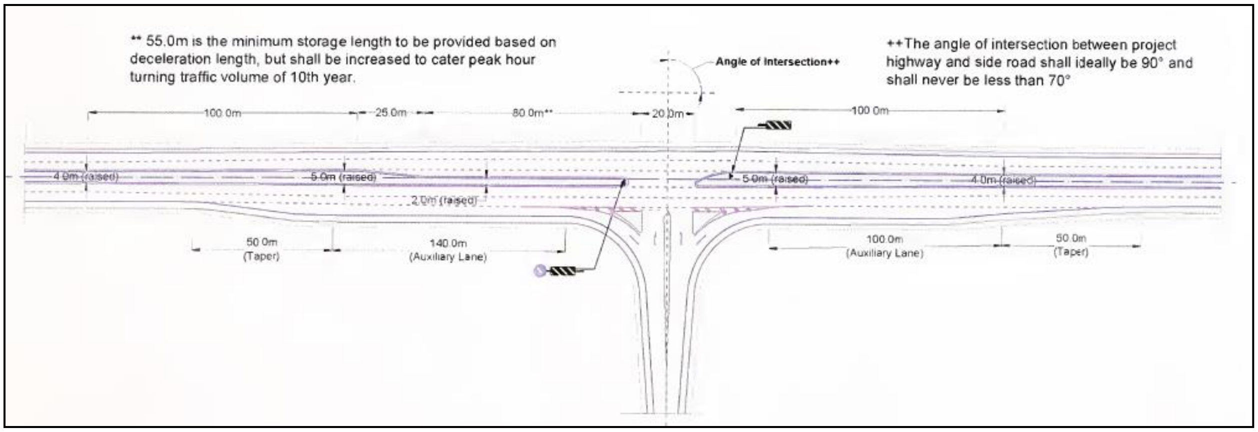


Fig 2.11: Layout for T-Intersection (with Right Turn Protected Arrangement)

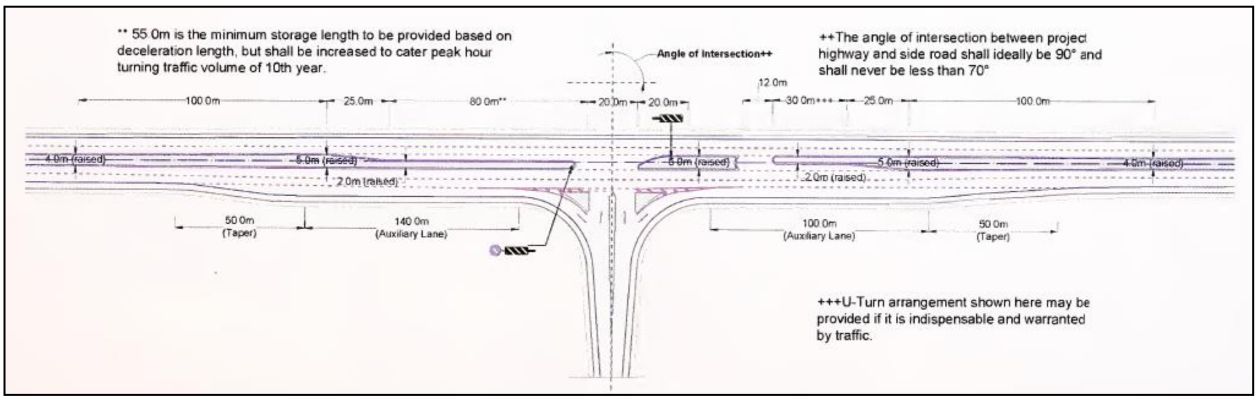


Fig 2.12: Layout for T-Intersection with U-Turn Facility (At locations having substantial U-Turn Traffic volume)

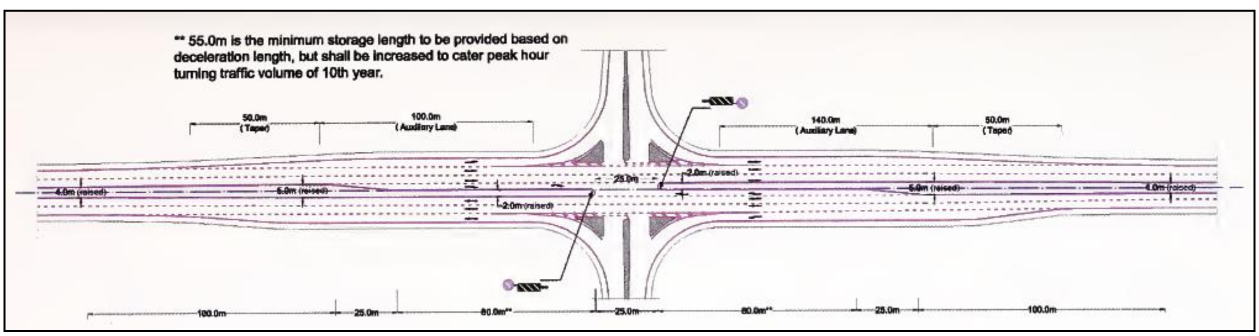


Fig 2.13: Layout for Cross Road Intersection (with Right Turn Protected Arrangement)

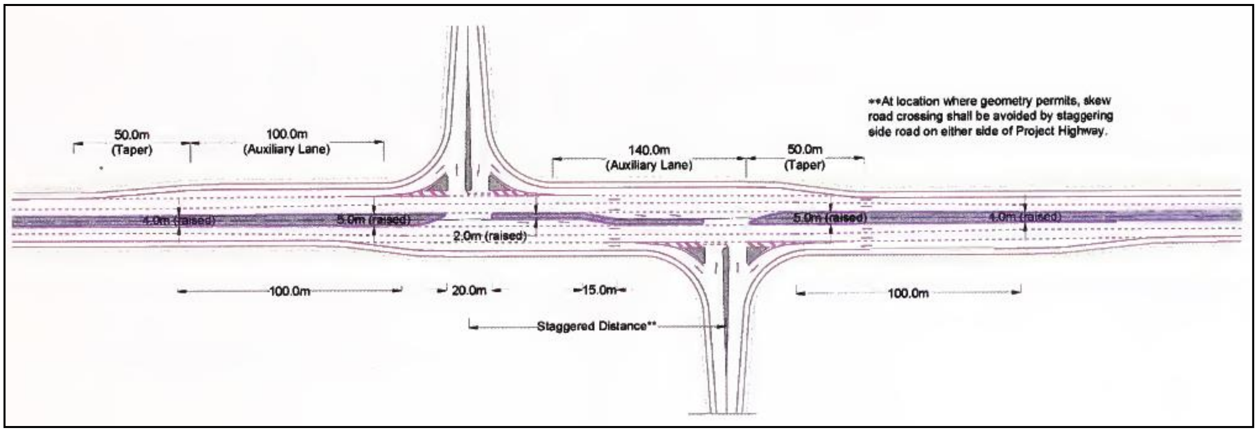


Fig 2.14: Layout for Staggered Intersection (with Right Turn Protected Arrangement)

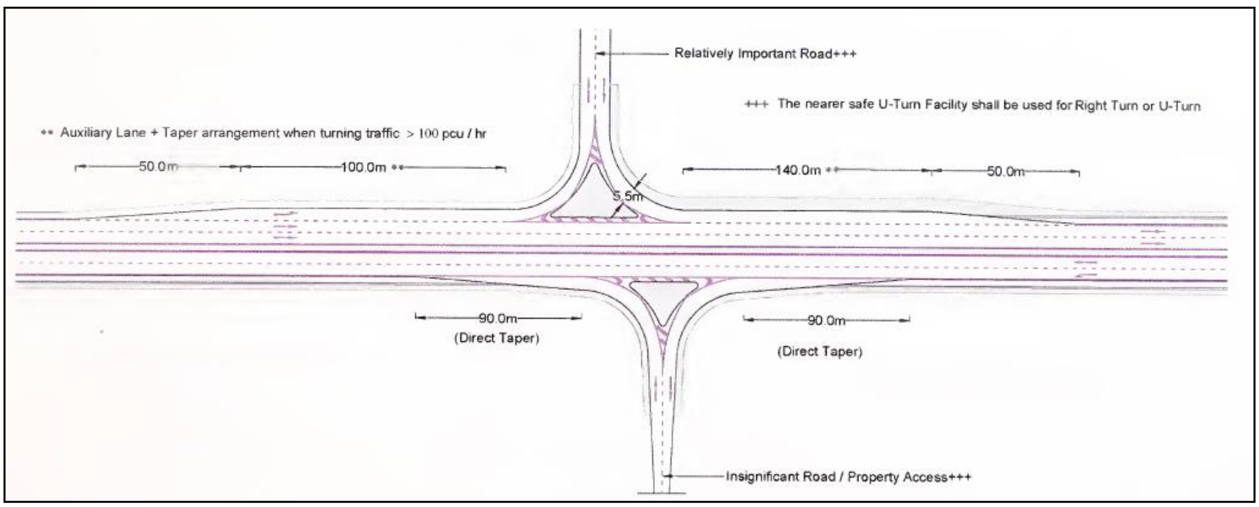


Fig 2.15: Left-in/Left-out Arrangement

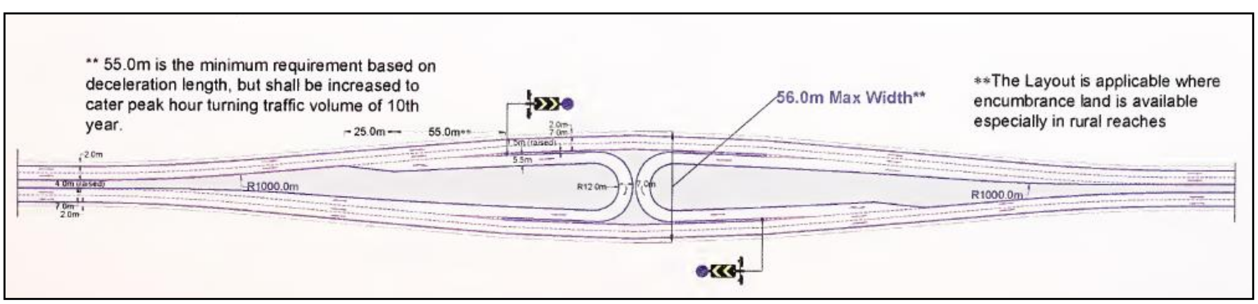


Fig 2.16: Self-Regulated U-Turn Facility

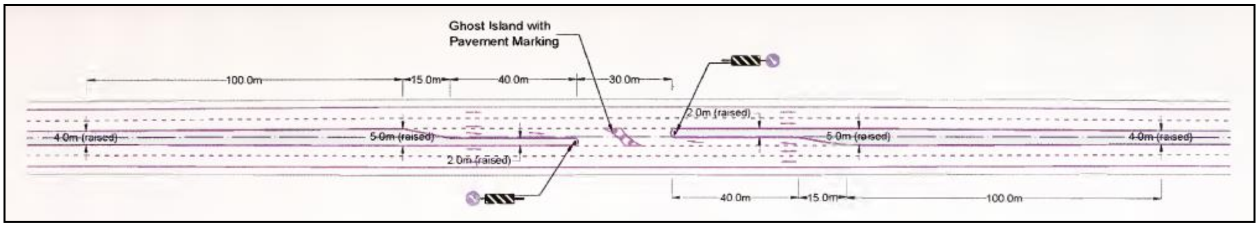


Fig 2.17: Layout for U-Turn

The 4-lane highway encounters many at-grade maneuvering situations and the layout provided below are suggested for at-grade intersections on the project highway including that for U-turn.

Fig. 2.11: Layout for T-Intersection (with Right Turn Protected Arrangement). The angle of interaction between project highway and side road shall never be less than 70 degree and shall be ensured for T-junction including new bypass junctions.

Fig. 2.12: Layout for T-Intersection (with Protected U-Turn Arrangement). The U-turn arrangement shall be provided at locations where is indispensable and traffic warrants to provide such a facility).

Fig. 2.13: Layout for Cross Road Intersection (With Right Turn Protected Arrangement). The 5 m wide median shall be continued to cater protected right turning. Moreover, wherever land permits, the median Width shall be increased to 7 m to avoid narrow median width at storage lane location.

Fig. 2.14: Layout for Staggered Intersection (With Right Turn Protected Arrangement). At location where geometry permits, skew road crossing shall be avoided by staggering side road on either side of Project Highway.

Fig. 2.15: Left-in/Left out Arrangement. For right turn or U-turn, the nearest safe U-turn facility shall be used.

Fig. 2.16: Self-Regulated U-Turn Facility. The Layout is applicable where encumbrance free land is available especially in rural reaches.

Fig. 2.17: Layout for U-turn.

In the above layouts, the width of right turning storage lane may be 3.0-3.5 m.

2.7.2 Grade Separated Intersections and Interchanges

An interchange is justified at locations where traffic on cross roads is moderate to heavy and for safe and efficient traffic flow, ramps are necessary for cross road traffic.

Encompassing safety requirement and also to have better traffic control following layouts are suggested for at-grade intersections below structures on the project highway.

Fig 2.18: Junction Layout below a VUP for Low Traffic Volume (Turning Radii for Light Commercial

Fig 2.19: Vehicle Junction Layout below a VUP for Low Traffic Volume (Turning Radii for Trucks/Buses).

Fig 2.20: Junction Layout for Medium Traffic Volume (Single Span Flyover & Control by Priority or Traffic Signal).

Fig 2.21: Junction Layout for Medium Traffic Volume (Flyover with Viaduct Spans & Traffic Regulation by Roundabout).

Fig 2.22: Junction Layout for High Traffic Volume (Flyover with Viaduct Spans & Traffic Control by Signalization.

Fig 2.23: Junction below a Half Flyover connecting Slip roads.

Fig 2.24: Local Grade Separation for an Important Side Road (Two Lane Bridge over At-grade Project Highway).

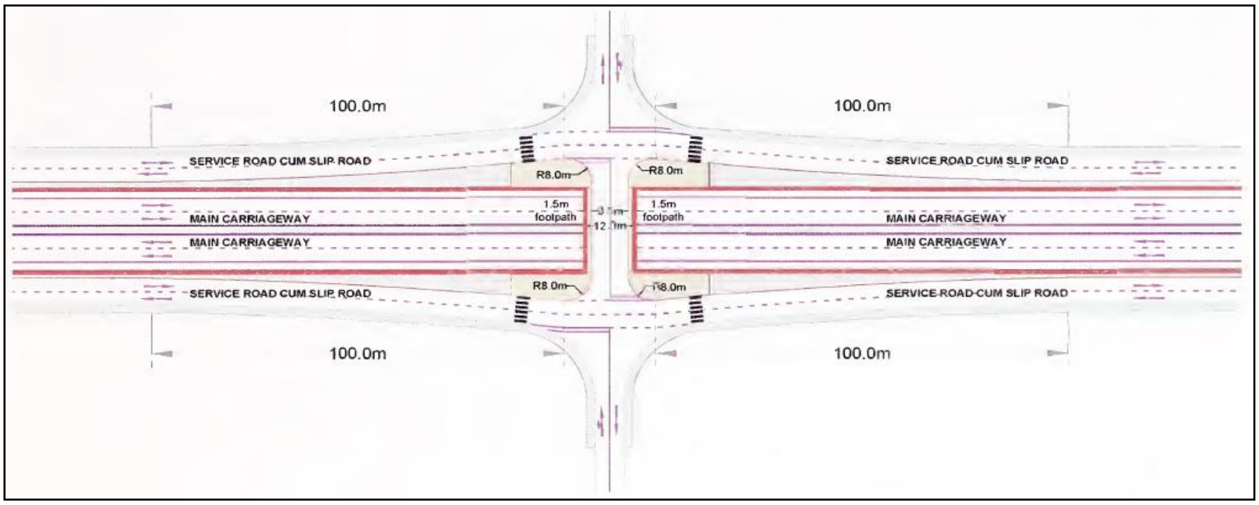


Fig 2.18: Junction Layout below a VUP for Low Traffic Volume (Turning Raddi for Light Commercial Vehicle).

