2.3 Guardfence

Summary of Warrants

1. Roadside guardfence

1) Sections having serious roadside hazards
- Sections which have obstacles, such as big trees, traffic signals and houses, in the 2m zone to the carriageway.
- Sections along the water such as pond, river, canal and ditch, which depth is more than 1.5 m.
- Sections on bridges and flyovers.

2) Low-standard design sections
- Curves having radius of 200 m or less.
- Down slopes having 4% or more gradient.
- Sections where the carriageway width or number of lanes is reduced abruptly.

3) Proximities to bridges, culverts, etc.
- Approaches to bridges, viaducts, tunnels or culverts.
- Sections where pier, abutment, retaining wall or other rigid structure is in the 2m zone to the carriageway.

4) Sections which have numbers of accidents
- Sections where considerable number of run-off-road accidents happened or are suspected to happen.

2. Median guardfence (width of less than 10 m)
- Sections where 85 percentile speed is 80 km/hr or more and meet one of the following conditions:
  * longitudinal gradient is 3% or more, or
  * curve radius is 750 m or less.
- Sections where median guardfence installation is necessitated because of high running speed.
- Sections where carriageway crossing by pedestrians should be prohibited.
- Sections where prevention of glare by headlights (high-beam) of vehicles from the opposite direction are desirable.

3. Sidewalk guardfence

1) Guardfence to restrain the errant vehicle
- Sections where vehicles are suspected to run into pedestrians on sidewalks due to poor horizontal alignment.
- Sections where prevailing speed is considerably high and safeguard of pedestrians is considered to be requisite.
- Sections on bridges with sidewalk

2) Guardfence to discourage pedestrians from crossing the carriageway
- Sections where carriageway crossing by pedestrians should be prohibited.

3) Guardfence to prevent pedestrians from dropping off

- Sections along the roadside hazard such as ditch, river or low-height ground.

(1) Function and classification of guardfences

1) Function

The main function of guardfences is to restrain errant and uncontrolled vehicles from running into the hazards and getting severe damages. In addition, there are following other functions:
- To minimize damage to vehicle as well as occupants.
- To redirect errant vehicle without endangering other traffic.
- To ensure pedestrian safety.
- To restrain pedestrians from crossing carriageway recklessly.

There are a number of papers reporting that guardfences which are designed and placed in appropriate manners bring delightful results to road safety. Guardfences, on the contrary to the multi-purpose functions as mentioned above, can also be serious roadside hazards to the drivers when improperly installed. Hence, the study leads to an understanding that guardfences shall be a great help to road safety, only when installed by "sound engineering judgment". This also requires the need of a careful and comprehensive guideline for guardfences as regard to warranting conditions, design and material.

2) Classification by type

Since there are various sorts of guardfences, classification and definition are attempted in this study for better understanding of guardfences. Among the many kinds of guardfences, following five types of guardfence are in general use, i.e., guardrail, guardpipe, box-beam guardfence, guard-cable and rigid guardfence. The major features of each type of guardfence are briefly described below. Examples of these types of guardfences are illustrated in Figure 2.3.1.

a) Guardrail, as defined in this report, is a fence of which rail is made of corrugated steel beam in a shape of "W", being supported by a row of steel or wooden posts. Guardrail absorbs collision energy with plastic deformation of "W" beam and deformation of posts.

b) Guard-pipe, which is used mainly aiming at pedestrian safety, is composed of plural number of steel pipes and supporting posts. Collision energy is absorbed in plastic deformation of pipes.

c) Box-beam guardfence is composed of fabricated box-section steel beams and supporting posts. This type of guardfence possesses an advantage to be installed on median, because of its symmetrical cross section. Box-beam guardfences cope with collision impact by bending resistance.

d) Guard-cable consists of strained steel cables, and supporting posts. It resists collision impact by elastic tension of steel cables.

e) Rigid guardfence is usually constructed by the reinforced concrete, hence collision impact fully affects the collided vehicle.

Guardfences are further divided into three categories by purpose of installation, i.e., roadside guardfence, median guardfence and sidewalk guardfence.

Roadside guardfence is installed mainly to protect the uncontrolled vehicle from lateral drop off where sidewalk is not existing. Median guardfence installation aims at decreasing head-on collision between contra-flow vehicles, while sidewalk guardfence is to assure pedestrian safety.