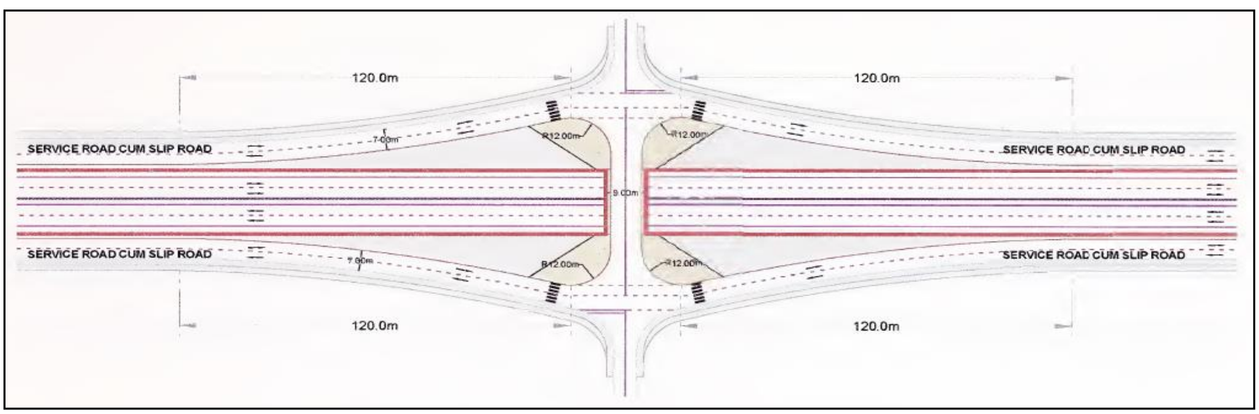


Fig 2.19: Junction Layout below a VUP for Low Traffic Volume (Turning Raddi for Truck/Buses).

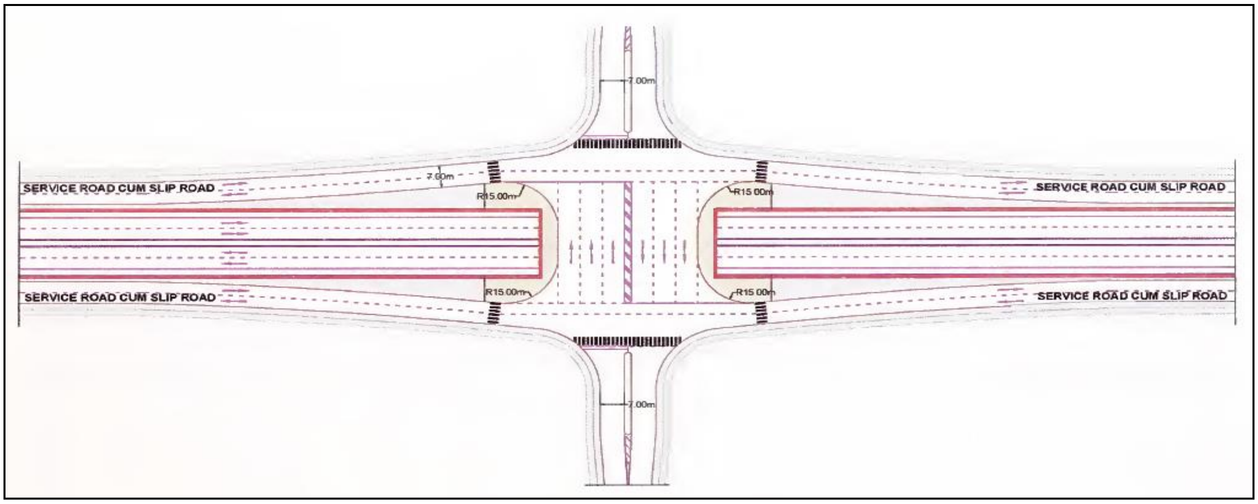


Fig 2.20: Junction Layout for Medium Traffic Volume (Single Span Flyover & Control by Priority or Traffic Signal).

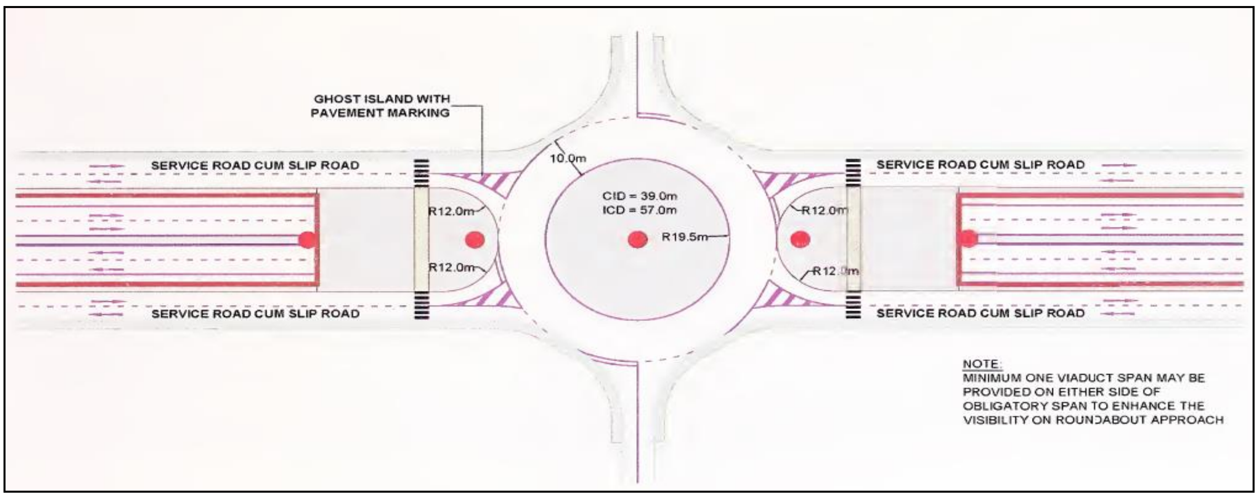


Fig 2.21: Junction Layout for Medium Traffic Volume (Flyover with Viaduct Spans & Traffic Regulation by Roundabout).

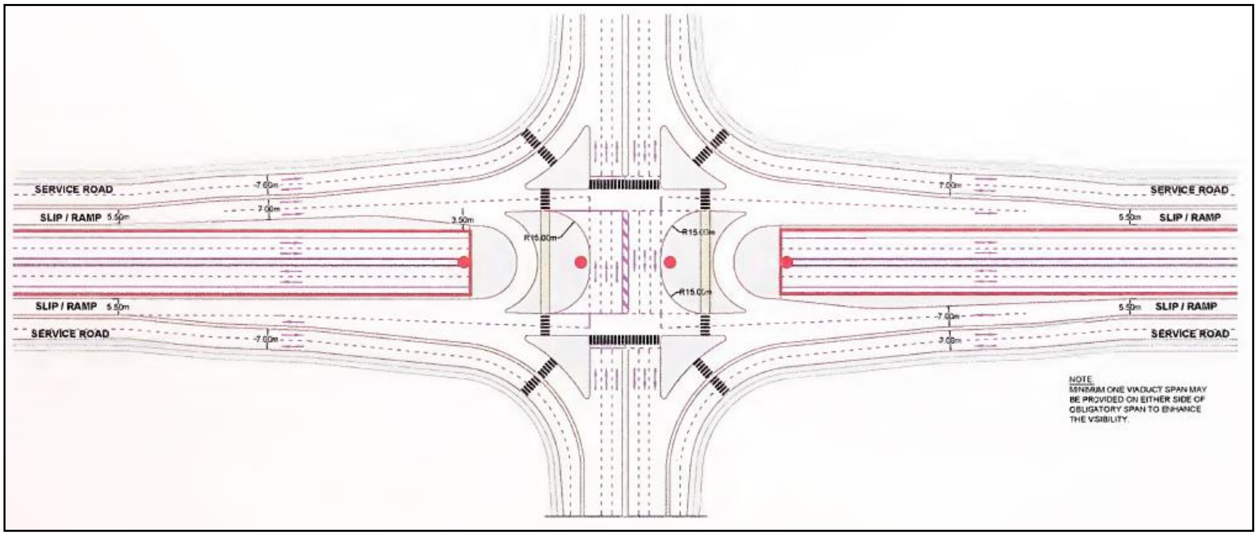


Fig 2.22: Junction Layout for Medium Traffic Volume (Flyover with Viaduct Spans & Traffic Control by Signalization).

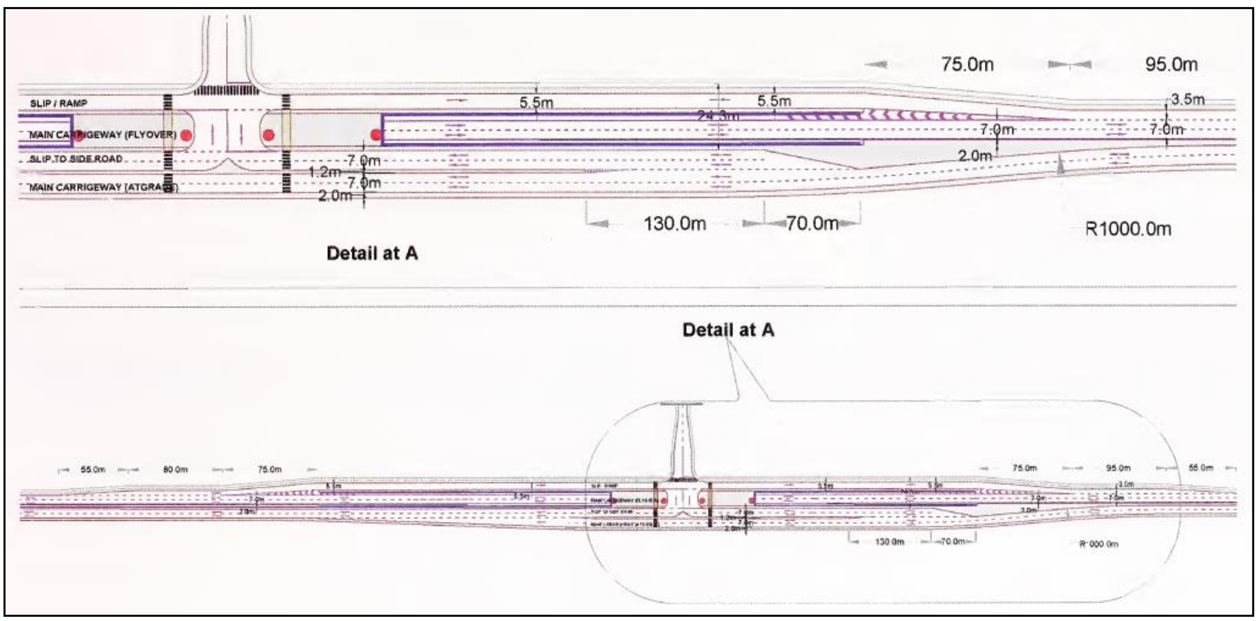


Fig 2.23: Junction below a Half Flyover connecting Slip Roads.

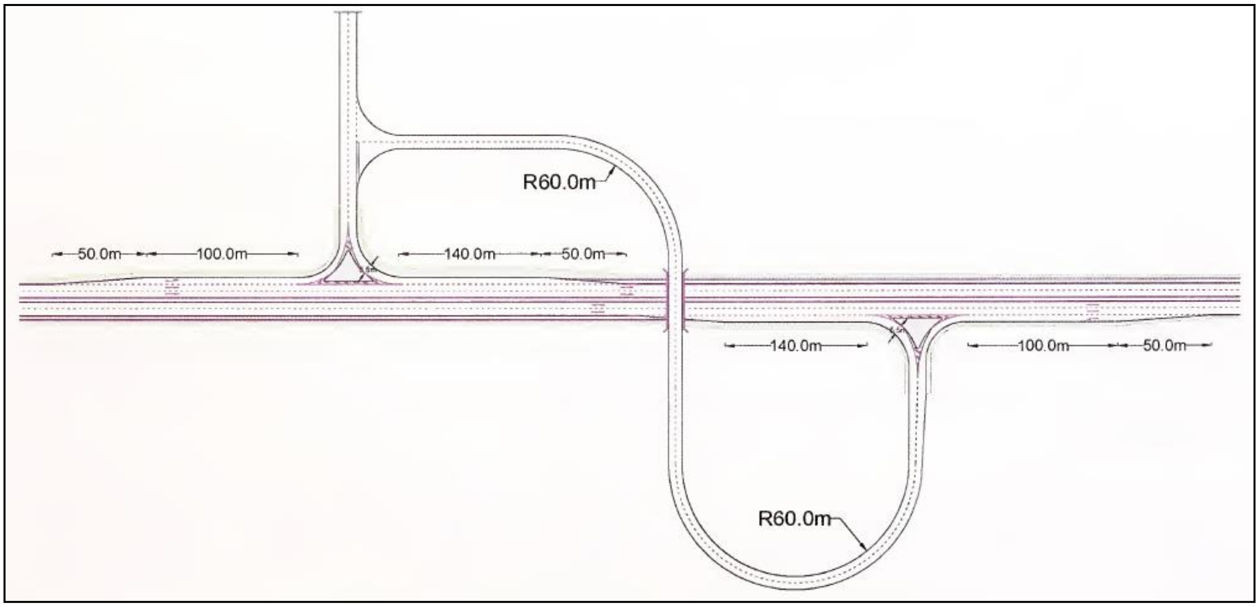


Fig 2.24: Local Grade Separation for an Important Side Road (Two Lane Bridge over At-Grade Project Highway).

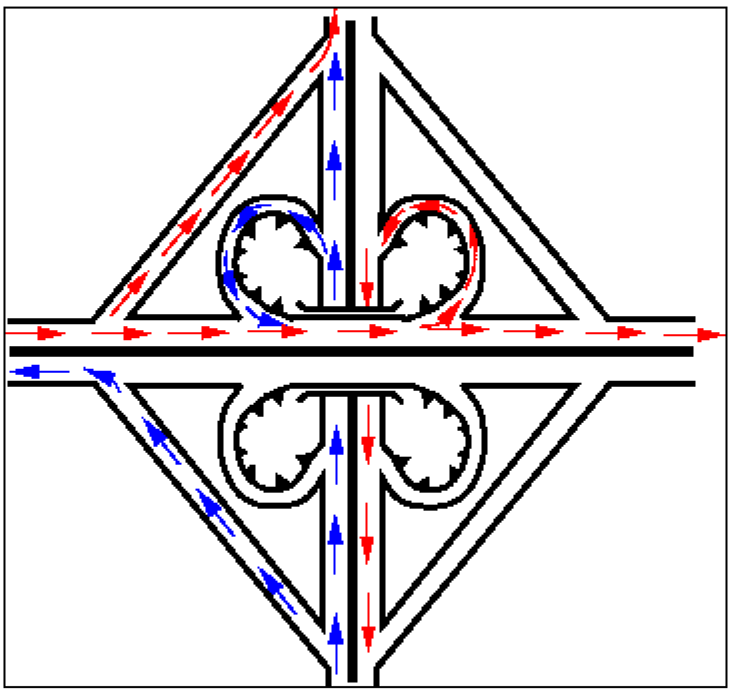


Fig 2.24A: Cloverleaf interchange

2.8 Toll Plazas

The design of the Toll Plazas should be such that they are aesthetically pleasing and efficient and the fee collection staff should be quick, courteous and adequately trained before deployment.

2.8.1 Location of Toll Plaza:

The locations of Toll Plaza shall be decided keeping in view the following factors:

i) Land availability
ii) Stream of traffic on Toll Plaza
iii) Visibility for the approaching traffic
iv) Reasonably away from road intersections and/or rail crossings
v) Free from risk of flooding and submergence, etc.
vi) Preferably on flat land and away from congested urban locations

2.8.2 Land For Toll Plaza:

Adequate land for Toll Plaza shall be acquired to permit the provision of toll lanes for projected peak hour traffic of 20 years subject to a minimum number of 1 6 toll lanes including all other buildings and structures to be accommodated at the Toll Plaza location. Land shall be acquired as per provisions of the Concession Agreement.

2.8.3 Layout and Design of Toll Plaza:

Typical layout of a toll plaza is given in Fig. 2.25. The layout shall provide for future expansion of toll lanes. Stage construction of Toll Plaza in respect of number of toll lanes shall be allowed. However, other structures as envisaged in the Concession Agreement shall be provided at the initial stage itself.

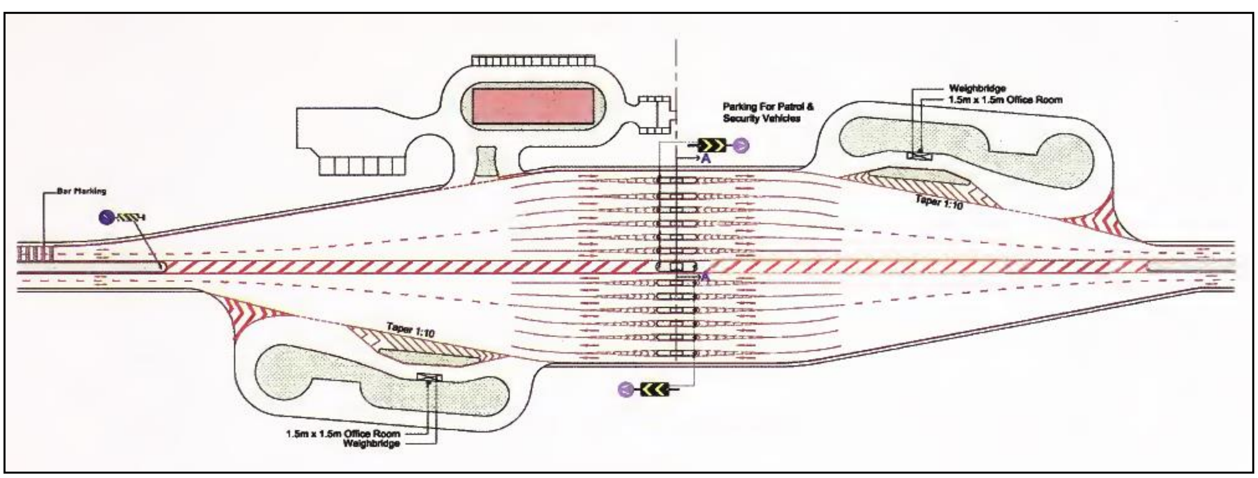


Fig 2.25: Typical Layout of a Toll Plaza

2.8.3.1 Width of Toll Lane:

The width of each toll lane shall be 3.2 m, except for the lane for over dimensioned vehicles, where it shall be 4.5 m.

2.8.3.2 Traffic Islands at the Toll Plaza:

Between each toll lane of the toll plaza, traffic islands are required to accommodate toll booth. These islands shall be of minimum 25 m length and 1 .9 m width. Protective barriers of reinforced concrete and traffic impact attenuators shall be placed at the front of each island to prevent out of control approaching vehicles crashing into the toll booth. They would be painted with reflective chevron markings. For toll lane to be installed with weigh in motion system, the minimum length of islands shall be 35 m where 22.5 m on approach side.

2.8.3.3 Toll Booths:

Toll booths may be provided of prefabricated materials or of masonry. The toll booths shall have adequate space for seating of toll collector, computer, printer, cash box, etc. It should have provision for light, fan and air conditioning. The typical details of traffic island with toll booth are given in Fig. 2.26 & Plan View of Toll Booth are given in Fig 2.27. Toll booth shall be placed at the centre of each traffic island. The toll booth shall have large glass window to provide the toll collector with good visibility of approaching vehicles. The bottom of the toll window should be placed at such a height (0.9 m) above ground level so as to provide convenience of operation. The toll booths shall be ergonomically designed and vandal proof. There shall be CCTV camera installed at each booth.

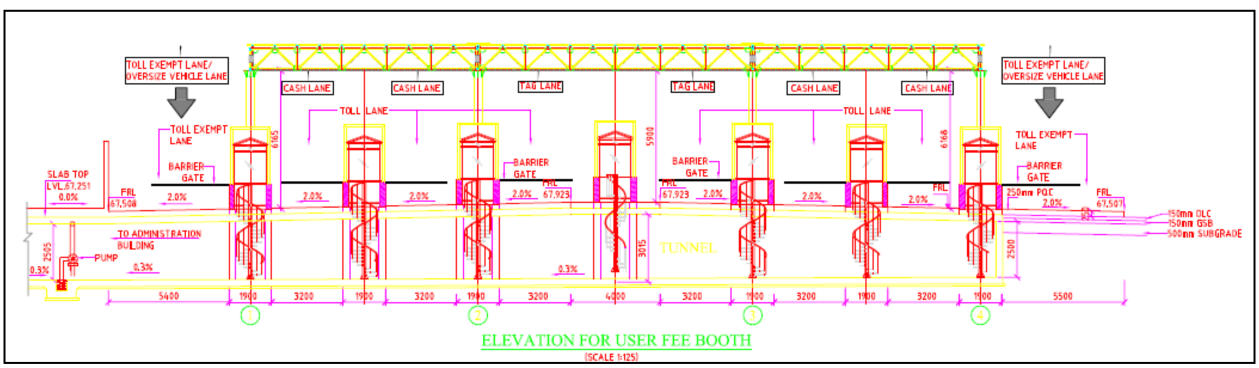


Fig 2.26: Typical Details of Toll Booth

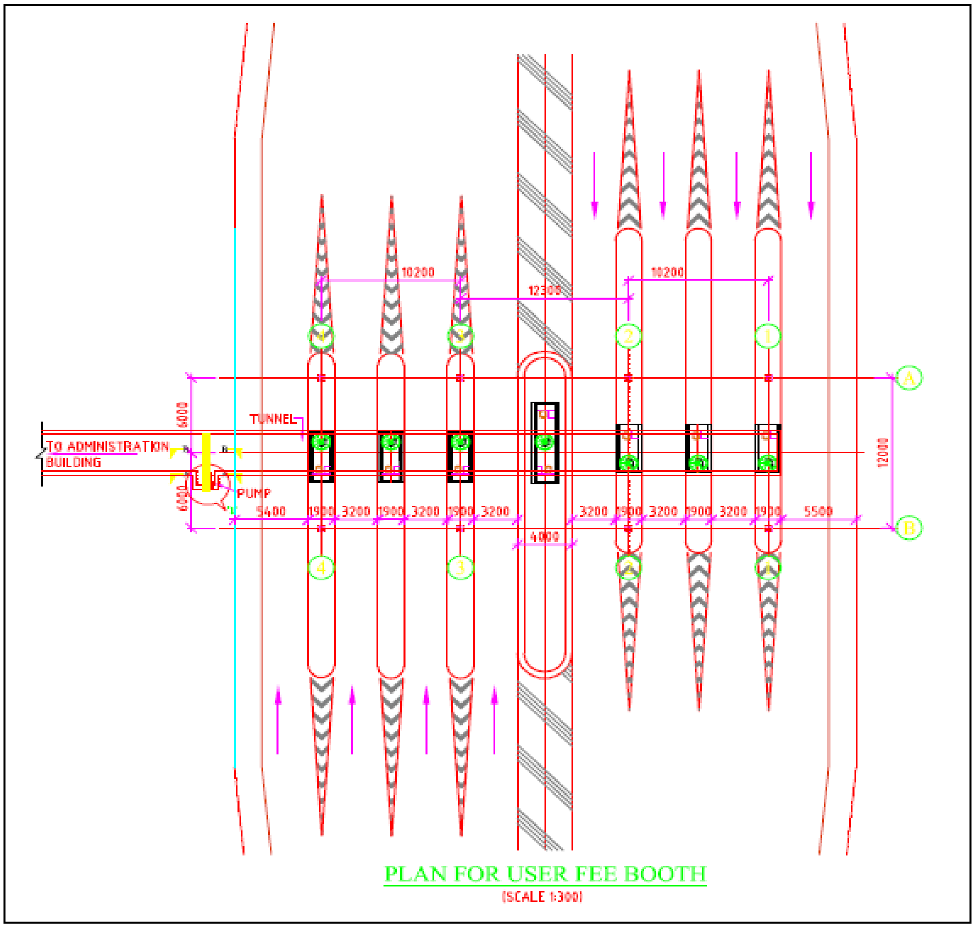


Fig 2.27: Plan View of Toll Booth.

2.8.3.4 Tunnels:

For the movement between toll office and toll booth of each toll lane, an underground tunnel across all toll lanes shall be provided. Its dimension would be sufficient to accommodate the required wiring/cable system and for convenient movement of personnel. It should also be provided with lighting and ventilation system so that the movement is convenient. The tunnel shall be of minimum 3 m width and 2.5 m height.

2.8.3.5 Transition:

A transition of 1 in 20 to 1 in 10 may be provided from four-lane section to the widened width at Toll Plaza on either side.

2.8.3.6 Canopy:

All the toll lanes and toll booths shall be covered with a canopy. The canopy shall be wide enough to provide weather protection to toll operators, drivers and facilities. The canopy shall be of aesthetically pleasing design with cylindrical support columns located at traffic island so that there is no restriction on visibility and traffic movement. The vertical clearance of Canopy shall be given in Canopy Elevation view, which is shown in fig 2.28 and Canopy Roof Plan is shown in fig 2.29.

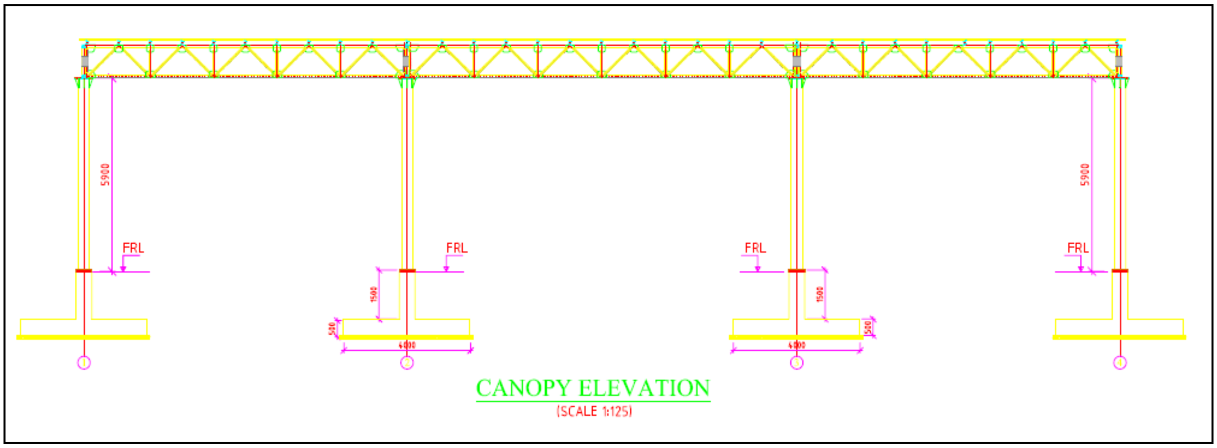


Fig 2.28: Canopy Elevation View.

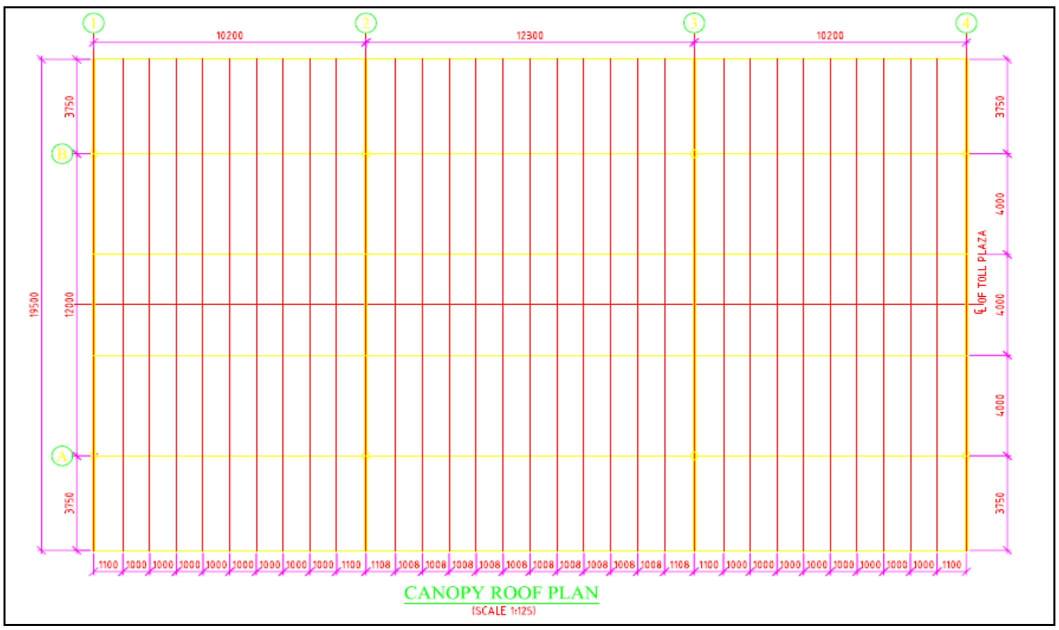


Fig 2.28: Canopy Roof Plan View.

2.8.3.7 Electronic Toll Collection:

Two lanes in each direction of travel shall be provided with the system of payment through Electronic Toll Collection (ETC) out of which one lane shall be dedicated for ETC exclusively and the second lane shall be standby ETC lane. The standby ETC lane may be converted to dedicated ETC lane in case of failure/maintenance of first ETC lane.

2.8.3.8 Number of Lanes at Toll Plaza:

The total number of toll booths and lanes shall be such as to ensure the service time of not more than 10 second per vehicle at peak flow regardless of methodology adopted for fee collection. For purpose of guidance following parameters are suggested as a capacity of individual toll lane for design purpose:

Semi-automatic toll lane (Automatic vehicle identification but manual fee transaction)	240 vehicle/hour
Electronic toll collection (ETC lanes) (Toll collection through RFID Tags and no stoppage of vehicles)	1200 vehicle/hour

Not less than 2 middle toll lanes shall be capable of being used as reversible lane to meet the demand of tidal flow. Toll plazas shall be designed for projected peak hour traffic of 20 years.

2.8.3.9 Lighting:

The toll plaza shall have lighting system to provide visibility to drivers for the use of facility especially to access the correct service lane and also to the toll collector. Indian Standard 'Code of Practice for Lighting of Public Thorough fare IS: 1944 shall be followed. This would be done by interior and exterior lighting as indicated below. Power supply shall be from public power supply system, but stand by generating set of the capacity to supply the required power shall be provided at toll plaza.