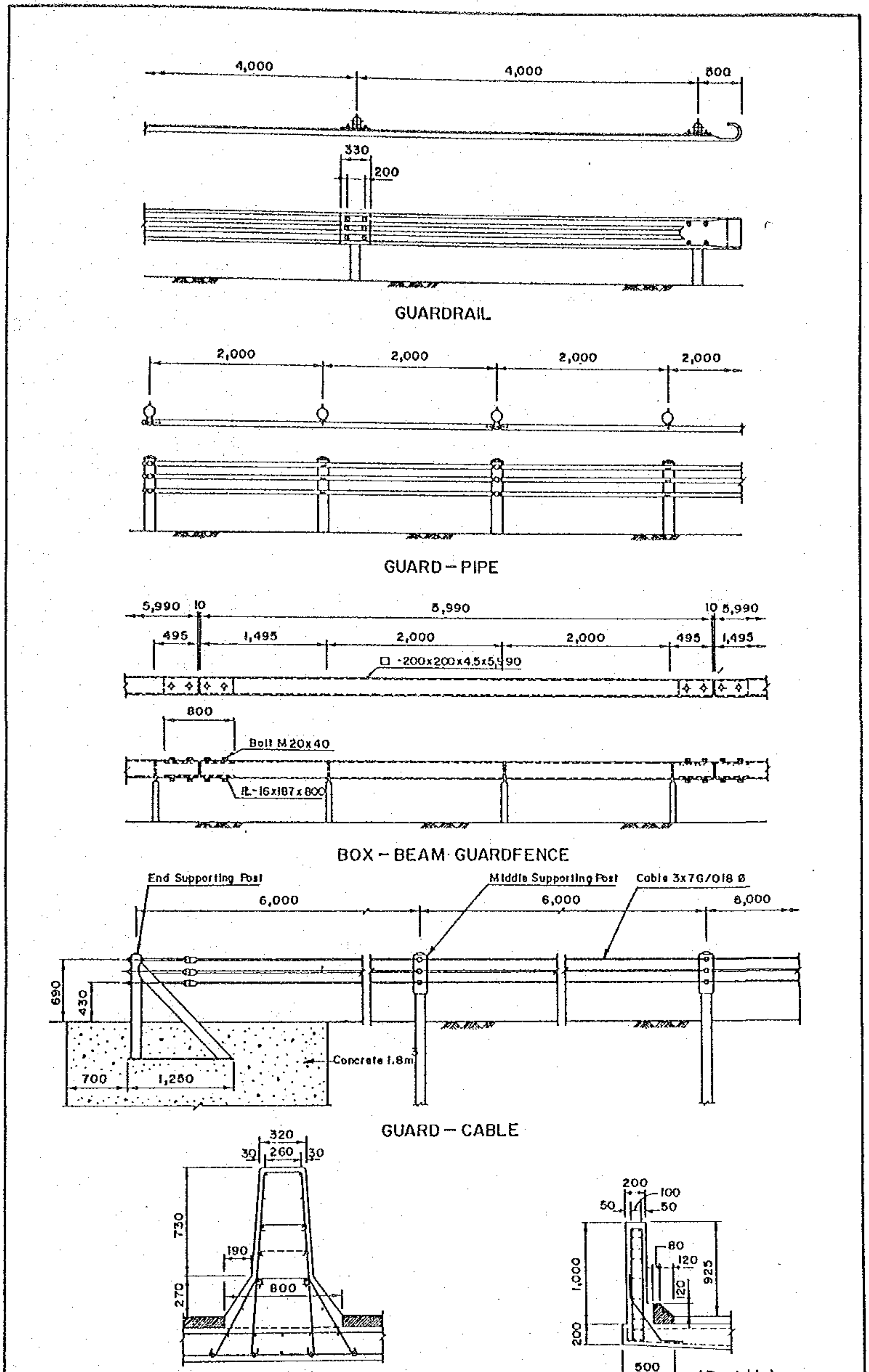


Figure 2.3.1 Example of Various Types of Guardfence

(2) Warranting conditions

1) Roadside guardfence

Roadside guardfences are needed where errant or uncontrolled vehicles are apt to run into roadside hazards resulting in serious damage if guardfence were not installed. Road sections that justify guardfence installation are as follows:

- Sections where roadside areas could be serious hazards.
- Low-standard design sections.
- Proximity to bridges, culverts, etc.
- Sections which have the experiences of a number of accidents.

a) Sections where roadside areas could be hazards

Typical road section in this category is that with high road surface level to ground. In Bangkok, since the land is almost flat, above mentioned type of road sections can only be exist as flyovers and bridges. However, degree of hazardousness at such road sections are very high, since lateral drop off of vehicles from a flyover/bridge causes serious accident. Therefore, it is definitely required to install guardfences, particularly rigid guardfences, along these road sections in order to absolutely prevent drop off type of accidents.