Interior Lighting: The toll booths and facility building office shall be illuminated adequately. Indoor lighting shall be with fluorescent lamps. Lighting should be provided in such a manner that glare is avoided or minimized. The level of illumination shall be 200 to 300 Lux as per IS: 3646 Part II.

Exterior Lighting: Lighting of the Toll Plaza is important for enhancing the night visibility. The lighting system shall consist of the following major components.

i) High Mast lighting
ii) Lighting on both side approaches to the Toll Plaza
iii) Canopy lighting of complex

High Mast Lighting: Normal low light poles are not able to give the required lighting conditions. It is, therefore, necessary to install high mast. A height of 30 m for the mast is considered suitable to have uniform spread of desired level of illumination in the Toll Plaza area for safe movement of vehicles.

Highway Lighting: A minimum requirement of illumination on the road surface of 40 Lux shall be ensured. Lighting in minimum 500 m length on both side approaches of toll plaza (toll booth) shall be provided to enhance the safety at night on the Project Highway and to make the drivers conscious of their approaching the toll gate. These shall be provided on the mild steel welded tubular pole of 10m height from road surface and with 2 m overhang. Sodium Vapour lamp of 200-250 watts should be provided for these poles on both sides at 50 m staggered spacing. Now we are using LED Street Light to achieve our required Lux level to ensure uniform illumination of the area & to make more efficient lighting. There should be provision for flashing signals for foggy weather conditions.

Canopy Lighting: A higher level of illumination up to 100 Lux by providing 150 watt metal halide lamps shall be provided at the toll gate and at toll booth locations. 1000-watt halogen lamps shall be provided at the selected nodes of space frame of the canopy to ensure uniform illumination of the area. Now we are using LED Street Light to achieve our required Lux level to ensure uniform illumination of the area & to make more efficient lighting.

2.9 Bus Bays and Passenger Shelters

The buses shall be allowed to stop for dropping and picking up passengers only at the bus bays, which shall be provided near the pedestrian underpass overpass locations. The number and broad location of bus bays to be provided by the Concessionaire. The bus bays shall conform to the specifications and standards given in this Section.

2.9.1 Location

The bus bays shall be located only near the pedestrian underpass overpass locations. In hilly areas, the bus bays shall be located, preferably, where the road is straight on both sides, gradients are flat and the visibility is reasonably good (usually not less than 50 m). Subject to these requirements, it will be advisable to choose locations where it is possible to widen the roadway economically for accommodating bus bays.

2.9.2 Layout and Design

i) For plain area, typical/layouts of bus bays given in Fig. 2.29 shall be adopted. The length "L" shown in Fig.2.29 shall be 15 m. which shall be increased in multiples of 15 m if more than one bus is likely to halt at the bus bay at one time.

ii) For hilly areas, where there is a general constraint on space, the layout indicated in Fig. 2.30 may be adopted.

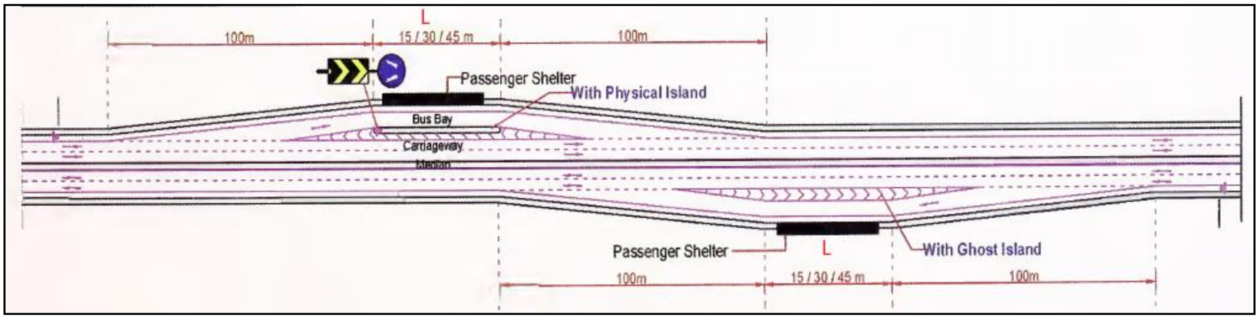


Fig 2.29: Typical Layout of Bus Bay

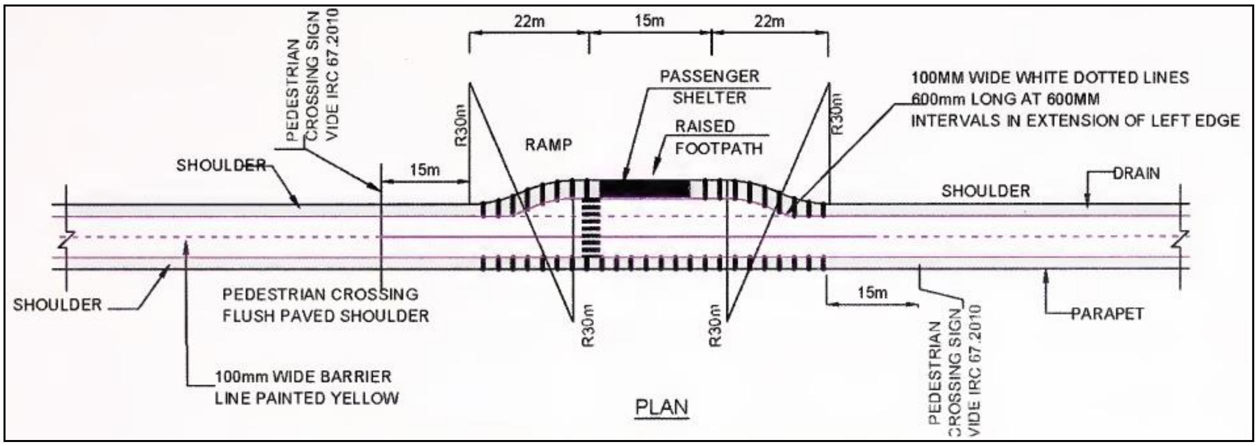


Fig 2.30: Typical Layout of Pick-up Bus Stop on Hilly Area

iii) The Channelizing Island between the paved shoulder and bus-bay shall not be raised but it shall be paved with CC blocks.

iv) Bus bays shall be provided on both sides of the Project Highway for each direction of travel independently. Covered steps with rise not exceeding 150 mm (minimum 5 m wide) along with a ramp for use of disabled persons (1 m wide minimum) with railing on either side shall be provided for climbing up/down from Bus Shelter to underpass/overpass to carriageway and vice versa. The cover of the steps shall be aesthetically pleasing and protect the users from sun, wind and rain. The entire area used by the pedestrians shall be provided with granite stone cladding and flooring.

v) The bus bay shall be provided with a shelter for passengers. The shelter shall be structurally safe and aesthetic in appearance, while also being functional so as to protect the waiting passengers adequately from sun, wind and rain. If the shelter is constructed on the till side, slopes shall be properly dressed and suitably protected to avoid slips.

vi) The bus bay and passenger shelter shall be designed to provide for safe and convenient use by physically challenged persons as well.

2.10 Truck Lay Byes

The project Highway should maintain adequate number and size of truck lay-byes for parking of trucks by the side of the Project Highway. The guidelines, as given here, shall be followed in regard to location, size and facilities to be provided at the truck lay-byes. Typical Layout of Truck Lay Bye is shown in fig 2.31.

2.10.1 Location and Size

Truck lay-byes shall, in general, be located near check barriers, interstate borders, places of conventional stops of the truck operators, etc. The places be identified on the basis of field survey and shall have adequate space for facilities as specified in this section and future growth.

2.10.2 Facilities

The truck lay-byes shall have the following facilities:

i) Paved parking,
ii) Rest areas with toilets, drinking water,
iii) Telephone.

2.10.3 Lighting

The truck lay-byes and 50 m length of the Project Highway on its either side shall be illuminated at night to provide a minimum illumination of 40 Lux. Suitably designed electric poles having aesthetic appeal and energy saving bulbs may be used to provide required illumination. Alternatively, photo voltaic lamps may be used.

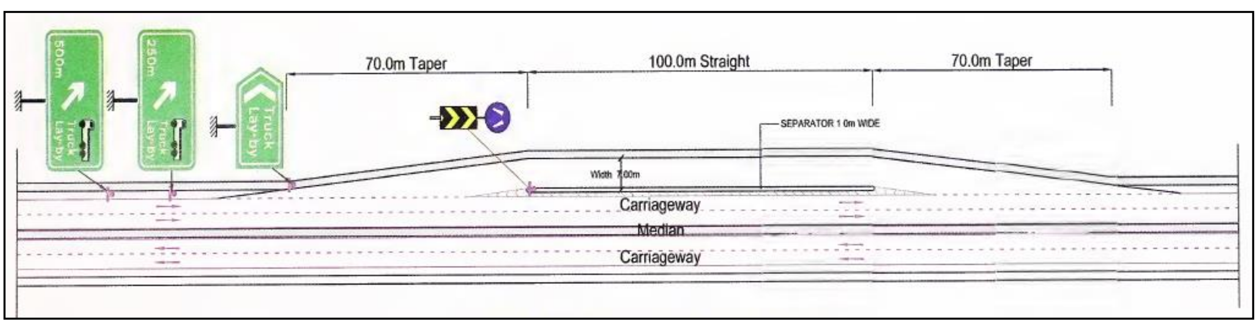


Fig 2.31 Typical Layout of Truck Lay Bye

2.11 Case Studies

The lighting designs for the Carriageways, Junctions, Toll Plazas, Bus bays, Truck lay-byes, Vehicular underpasses and Pedestrian underpasses have been simulated by using AGI32 Lighting Software.

2.11.1 Case Study – 26M Wide Roadway:

The layout of the Roadway contains 5M Median, 7M wide Carriageway, 1.5M wide Paved Shoulder and 2M wide Earthen Shoulders on the both side of the Median as shown in the figure 2.32 and figure 2.33.

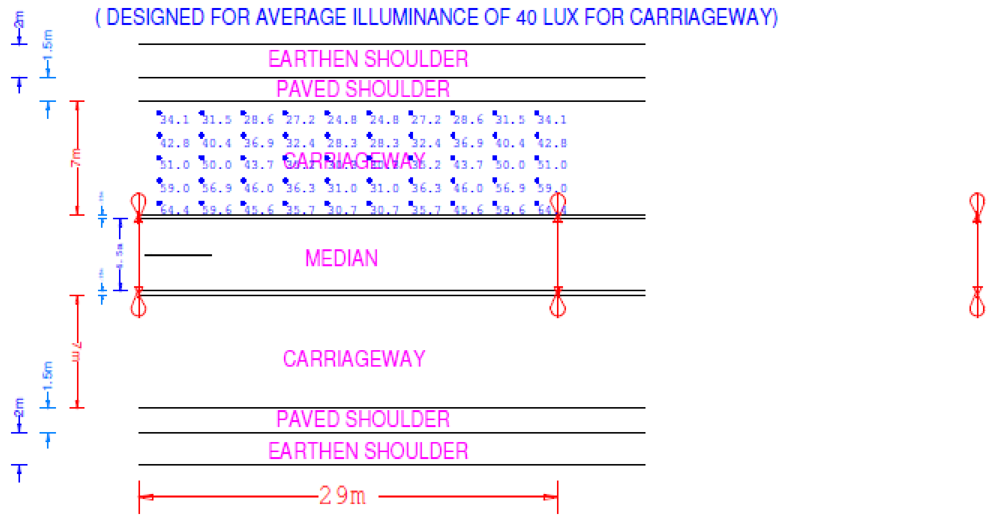
In the fig 2.32 design has been carried out with 10m pole by using luminaire SSGN1225H/FG (1X250W HPSV/T) having IP 66 protection with maintenance factor 0.75 and in the fig 2.33 design has been carried out with 10m pole by using luminaire LSTN1-180-CDL-A-HP (180W LED STREET LIGHT) having IP 66 protection with maintenance factor 0.75.

Illumination design has been carried out for an average illuminance of 40 lux in order to achieve overall uniformity (E_{min}/E_{avg}) $\geq$ 0.40 and $E_{min}/E_{max} \geq 0.33$ according to client requirements.

In figure 2.32, for carriageway, average illuminance 40.10 lux with $E_{min}/E_{avg} = 0.62$ and $E_{min}/E_{max} = 0.39$ is achieved with 29m pole span and in figure 2.33, for carriageway, average illuminance 40.01 lux with $E_{min}/E_{avg} = 0.55$ and $E_{min}/E_{max} = 0.39$ is achieved with 36m pole span.

ILLUMINATION DESIGN FOR TCS ROAD WITH 10M POLE

(DESIGNED FOR AVERAGE ILLUMINANCE OF 40 LUX FOR CARRIAGEWAY)



ROAD WIDTH : 2X7M CW+ 5M MEDIAN
POLE HEIGHT : 10M ABOVE G/L
ARRANGEMENT: TWIN CENTRAL (DUAL LIGHTS ON SINGLE POLE)
BRACKET ARM LENGTH: 2M
TILT : 10°
LUMINAIRE : SSGN1225H/FG (1X250W HPSV/T)
TOTAL LAMP LUMENS : 32000
MAINTENANCE FACTOR : 0.75

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE G/L WITHOUT CONSIDERING ANY OBSTRUCTIONS:

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
CARRIAGEWAY_Illum	Illuminance	Lux	40.10	64.4	24.8	0.62	0.39

POLE SPACING : 29 M

Fig 2.32: 26M wide Roadway Lighting Design with Conventional Luminaire.

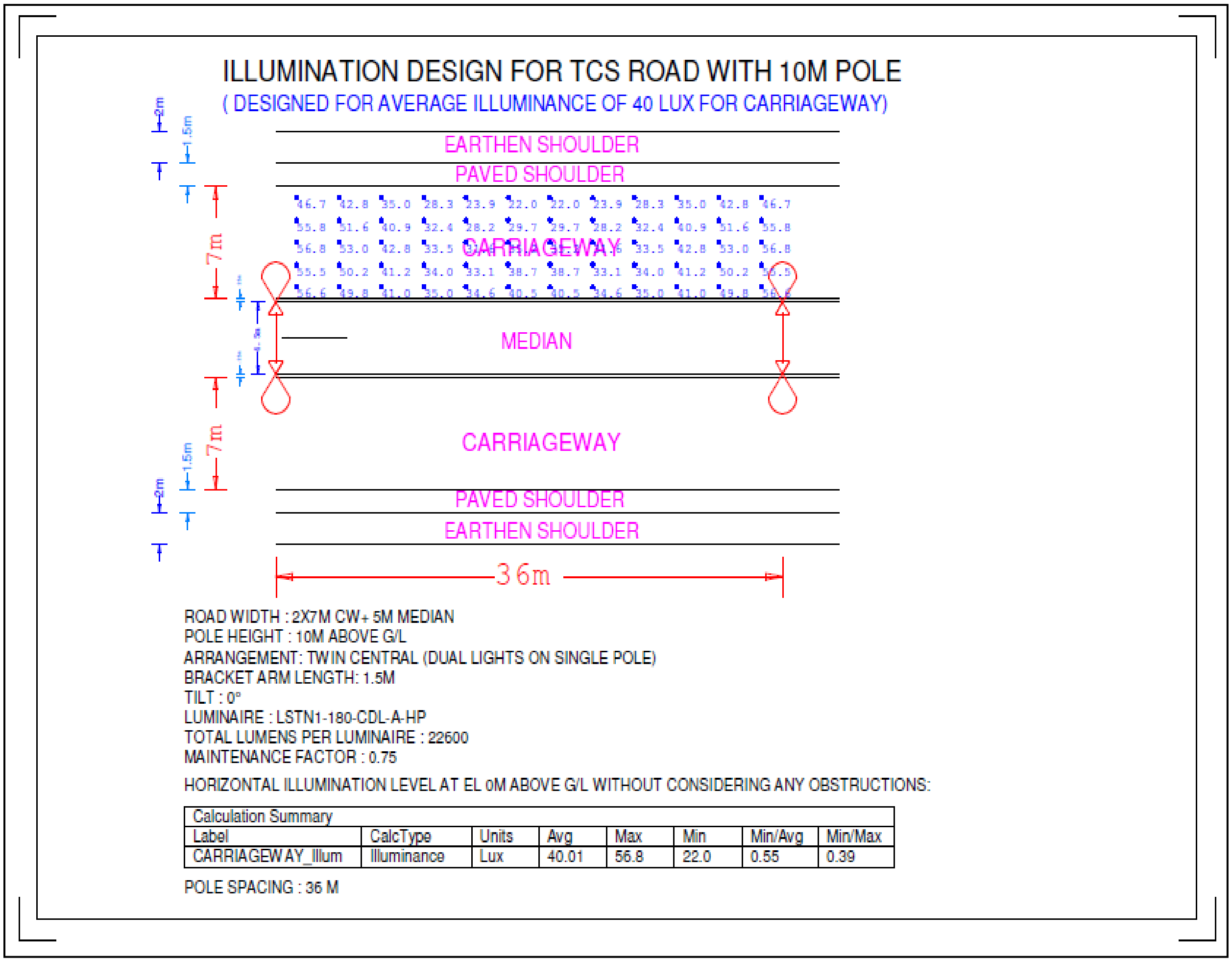


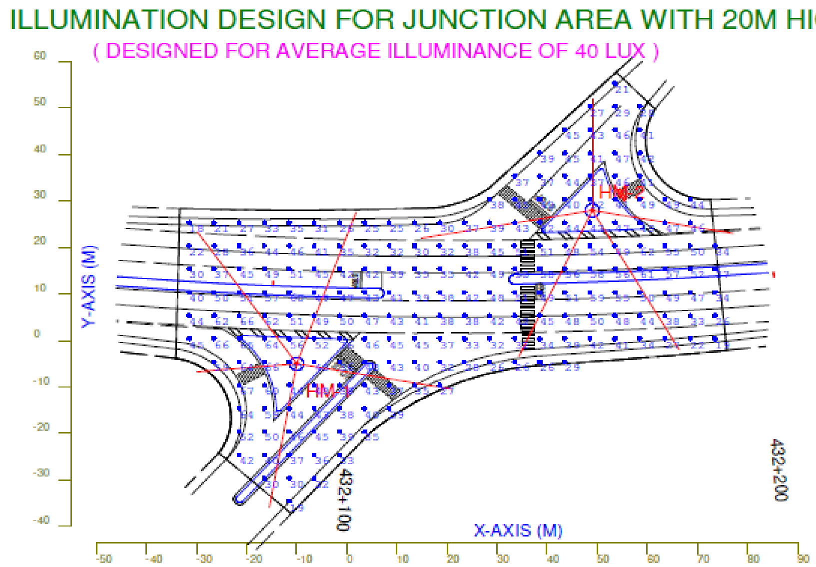
Fig 2.33: 26M wide Roadway Lighting Design with LED Luminaire.

2.11.2 Case Study – Junction Lighting:

The simulated lighting design of the junction by using AGI32 Lighting Software is shown in the figure 2.34 and figure 2.35. In figure 2.34 the design has been carried out with two numbers of 20m high mast using luminaires FHD1724 (2X400W HPSV/T) with maintenance factor 0.75 and in figure 2.35 the design has been carried out with two numbers of 20m high mast using luminaires LSFO-350-CDL/60-HE & LSFO-350-CDL/30-HE with maintenance factor 0.75 to get better performance of the lighting design.

Illumination design has been carried out for an average illuminance of 40 lux in order to achieve overall uniformity (E_{min}/E_{avg}) $\geq$ 0.40 and $E_{min}/E_{max} \geq 0.25$ according to client requirements.

In figure 2.34, average illuminance 42.23 lux with $E_{min}/E_{avg} = 0.43$ and $E_{min}/E_{max} = 0.27$ is achieved with 10 numbers of conventional floodlight and in figure 2.35, average illuminance 40.23 lux with $E_{min}/E_{avg} = 0.55$ and $E_{min}/E_{max} = 0.34$ is achieved with 12 numbers of LED floodlight.



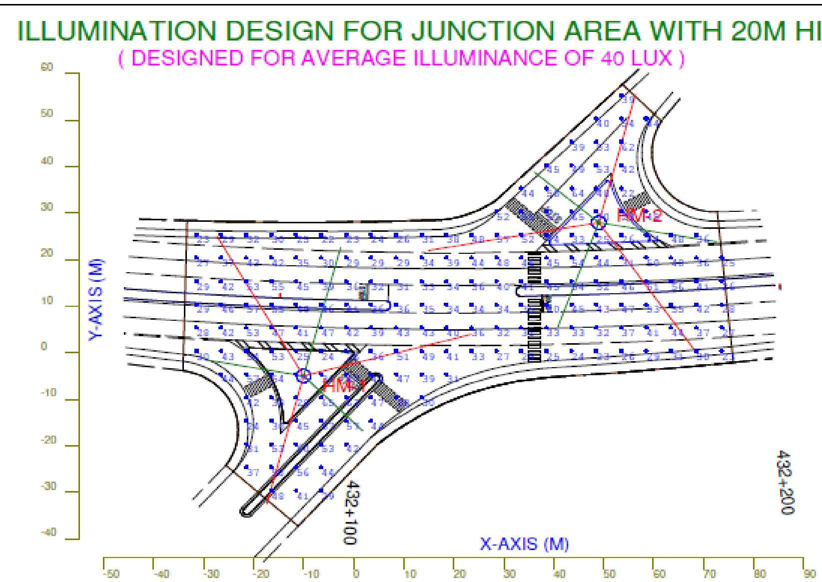
HM-1 & HM-2 : 20M HIGHMAST (ABOVE G/L)
LUMINAIRES PER EACH MAST : 5 NUMBERS.

Luminaire Schedule						
Symbol	Qty	Label	Lumens/Lamp	Total Lamp Lumens	LLF	Description
	10	A	48000	96000	0.750	FHD1724 (2X400W HPSV/T)

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE GROUND LEVEL WITHOUT OBSTRUCTIONS

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
JUNCTION	Illuminance	Lux	42.23	67	18	0.43	0.27

Fig 2.34: Junction Lighting Design with Conventional Floodlight.



HM-1 & HM-2 : 20M HIGHMAST (ABOVE G/L)

Luminaire Schedule				
Symbol	Qty	Label	LLF	Description
	6	A	0.750	LSFO-350-CDL_60-HE
	6	B	0.750	LSFO-350-CDL_30-HE

HIGH MAST	QTY 'A'	QTY 'B'
HM-1	3	3
HM-2	3	3

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE GROUND LEVEL WITHOUT OBSTRUCTIONS

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
JUNCTION	Illuminance	Lux	40.23	65	22	0.55	0.34

Fig 2.35: Junction Lighting Design with LED Floodlight.

2.11.3 Case Study – Toll Plaza Lighting:

The simulated lighting design of the Toll Plaza by using AGI32 Lighting Software is shown in the figure 2.36 and the figure 2.37. In figure 2.36 the design has been carried out with four numbers of 30m high mast using luminaires FHD1724 (2X400W HPSV/T) with maintenance factor 0.75 and in figure 2.37 the design has been carried out with four numbers of 30m high mast using luminaires LFLPI 2x200-CDL/30-HE (400 W LED FLOODLIGHT) with maintenance factor 0.75 to get better performance of the lighting design.

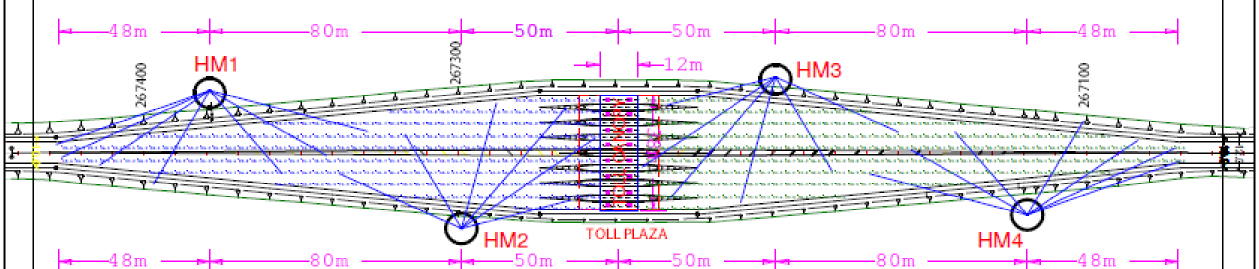
Illumination design has been carried out for an average illuminance of 40 lux in order to achieve overall uniformity (E_{min}/E_{avg}) ≥ 0.40 and E_{min}/E_{max} ≥ 0.25 according to client requirements.

The simulated lighting design of the Toll Plaza Canopy Lighting by using AGI32 Lighting Software is shown in the figure 2.36. The design has been carried out with luminaires MHB1315IH/P (150W MH HIGHBAY LUMINAIRE) at height 6.5m above ground level with maintenance factor 0.75 and figure 2.37 the design has been carried out with Canopy luminaires LCNP-80-CDL (80W LED CANOPY LUMINAIRE) at height 6.5m above ground level with maintenance factor 0.75 .

Illumination design has been carried out for an average illuminance of 100 lux in order to achieve overall uniformity (E_{min}/E_{avg}) ≥ 0.50.

ILLUMINATION DESIGN FOR TOLL PLAZA WITH 30M HIGH MAST

(DESIGNED FOR AVERAGE ILLUMINANCE OF 40 LUX)



FOR TOLL PLAZA AREA WITH MAST :

HIGH MAST HEIGHT : 30 M (ABOVE G/L)
QUANTITY OF MASTS : 4 NUMBERS
LUMINAIRE TYPE: FHD1724 (2X400W HPSV/T)
TOTAL QUANTITY OF FLOODLIGHTS : 26 NUMBERS

FOR TOLL CANOPY (UNDER CANOPY LUMINAIRE)

CANOPY DIMENSION: 12M X 38M X 6.5M FLOATING OBSTRUCTION HAS BEEN CONSIDERED
LUMINAIRE MOUNTING HEIGHT : 6.5M ABOVE G/L
LUMINAIRE TYPE: MHB1315IH/P (150W MH HIGHBAY LUMINAIRE)
TOTAL QUANTITY OF CANOPY LUMINAIRES : 16 NUMBERS

Luminaire Schedule						
Symbol	Qty	Label	Lumens/Lamp	Total Lamp Lumens	LLF	Description
	26	A	48000	96000	0.750	FHD1724 (2X400W HPSV/T)
	16	B	11500	11500	0.750	MHB1315IH/P (150W MH HIGHBAY LUMINAIRE)

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE G/L WITHOUT CONSIDERING ANY OTHER OBSTRUCTIONS:

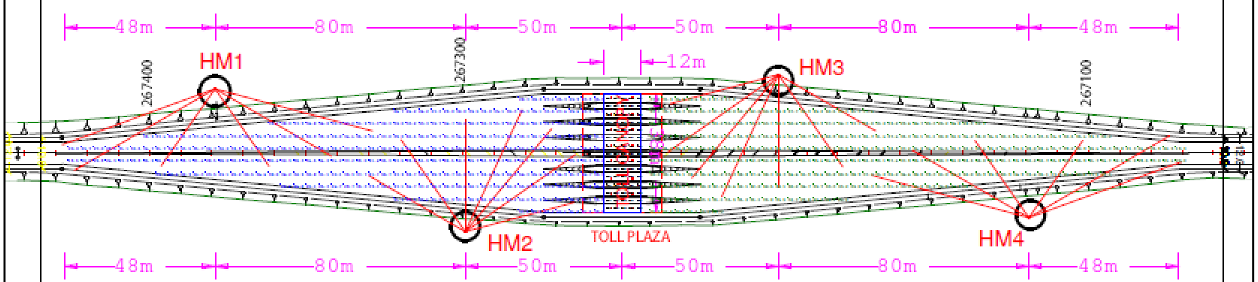
Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
LHS TOLL PLAZA	Illuminance	Lux	44.84	63.8	19.6	0.44	0.31
RHS TOLL PLAZA	Illuminance	Lux	44.86	63.8	19.5	0.43	0.31
TOLL CANOPY	Illuminance	Lux	176.95	231.9	118.7	0.67	0.51

HIGH MAST	LUM OF "A"
HM1	7
HM2	6
HM3	6
HM4	7

Fig 2.36: Toll Plaza Lighting Design with Conventional Luminaires.

ILLUMINATION DESIGN FOR TOLL PLAZA WITH 30M HIGH MAST

(DESIGNED FOR AVERAGE ILLUMINANCE OF 40 LUX)



FOR TOLL PLAZA AREA WITH MAST :

HIGH MAST HEIGHT : 30 M (ABOVE G/L)
QUANTITY OF MASTS : 4 NUMBERS
LUMINAIRE TYPE: LFLPI 2x200-CDL/30-HE (400 W LED FLOODLIGHT)
TOTAL QUANTITY OF FLOODLIGHTS : 26 NUMBERS

FOR TOLL CANOPY (UNDER CANOPY LUMINAIRE)

CANOPY DIMENSION: 12M X 38M X 6.5M FLOATING OBSTRUCTION HAS BEEN CONSIDERED
LUMINAIRE MOUNTING HEIGHT : 6.5M ABOVE G/L
LUMINAIRE TYPE: LCNP-80-CDL (80W LED CANOPY LUMINAIRE)
TOTAL QUANTITY OF CANOPY LUMINAIRES : 16 NUMBERS

Luminaire Schedule

Symbol	Qty	Label	LLF	Description
⊡	16	B	0.750	LCNP-80-CDL (80W LED CANOPY LUMINAIRE)
→	26	A	0.750	LFLPI 2x200-CDL/30-HE (400 W LED FLOODLIGHT)

HIGH MAST	LUM OF "A"
HM1	6
HM2	7
HM3	7
HM4	6

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE G/L WITHOUT CONSIDERING ANY OTHER OBSTRUCTIONS:

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
LHS TOLL PLAZA	Illuminance	Lux	40.02	56.3	19.5	0.49	0.35
RHS TOLL PLAZA	Illuminance	Lux	40.01	56.3	19.4	0.48	0.34
TOLL CANOPY	Illuminance	Lux	210.71	253.7	158.1	0.75	0.62

Fig 2.37: Toll Plaza Lighting Design with LED Luminaires.