On the other hand, the existence of hard obstacles in the very proximity to the carriageway such as big trees, sign supports, lighting poles, traffic signals, houses, etc., can generally justify the guardfence erection. Besides, sections along the waters such as pond, river, canal, ditch, etc., are generally regarded as the dangerous sections which require the provision of guardfences, when they have a certain depth. One and a half meter of depth is considered as a limit whether passengers are relieved or not from the vehicle sunk in water.

b) Low-standard design section

Relations between geometric parameters of roads and traffic accidents have been widely examined and reported on many occasions, indicating that smaller radii of curves and steep downgrades make the roads more hazardous.

Regarding curve radius, the curves with radii of less than 200m are considered as dangerous as seen in Figure 2,3.2, while moderate curve sections produce safer driving conditions. On the other hand, the value of "safe" curve radius can be calculated, i.e., the following formula gives a limit value of a vehicle's lateral slip.

$$R = \frac{V^2}{127(e+f)}$$

where R : Limit curve radius.
V : Driving speed.
e : Superelevation.
f : Lateral force coefficient.

When 80km/hr for "V", 0.06 for "i", and 0.2 for "f" are substituted in the formula, the resultant curve radius "R" comes out to be 194m. This indicates the curve of which radius is less than 200m is rather dangerous to a vehicle running at 80km/hr or more, especially in a bad weather such as heavy rainfall. In respect to the relation between roadway gradient and traffic accidents, the down slopes having 4% or more gradient are highly dangerous as shown in Figure 2.3.3. This is because drivers are apt to speed up and lose vehicle control at such down slopes.

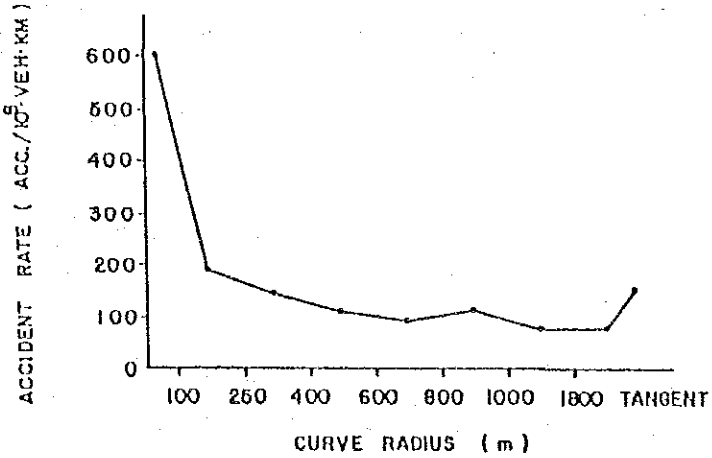


Figure 2.3.2 Relation Between Curve Radius and Accident
(Ordinary Road, Japan)

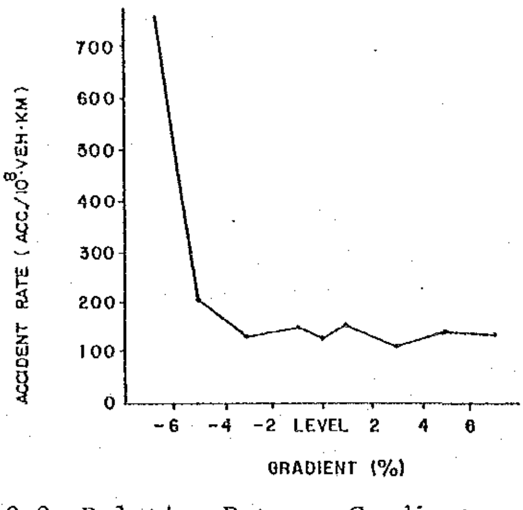


Figure 2.3.3 Relation Between Gradient and Accident
(Ordinary Road, Japan)

The sections where the effective width of carriageway or number of lanes is reduced abruptly (rate of transition is larger than 1:2), are also dangerous, especially at nighttime and need for guardfence.

c) Proximately to bridges, culverts, etc.

Approaches to bridges, flyovers or culverts where carriageway width changes sharply, require guardfences. Collisions with those structures are expected to induce severe damage to the passengers as well as structures themselves.

Sections where bridge pier, abutment, retaining wall or other rigid structure exists in the very vicinity (within about 2 m zone) to the carriageway are regarded hazardous and require guardfences.

d) Sections which have the experience of a number of accidents

The determination whether guardfence should be installed or not requires, in most cases, a close examination by highway/traffic engineer on a case-by-case basis. In other words, it depends on "sound engineering judgment" of concerned engineers.