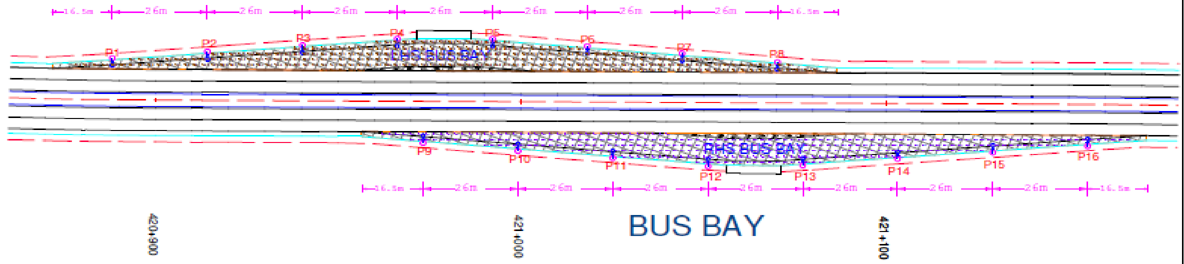
2.11.4 Case Study – Bus Bay Lighting:

The simulated lighting design of the Bus Bay by using AGI32 Lighting Software is shown in the figure 2.38 and the figure 2.39. In figure 2.38 the design has been carried out with 9m pole using fixtures SSGN1225IH/FG (1X250W HPSV/T) by considering maintenance factor 0.75 with 26M pole span and in figure 2.39 the design has been carried out with 9m pole using fixtures LSTN-200-CDL-A-HP (200W LED STREET LIGHT) by considering maintenance factor 0.75 with 29M pole span.

Illumination design has been carried out for an average illuminance of 40 lux in order to achieve overall uniformity (E_{min}/E_{avg}) $\geq$ 0.40 and E_{min}/E_{max} $\geq$ 0.33 according to client requirements.

ILLUMINATION DESIGN FOR TYPICAL BUS BAY WITH 9M POLES

(DESIGNED FOR AVERAGE ILLUMINANCE OF 40 LUX)



POLES FROM P1 TO P8 (LHS SIDE) :

POLE HEIGHT : 9M ABOVE G/L
ARRANGEMENT : SINGLE SIDE
BRACKET ARM LENGTH : 1M
TILT : 10 DEG
LUMINAIRE : SSGN1225IH/FG (1X250W HPSV/T)
POLE SPACING: 26 M

POLES FROM P9 TO P16 (RHS SIDE) :

POLE HEIGHT : 9M ABOVE G/L
ARRANGEMENT : SINGLE SIDE
BRACKET ARM LENGTH : 1M
TILT : 10 DEG
LUMINAIRE : SSGN1225IH/FG (1X250W HPSV/T)
POLE SPACING: 26 M

Luminaire Schedule

Symbol	Qty	Label	Lumens/Lamp	Total Lamp Lumens	LLF	Description
	16	A	27000	27000	0.750	SSGN1225IH/FG (1X250W HPSV/T)

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE G/L WITHOUT CONSIDERING ANY OTHER OBSTRUCTIONS

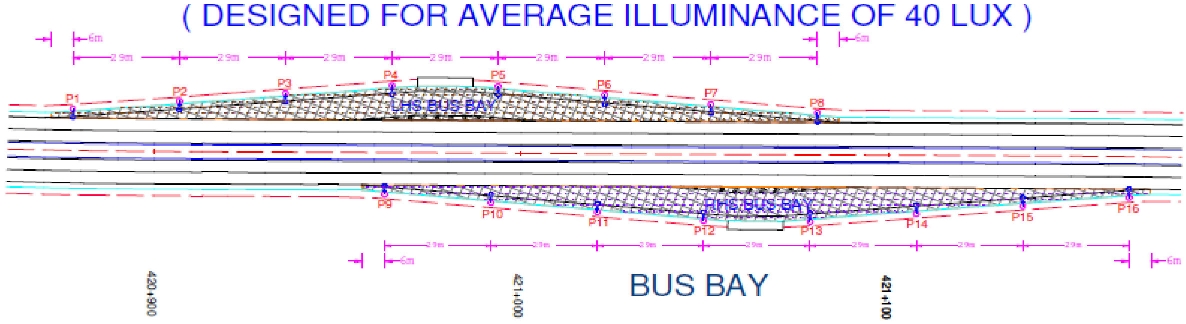
Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
BUS_BAY_LHS	Illuminance	Lux	40.85	69.2	23.0	0.56	0.33
BUS_BAY_RHS	Illuminance	Lux	40.53	68.5	22.3	0.55	0.33

Fig 2.38: Bus Bay Lighting Design with Conventional Luminaires.

ILLUMINATION DESIGN FOR TYPICAL BUS BAY WITH 9M POLES

(DESIGNED FOR AVERAGE ILLUMINANCE OF 40 LUX)



POLES FROM P1 TO P8 (LHS SIDE) :

POLE HEIGHT : 9M ABOVE G/L
ARRANGEMENT : SINGLE SIDE
BRACKET ARM LENGTH : 1M
TILT : 5°
LUMINAIRE : LSTN-200-CDL-A-HP (200W LED STREET LIGHT)
POLE SPACING: 29 M

POLES FROM P9 TO P16 (RHS SIDE) :

POLE HEIGHT : 9M ABOVE G/L
ARRANGEMENT : SINGLE SIDE
BRACKET ARM LENGTH : 1M
TILT : 5°
LUMINAIRE : LSTN-200-CDL-A-HP (200W LED STREET LIGHT)
POLE SPACING: 29 M

Luminaire Schedule

Symbol	Qty	Label	LLF	Description
	16	A	0.750	LSTN-200-CDL-A-HP (200W LED STREET LIGHT)

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE G/L WITHOUT CONSIDERING ANY OTHER OBSTRUCTIONS

Calculation Summary

Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
BUS_BAY_LHS	Illuminance	Lux	41.19	55.6	29.1	0.71	0.52
BUS_BAY_RHS	Illuminance	Lux	41.63	55.3	30.1	0.72	0.54

Fig 2.39: Bus Bay Lighting Design with LED Luminaires.

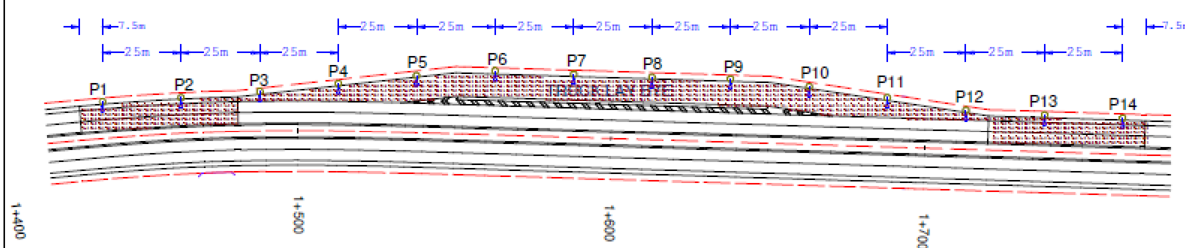
2.11.5 Case Study – Truck Lay Bye Lighting:

The simulated lighting design of the Truck Lay Bye by using AGI32 Lighting Software is shown in the figure 2.40 and the figure 2.41. In figure 2.40 the design has been carried out with 9m pole using fixtures SSGN1225IH/FG (1X250W HPSV/T) by considering maintenance factor 0.75 with 25M pole span and in figure 2.41 the design has been carried out with 9m pole using fixtures LSTN-200-CDL-A-HP (200W LED STREET LIGHT) by considering maintenance factor 0.75 with 30M pole span.

Illumination design has been carried out for an average illuminance of 40 lux in order to achieve overall uniformity (E_{min}/E_{avg}) ≥ 0.40 and E_{min}/E_{max} ≥ 0.33 according to client requirements.

ILLUMINATION DESIGN FOR TRUCK LAY BYE WITH 9M POLES

DESIGNED FOR AVERAGE ILLUMINANCE OF 40 LUX



POLES FROM P1 TO P14 : (QTY OF POLES : 14 NUMBERS)
POLE HEIGHT: 9M ABOVE G/L
ARRANGEMENT: SINGLE SIDED
BRACKET ARM LENGTH: 1.5M
TILT: 10°
LUMINAIRE: SSGN1225H/FG (1X250W HPSV/T)
TOTAL LAMP LUMENS : 32000
MAINTENANCE FACTOR : 0.75

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE G/L WITHOUT CONSIDERING ANY OBSTRUCTIONS:

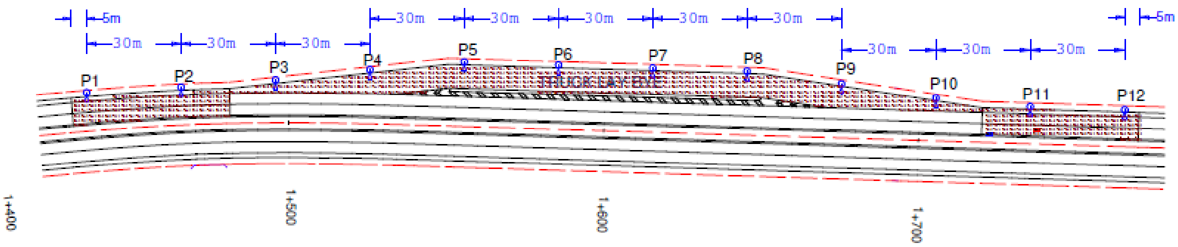
Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
TRUCK LAY BYE	Illuminance	Lux	41.10	60.7	20.5	0.50	0.34

POLE SPACING: 25M

Fig 2.40: Truck Lay Bye Lighting Design with Conventional Luminaires.

ILLUMINATION DESIGN FOR TRUCK LAY BYE WITH 9M POLES

DESIGNED FOR AVERAGE ILLUMINANCE OF 40 LUX



POLES FROM P1 TO P12 : (QTY OF POLES : 12 NUMBERS)
POLE HEIGHT: 9M ABOVE G/L
ARRANGEMENT: SINGLE SIDED
BRACKET ARM LENGTH: 1M
TILT: 5°
LUMINAIRE: LSTN-200-CDL-A-HP (200W LED STREET LIGHT)
MAINTENANCE FACTOR : 0.75

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE G/L WITHOUT CONSIDERING ANY OBSTRUCTIONS:

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
TRUCK LAY BYE	Illuminance	Lux	40.66	55.4	26.2	0.64	0.47

POLE SPACING: 30M

Fig 2.41: Truck Lay Bye Lighting Design with LED Luminaires.

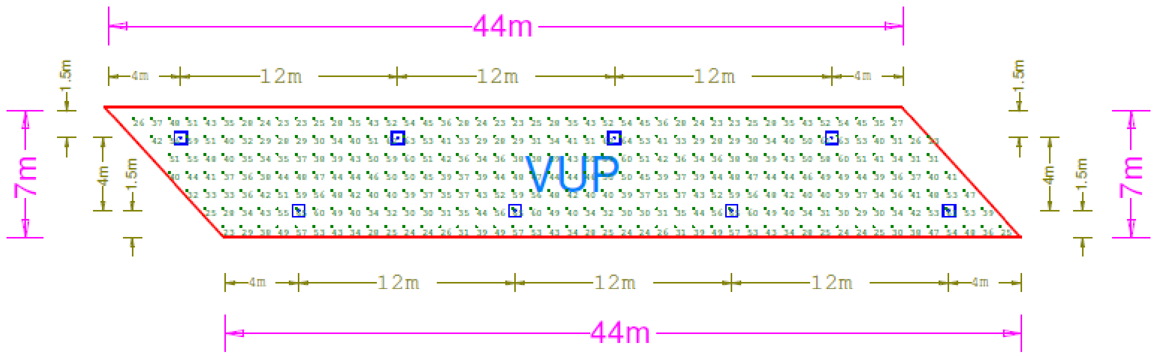
2.11.6 Case Study – Vehicular Underpass Lighting:

The simulated lighting design of the Vehicular Underpass Lighting by using AGI32 Lighting Software is shown in the figure 2.42. The design has been carried out by using LFLN11-35-CDL/60 (35W LED FLOODLIGHT) fixtures) by considering maintenance factor 0.75.

Illumination design has been carried out for an average illuminance of 40 lux in order to achieve overall uniformity (E_{min}/E_{avg}) $\geq$ 0.50 according to client requirements.

For VUP area, average illuminance of 40.65 lux, with E_{min}/E_{avg} = 0.57 & E_{min}/E_{max} = 0.35 is achieved as shown in the simulated lighting design.

TYPICAL ILLUMINATION DESIGN FOR VEHICULAR UNDERPASS (VUP)
(DESIGNED FOR AVERAGE ILLUMINANCE OF 40 LUX)



LUMINAIRE MOUNTING HEIGHT : 5.5M ABOVE G/L

Luminaire Schedule				
Symbol	Qty	Label	LLF	Description
⊡	8	A	0.750	LFLN11-35-CDL/60 (35W LED FLOODLIGHT)

HORIZONTAL ILLUMINATION LEVEL AT EL 0M ABOVE G/L WITHOUT CONSIDERING ANY OBSTRUCTIONS:

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
VUP	Illuminance	Lux	40.65	65	23	0.57	0.35

Fig 2.42: Vehicular Underpass Lighting Design with LED Luminaires.

2.11.7 Case Study – Pedestrian Underpass Lighting:

The simulated lighting design of the Pedestrian Underpass Lighting by using AGI32 Lighting Software is shown in the figure 2.43. The design has been carried out by using LFLN11-30-CDL/60 (30W LED FLOODLIGHT) fixtures) by considering maintenance factor 0.75.

Illumination design has been carried out for minimum illuminance of 30 lux in order to achieve overall uniformity (E_{min}/E_{avg}) ≥ 0.50 according to client requirements.

For VUP area, average illuminance of 62.37 lux, minimum illuminance of 36 lux with E_{min}/E_{avg} = 0.50 & E_{min}/E_{max} = 0.24 is achieved as shown in the simulated lighting design.

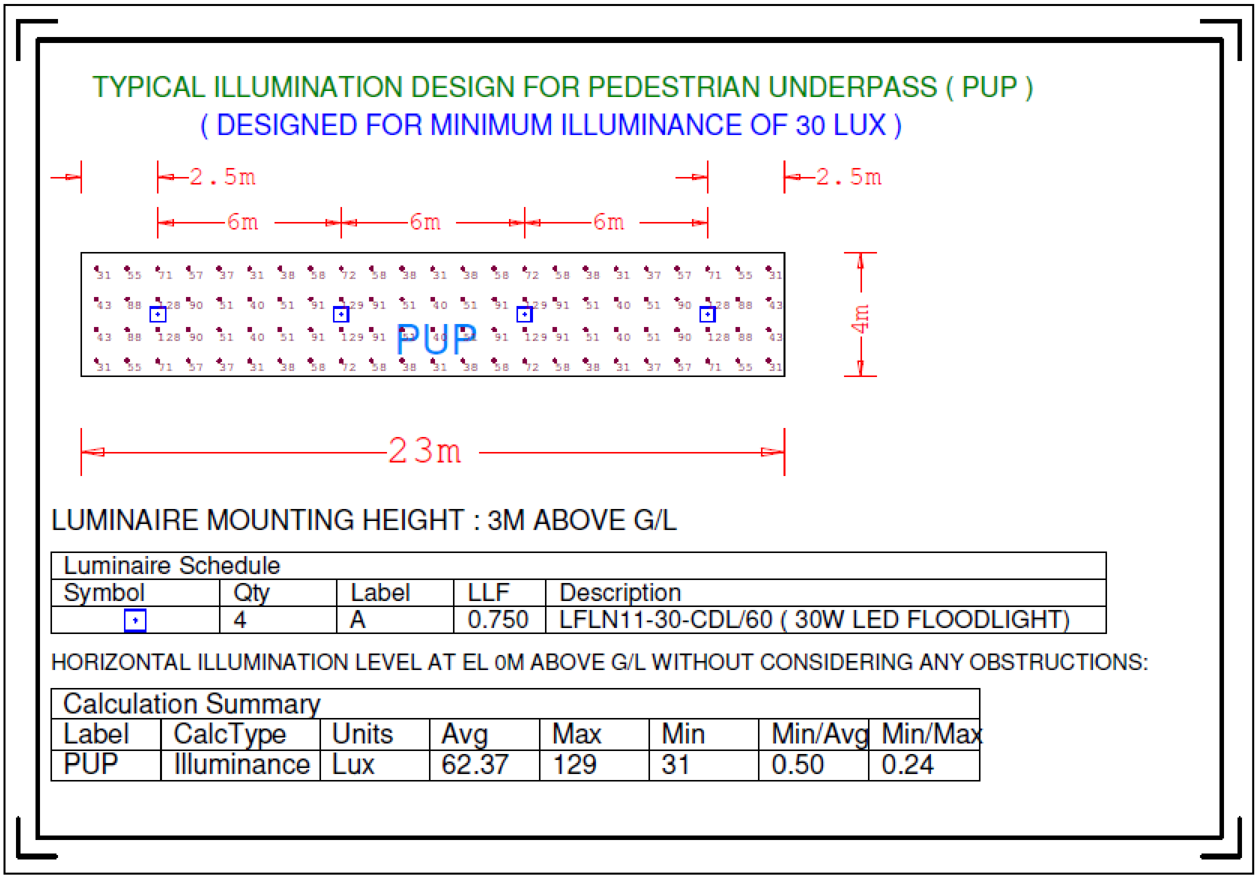


Fig 2.43: Pedestrian Underpass Lighting Design with LED Luminaires.

2.12 Conclusion:

The lighting designs for the highways such as Carriageways, Junctions, Toll Plazas, Bus Bays, Truck Lay Byes, Vehicular Underpasses and Pedestrian Underpasses have been simulated successfully by using AGI32 Lighting Software and simulation have been done between Conventional & LED.

In 26M Wide Roadway,

Lighting Fixture Type	**Pole Height (Above G/L)**	**Bracket Arm Length**	**Tilt**	**Luminaire Cat. No.**	**Luminaire Wattage**	**Pole Span (In Meter)**
Conventional	10M	2M	10°	SSGN1225H/FG	250	29M
LED	10M	1.5M	0°	LSTN1-180-CDL-A-HP	180	36M

Table 2.8: Comparison between Conventional and LED Luminaire of 26M Wide Roadway.

Table 2.8 shows that the comparison between Conventional luminaire & LED luminaire lighting design of 26M wide road to match the requirements of the lighting design parameters. Uses of LED luminaire will save more energy and the total quantity of poles and total quantity of luminaires will be reduce and pole span will be maximum and uniformity will be better than the uses of conventional luminaire. So uses of LED luminaires are more efficient than Conventional luminaires.

In Junction Lighting,

Lighting Fixture Type	High Mast Height (In Meter)	Luminaire Cat. No.	Luminaire Wattage	Total Qty. Of Luminaire
Conventional	20	FHD1724	800	10
LED	20	LSFO-350-CDL/60-HE	350	6
		LSFO-350-CDL/30-HE		6

Table 2.9: Comparison between Conventional and LED Luminaire of Junction Lighting.

Table 2.9 shows that the comparison between Conventional luminaire & LED luminaire lighting design of junction lighting to match the the requirements of the lighting design parameters. Uses of LED luminaire will save more energy and it will get better uniformity then the uses of conventional luminaire. So uses of LED luminaires are more efficient than Conventional luminaires.

In Toll Plaza Lighting,

Lighting Fixture Type	High Mast Height (In Meter)	Luminaire Cat. No.	Luminaire Wattage	Total Qty. Of Luminaire
Conventional	30	FHD1724	800	26
		MHB1315IH/P	150	16
LED	30	LFLPI 2x200-CDL/30-HE	400	26
		LCNP-80-CDL	80	16

Table 2.10: Comparison between Conventional and LED Luminaire of Toll Plaza Lighting.

Table 2.10 shows that the comparison between Conventional luminaire & LED luminaire lighting design of Toll Plaza to match the requirements of the lighting design parameters & in this Toll Plaza lighting design of both Conventional luminaire & LED luminaire quantities are same but uses of Wattage in Conventional Luminaire are double than LED Luminaire. So uses of LED luminaire will save more energy and it will get better uniformity. So LED Luminaires are more efficient than Conventional luminaires.

In Bus Bay Lighting:

Lighting Fixture Type	Pole Height (Above G/L)	Bracket Arm Length	Tilt	Luminaire Cat. No.	Luminaire Wattage	Pole Span (In Meter)
Conventional	9M	1M	10°	SSGN1225H/FG	250	26M
LED	9M	1M	5°	LSTN-200-CDL-A-HP	200	29M

Table 2.11: Comparison between Conventional and LED Luminaire of Bus Bay Lighting.

Table 2.11 shows that the comparison between Conventional luminaire & LED luminaire lighting design of Bus Bay to match the requirements of the lighting design parameters. Uses of LED luminaires are more efficient than the uses of Conventional luminaires because LED Luminaire takes less power than conventional Luminaire to fulfill the requirements of lux level and LED Luminaire will give long life than Conventional Luminaire.

In Truck Lay Bye Lighting:

Lighting Fixture Type	Pole Height (Above G/L)	Bracket Arm Length	Tilt	Luminaire Cat. No.	Luminaire Wattage	Pole Span (In Meter)
Conventional	9M	1.5M	10°	SSGN1225H/FG	250	25M
LED	9M	1M	5°	LSTN-200-CDL-A-HP	200	30M

Table 2.12: Comparison between Conventional and LED Luminaire of Truck Lay Bye Lighting.

Table 2.12 shows that the comparison between Conventional luminaire & LED luminaire lighting design of Truck Lay Bye to match the requirement of the lux level. Conventional luminaire takes more power than the uses of LED Luminaire to fulfill the requirements of the lighting design parameters and when LED Luminaires are used in this lighting design then it will take two poles less with the same dimension of the Truck Lay Bye than the uses of Conventional Luminaires are used to cover the entire Truck Lay Bye and LED Luminaire will give long life than Conventional Luminaire. So uses of LED Luminaires are more efficient than the uses of Conventional Luminaires.

In Vehicular Underpass Lighting:

In vehicular Underpass lighting design has been carried out LFLN11-35-CDL/60 (35W LED FLOODLIGHT) fixture and the entire Vehicular Underpass area lighting design is done by staggered arrangement because to provide less quantity of luminaire as well as to provide better quality of light without feels glare to meet all the requirements of the lighting design parameters.

In Pedestrian Underpass Lighting:

In Pedestrian Underpass lighting design has been carried out LFLN11-30-CDL/60 (30W LED FLOODLIGHT) fixture and luminaire mounting height is 3M above the ground level and four quantities of luminaire are used to meet all the requirements of the lighting design parameters.

Chapter 3

Light Pollution

3.1 Introduction

Outdoor lighting has become a necessary integral part of society. Light pollution is a by-product of outdoor lighting. Light pollution can be reduced by lighting only what is actually needed, when it is needed, and to the appropriate level. The three main elements of light pollution, which are sky glow, light trespass, and glare and the undesirable effects of each element should be minimized or eliminated when designing and using outdoor lighting.

Light our outdoor night time environment to meet certain societal goals, such as increasing safety and security, enhancing economic development, as well as highlighting historic areas or landmarks of cities or towns. Our society has become a 24-hour society, and nighttime lighting has become a necessity to facilitate using our roadways and downtown areas.

Light pollution is a by-product of lighting at night, especially when we use inefficient luminaires and lamps and when we light to excessive levels. We can minimize our impact on light pollution by lighting more efficiently. When we choose efficient luminaires and lamps, fewer lamps may be required to meet the lighting objectives, resulting in less wasted light emitted into areas where the light is not needed.

Light pollution is an unwanted consequence of outdoor lighting and includes such effects as sky glow, light trespass, and glare. An illustration of both useful light and the components of light pollution are illustrated in Figure 3.1.

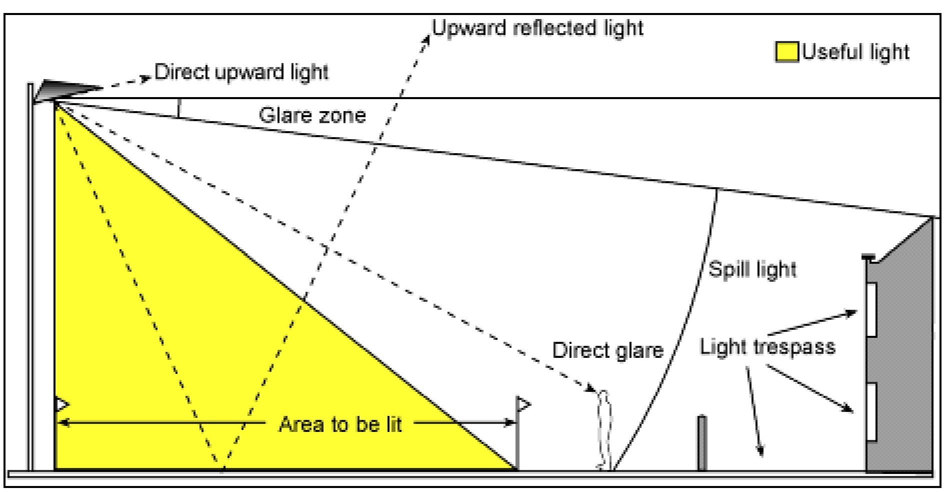


Fig 3.1: Light Pollution from a typical Pole-Mounted Outdoor Luminaire.

3.2 Sky Glow

Sky glow is a brightening of the sky caused by both natural and human-made factors. The key factor of sky glow that contributes to light pollution is outdoor lighting.

Sky Glow occurs from both natural and human-made sources. The natural component of sky glow has five sources: sunlight reflected off the moon and earth, faint air glow in the upper atmosphere (a permanent, low-grade aurora), sunlight reflected off interplanetary dust (zodiacal light), starlight scattered in the atmosphere, and background light from faint, unresolved stars and nebulae (celestial objects or diffuse masses of interstellar dust and gas that appear as hazy smudges of light).

Electric lighting also increases night sky brightness and is the human-made source of sky glow. Light that is either emitted directly upward by luminaires or reflected from the ground is scattered by dust and gas molecules in the atmosphere, producing a luminous background. It has the effect of reducing one's ability to view the stars, as seen in Figure 3.2. Sky glow is highly variable depending on immediate weather conditions, quantity of dust and gas in the atmosphere, amount of light directed skyward, and the direction from which it is viewed. In poor weather conditions, more particles are present in the atmosphere to scatter the upward-bound light, so sky glow becomes a very visible effect of wasted light and wasted energy.

Figure 3.2: Example of sky glow over a city

Sky glow is of most concern to astronomers because it reduces their ability to view celestial objects. Sky glow increases the brightness of the dark areas of the sky, which reduces the contrast of stars or other celestial objects against the dark sky background. Astronomers typically like very dry clear dark nights for observing. A typical suburban sky is 5 to 10 times brighter at the zenith than the natural sky (the zenith is the angle that points directly upward, or 180°, from the observation point). In city centers, the zenith may be 25 or 50 times brighter than the natural background.

This is a very challenging task, because many factors play a role in sky glow. One must not only consider the lighting, but also the angular distribution of the light emitted from the luminaire, the light reflected from the ground and its angular distribution, as well as atmospheric effects of humidity and the interaction of light with aerosols (particles in the atmosphere that may be caused by manufactured pollutants, fire, volcanic eruptions, etc.), all of which can change from moment to moment.

3.3 Light Trespass

Light trespass is light being cast where it is not wanted or needed, such as light from a streetlight or a floodlight that illuminates a neighbor's bedroom at night making it difficult to sleep.

Light trespass occurs when spill light is cast where it is not wanted. Light trespass is somewhat subjective because it is difficult to define when, where, and how much light is unwanted. An example of light trespass is when spill light from a streetlight or floodlight enters a window and illuminates an indoor area. Figures 3.3 and 3.4 depict examples of light trespass.

Figure 3.3: Example of light trespass

Figure 3.4: Example of light trespass from a floodlight

3.3.1 Measurement of Light Trespass

The Institution of Lighting Engineers (ILE) specifies light trespass limits for light entering windows in terms of environmental zones (ILE 2000). It is difficult to measure light trespass because the occurrences are so different. Illuminance on a vertical plane (for example vertical illuminance at the window, as depicted in Figure 3.4) may be appropriate in some cases. Horizontal illuminance might be appropriate in other cases (for example, horizontal illuminance on a bed). An illuminance level of 1 lux (0.1 footcandle) might be acceptable to some and completely objectionable to another. For reference, 0.3 lux (0.03 footcandle) is typical of the illuminance that results from moonlight.

In a recent study, suggest that light trespass be measured in a relative manner, at property boundaries, to take into account both light coming into the property as well as light inside the property. When designing the lighting for a site, imagine a vertical plane at the boundary between the site property and an adjacent property. Measure the illuminance on the vertical plane at the property boundary, directed toward the lighting design site, 180° away from the adjacent property. Then rotate 180° away from the lighting design site, and measure the illuminance on the vertical plane, directed toward the adjacent property.

Calculate the ratio of the illuminance on the plane pointing toward the lighting design site to the illuminance on the plane pointing toward the adjacent property. If the ratio of the measured illuminances is less than unity (one), this implies that the design site receives more light from the adjacent property than the design site delivers to the adjacent property. If the ratio is greater than unity, then the design site delivers more light to the adjacent property than the adjacent property delivers to the site. The larger the ratio, the more likely light trespass complaints are to occur.

3.4 Glare

Glare is a visual sensation caused by excessive and uncontrolled brightness. It can be disabling or simply uncomfortable. There are two types of glare, disability glare and discomfort glare.It is subjective, and sensitivity to glare can vary widely. Older people are usually more sensitive to glare due to the aging characteristics of the eye. Disability glare is the reduction in visibility caused by intense light sources in the field of view, while discomfort glare is the sensation of annoyance or even pain induced by overly bright sources. Reducing glare is an effective way to improve the lighting.

Luminaire manufacturers have concentrated on providing highly efficient luminaires with given beam distributions while meeting the cutoff classifications set by the Illuminating Engineering Society of North America (IESNA) to reduce glare as well as wasted light. Luminaires are designed to have lighting distributions that are appropriate for specific applications. Virtually any luminaire can generate sky glow, light trespass, and glare if installed improperly or in the wrong application. These problems can be avoided by selecting luminaires that have the appropriate distribution for the application and installing them correctly to limit spill light and uplight.

3.5 Lighting Environmental Zones

Although the goal may be to eliminate light pollution, in some locations light pollution cannot be avoided altogether. The environmental consequences of the pollution, however, need not be equally detrimental across all locations. The International Commission on Illumination (CIE) has outlined four environmental zones to establish a basis for outdoor lighting regulations. The environmental zone rating can be used to help ensure that the lighting goals of an environment are appropriately defined and met, but not exceeded. The Illuminating Engineering Society of North America (IESNA) has adopted the concept of environmental zones (described in Table 3.1) and recommends their use in developing new outdoor lighting.

The IESNA gives recommendations for pre-curfew and post-curfew light levels to limit light trespass (IESNA 1999). Pre-curfew is from dusk until 11:00 p.m. local time, when the area being illuminated is more likely to be in use. Post-curfew is from 11:00 p.m. to 7:00 a.m. local time. Recommended lighting levels are higher during pre-curfew time

(IESNA 1999). The Institution of Lighting Engineers (ILE) provides guidelines on Obtrusive light limits for sky glow, light trespass, and glare in exterior lighting installations (ILE 2000).

Zone Rating	**Description**
E1	Areas with intrinsically dark landscapes: National parks, Areas of outstanding natural beauty (where Roads are usually unlit);
E2	Areas of "low ambient brightness": Generally outer urban and rural residential areas (where roads are lit to residential road standard);
E3	Areas of "medium ambient brightness": Generally urban residential areas (where roads are lit to traffic route standard);
E4	Areas of "high ambient brightness": Generally urban areas having mixed residential and commercial land use with high nighttime activity.

Table 3.1: Description of the lighting environmental zones, as adapted by IESNA

3.5.1 Sky Glow Control

While it is difficult to accurately model sky glow, at this point it is presumed that the most important factors are light output and lamp spectral characteristics, light distribution from the luminaire, reflected light from the ground, and aerosol particle distribution in the atmosphere. If the quantity of light going into the sky is reduced, then sky glow is reduced. Thus, current practice is to reduce sky glow by

i) Using full cutoff luminaires to minimize the amount of light emitted upward directly from the luminaire;
ii) Reducing light levels;
iii) Turning off unneeded lights;
iv) Limiting lighted hours of outdoor sales areas, parking areas, and signs around important observing sights;
v) Limiting lighting installations; and

For reducing sky glow, the Institution of Lighting Engineers (ILE) has suggested limits on the amount of luminaire emitted light that goes directly into the sky. The ILE's limits are specified by environmental zone, as shown in Table 3.2.

Environmental Zone	Sky Glow ULR* (max %)
E1	0.0
E2	2.5
E3	5.0
E4	15.0

Table 3.2: Limits on sky glow for different environmental zones

* ULR is the Upward Light Ratio of the installation and is the maximum permitted percentage of luminaire flux for the total installation that goes directly into the sky.

3.5.2 Light Trespass Control

Light trespass may be controlled or minimized by following the general suggestions provided by the Illuminating Engineering Society of North America (IESNA 1999):

- Consider the surrounding area during the lighting design, and select luminaires, locations, and orientations that minimize spill light onto adjacent properties.
- Select luminaires that control the intensity (candela) distribution.
- Use well-shielded luminaires.
- Keep floodlight aiming angles low so that the entire beam falls within the intended lighted area.

The Institution of Lighting Engineers (ILE) has suggested limits on light trespass in terms of the amount of light that is cast on the surface of a window for different environmental zones (see Table 3.3).

Environmental Zone	Light into Windows, Vertical Illuminance (lux)	
	Before Curfew	After Curfew
E1	2	1*
E2	5	1
E3	10	2
E4	25	5

Table 3.3: Limits on light trespass for different environmental zones

* Acceptable from public road lighting installations only

3.5.3 Glare Control

The cutoff classifications of the Illuminating Engineering Society of North America (IESNA) were developed to control glare. The IESNA Full Cutoff, Cutoff, and Semi Cutoff designations limit the intensity values in the glare zone. The Institution of Lighting Engineers (ILE) has suggested limits for glare for the different environmental zones, as shown in Table 3.4. In the table, the source intensity applies to each source in the potentially obtrusive direction, outside of the area being lit.

Environmental Zone	**Source Intensity (kilo Candela)**	
	Before Curfew	**After Curfew**
E1	0	0.0
E2	20	0.5
E3	30	1.0
E4	30	2.5

Table 3.4: Limits on glare for different environmental zones

Glare and light trespass are of special concern when installing floodlights. The International Commission on Illumination (CIE) provides design guidelines on the siting and aiming of floodlights (CIE in press). One objective when the lighting is installed is to ensure that, to the extent practicable, direct view of the bright parts of the floodlights is prevented from positions of importance at eye-height on neighboring properties. Where possible, shielding should be considered. To determine the mounting height of luminaires, the CIE suggests the following considerations:

- Higher mounting heights can often be more effective in controlling spill light, because floodlights with a more controlled light distribution (i.e., narrower beam) may be used, and the floodlights may be aimed in a more downward direction, making it easier to confine the light to the design area.
- Lower mounting heights increase the spill light beyond the property boundaries. To illuminate the space satisfactorily, it is often necessary to use floodlights with a broader beam and to aim the floodlights in directions closer to the horizontal than would occur when using higher mounting heights.
- Lower mounting heights make bright parts of the floodlights more visible from positions outside the property boundary, which can increase glare.

Figures 3.5 and 3.6 show how a higher mounting height compares to a lower mounting height for providing a given amount of light.

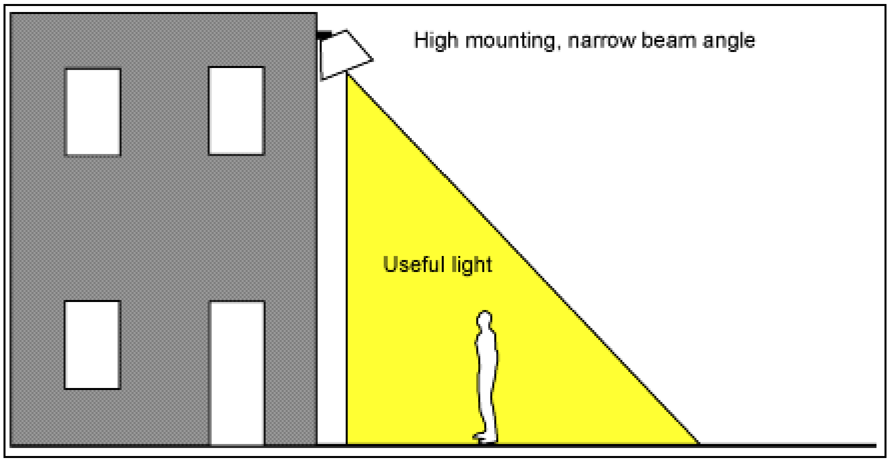


Figure 3.5: Floodlight at a higher mounting height with narrow beam angle, resulting in less spill light.

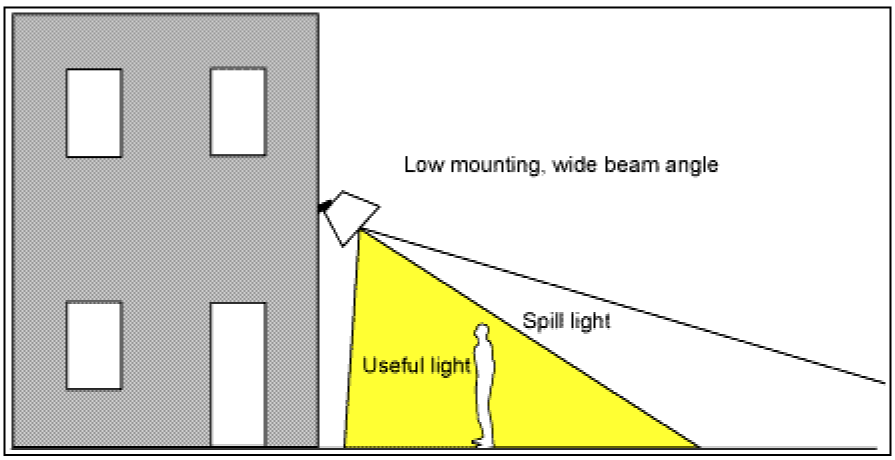


Figure 3.6: Floodlight at a lower mounting height with wider beam angle, resulting in more spill light

3.5.4 IESNA Cut off Classification

The Illuminating Engineering Society of North America (IESNA) defines several outdoor luminaire cutoff classifications, each with different photometric criteria. For these classifications, two relevant zones are defined with respect to the nadir of a luminaire (the nadir is defined as the angle that points directly downward, or 0°, from the luminaire). One zone applies to angles at or above 80° above nadir, and the second zone covers all angles at or above 90° above nadir, or above the horizontal plane of the luminaire (see Figure 3.7). Light emitted in the 80° to 90° zone is more likely to contribute to glare, and light emitted above the horizontal is more likely to contribute to sky glow. The four IESNA classifications are defined as follows (IESNA 2000):

- Full cutoff: The luminous intensity (in candelas) at or above an angle of 90° above nadir is zero, and the luminous intensity (in candelas) at or above a vertical angle of 80° above nadir does not numerically exceed 10% of the luminous flux(in lumens) of the lamp or lamps in the luminaire.
- Cutoff: The luminous intensity (in candelas) at or above an angle of 90° above nadir does not numerically exceed 2.5% of the luminous flux (in lumens) of the lamp or lamps in the luminaire, and the luminous intensity (in candelas) at or above a vertical angle of 80° above nadir does not numerically exceed 10% of the luminous flux (in lumens) of the lamp or lamps in the luminaire.
- Semicutoff: The luminous intensity (in candelas) at or above an angle of 90° above nadir does not numerically exceed 5% of the luminous flux (in lumens) of the lamp or lamps in the luminaire, and the luminous intensity (in candelas) at or above a vertical angle of 80° above nadir does not numerically exceed 20% of the luminous flux (in lumens) of the lamp or lamps in the luminaire.
- Noncutoff: There is no candela limitation in the zone above maximum candela.

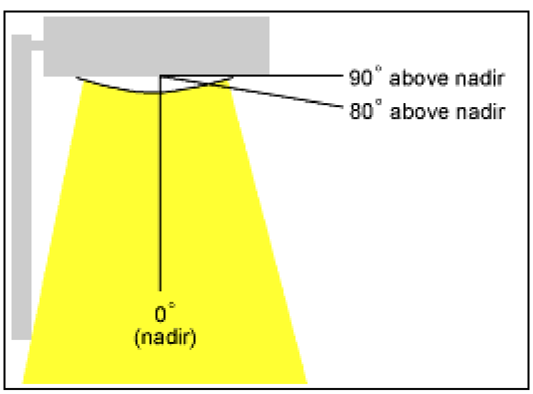


Figure 3.7: Angles referenced by the IESNA cutoff classifications.

Generalizing for each cutoff classification, ranges of lamp lumen percentage are shown in Table 5 in terms of uplight and lamp lumens in the glare zone. The direct uplight of a luminaire that has the IESNA semi cutoff classification theoretically can vary from 0% to 31% of the total lamp lumens and the lamp lumens in the glare zone can vary from 0% to 22%.

Luminaire Classification	**Range of Allowable Lamp Lumens Emitted Upward**	**Range of Allowable Lamp Lumens Emitted Between 80° and 90°**
Full Cutoff	0	0 - 11%
Cutoff	0 - 16%	0 - 11%
Semi Cutoff	0 - 31%	0 - 22%

3.6 Conclusion

In response to the demand to reduce light pollution, research and development efforts have focused on advancements in technology to design luminaires to efficiently direct light where it is needed. Luminaire manufactures have concentrated on providing highly efficient luminaires with given beam distributions while meeting the cutoff classifications set by the Illuminating Engineering Society of North America (IESNA) to reduce glare as well as wasted light. Advancements in lamp technologies have resulted in producing high efficiency light sources that reduce light pollution and have the added benefit of saving energy.

Luminaires are designed to have lighting distributions that are appropriate for specific applications. Virtually any luminaire can generate sky glow, light trespass and glare if installed improperly or in wrong application. These problems can be avoided by selecting lumiaires that have the appropriate distribution for the application and installing them correctly to limit spill light and uplight. With appropriate lighting design, luminaire selection, and controls light pollution can be minimized.

Conclusion and Future Scope

Outdoor lighting provides safety, security, aesthetics and economic development opportunities. There are many valid reasons to illuminate the outdoors. However, it is important to understand how much outdoor lighting is enough and how to balance the need for light while minimizing light pollution and increasing energy efficiency. Lighting not only aids visibility but also ensures security and this is very important in case of lighting at roads, highways and other different outdoor areas.

In this project the lighting design software AGI32 version 19.6 has been used to design and simulate different types of road lighting and highway lighting projects. During design stage different national and international lighting standards have been consulted.

Thanks to the advancement in the field of technology that has introduced to us solar street lights which is an amazing alternative to conventional street lights as it is a great way to save power and reduce wastage. The future scope of it is tremendous as there are so many wonderful features added in these street lights. Let now discuss some of those incredible features:

Cost Effective

There is no additional electricity cost because the panels in a solar street light convert the solar power into electricity. It is also quick and easy to charge the batteries and they last for almost 5 years. And since the poles are wireless it is simple to install and there is no additional cost of hiring too many workers.

Clear Light

The LED's used in these lights provide clear visibility at night. They are colored to match up with the desired color rendering index to resemble the sunlight during the daytime. This clear light also helps the pedestrians and the vehicles to avoid accidents.

Automatic

They are designed in a way that as soon as it detects that the ambient light is not enough. In the case of low lights, the LED's are automatically switched on. So sensing the outdoor light the solar lights automatically switch either on or off. This feature is really marvelous because it uses a special lens which helps to adjust the brightness level based on the battery voltage and running time. This helps to increase the backup time of the light.

Eco Friendly

It is the responsibility of each and every individual to take care of the environment. The invention of these lights exactly helps in minimizing the amount of waste and reduces carbon footprints. The LED's used in these lights contains no toxic elements and so it helps to protect the environment from any toxic waste.

Motion Sensor

In areas where there is no traffic in the night, it is not necessary to have the street lights switched on the whole night. Motion sensor helps in saving energy as it detects any motion either of a pedestrian or of a vehicle and switches all the LED's on. Also, another smart feature that this motion sensor has is that if it detects that there is no motion for more than 16 seconds, then all the LED's will automatically reduce brightness. Some of the solar street lights are also powered by footsteps which mean that the batteries get charged from the kinetic energy powered by the pedestrians' footsteps.

Smart Technology

Solar street lights can be operated and controlled either by a mobile phone or a computer from any location. This feature helps in adjusting settings of the light either to dim the light or to increase the brightness from a remote place without physically being present at the location. It also provides information in real time and helps to determine if there are any problems or if the light is out of order even before a complaint is received from the public. This system makes it easy to check on the status of the solar voltage, the battery voltage also provides data for the previous day usage of the voltage. This saves a lot of energy and does not require any worker to manually check on it. It can be remotely monitored and controlled using the Smartphone.

These are some features of solar street lights which make it a better option over a traditional street light. We can confidently say that solar-powered lights will inevitably be the street lights of the future. And investing and installing in these will play a major part in a clean, green environment. This will also contribute to a brighter future for the coming generations.

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Annexure

Numbers of lighting design projects have been done in indoor and outdoor applications by the lighting software of Dialux & AGI32 throughout internship. The following design have been done in indoor areas are

- Office Lighting
- Hospital Lighting
- Industrial Lighting
- Commercial Building Lighting.

and throughout internship majorly done lighting designs in outdoor areas are

- Streets Lighting
- Highways Lighting
    - Typical Cross-Sections
    - Junctions
    - Grade Separators
    - Toll Plazas
    - Bus Bay
    - Truck Lay Bye
    - Vehicular Underpass
    - Pedestrian Underpass, etc.
- Switchyard Lighting

The involvement of some projects name are given below:

1. Porbandar-Dwaraka Highway Lighting
2. Phagwara-Roopnagar Road Lighting Project
3. Losa Highway
4. NH-5 Oddisha Highway Lighting
5. Devanagere-Haveri Highway Lighting,Karnataka
6. NH-36 & 39 Dimapur Bypass
7. GNPT Highway
8. Pune Smart City Project
9. Punjab Mandi Project
10. 132/33kv Substation at Gez, Kaduna
11. L&T Interstate Road Corridor Ltd
12. Amaravati Zone-7
13. IIT Patna, Indoor Lighting
14. Thapar University, Indoor Lighting
15. AIIMS Hospital Lighting at New Delhi.