However, it is supposed that such sections which have the experiences of a considerable number of run-off-road accidents should be provided with roadside guardfences.

2) Median guardfence

Effectiveness of median guardfences in traffic safety may be a somewhat controversial subject. There are some papers reporting that median guardfences increase the number of accidents. These prove that guardfence itself can be a hazard to vehicles. Nevertheless, most of reports stress that run-over-the-median accidents, which are mostly fatal, would notably decrease after construction of median guardfences. There is a report that run-over-the-median accidents with median guardfences are reduced to 1/3 in Japan.

It is desirable, that the road sections with anticipated frequent head-on collisions, e.g., sections of high vehicle speed, considerable amount of vehicular traffic, relatively narrow median, and poor geometrical alignments, are provided with guardfences on the median.

An example of a relation between curve radii and traffic accidents of expressways is shown in Figure 2.3.4. It indicates that when vehicle speed is relatively high, curve radius of less than 750m produces increased danger to the drivers. An example showing ratios of head-on collision accidents to all accidents at gradients is presented in Figure 2.3.5. This example indicates that the gradient of more than 3% induces higher ratio of head-on collision. Thus median guardfences are advisable at the sections mentioned above.

Median guardfences are also very effective to prevent pedestrians from jaywalkings on carriageway and it is possible to reduce conflict points between vehicle traffic and pedestrians.

In addition, median guardfences can prevent glare by headlight (high-beam) of vehicles from the opposite direction, as a supplemental effect.

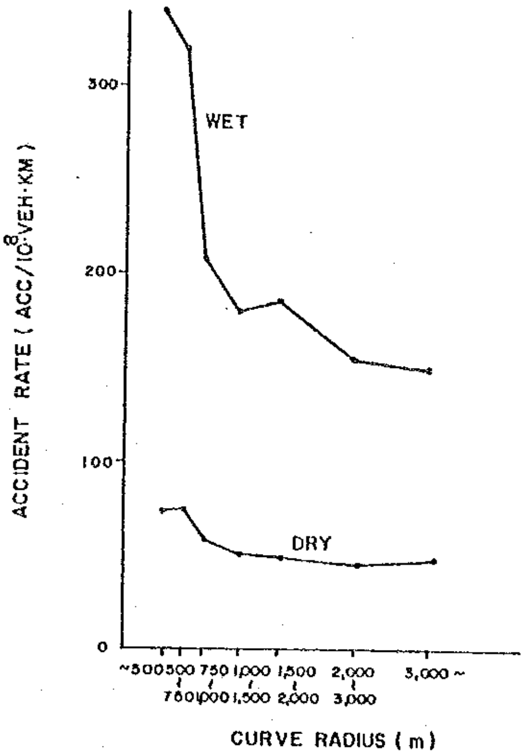


Figure 2.3.4 Relation Between Curve Radius and Accident (Tomei Expressway, Japan)

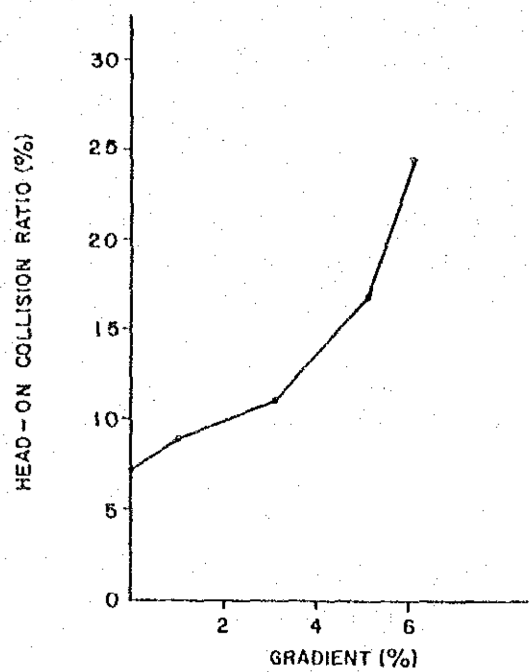


Figure 2.3.5 Relation Between Gradient and Head-on Collision Ratio (Ordinary Road, Japan)

3) Sidewalk guardfence

The objectives of sidewalk guardfences are as follows:

- To safeguard pedestrians from uncontrolled vehicles.
- To prevent pedestrians from dropping off the sidewalk.
- To prevent vehicles from running off the road.
- To discourage pedestrians to cross carriageway.
- To separate pedestrians from vehicle traffic.

At the sharp curvature of road, it is possible for errant vehicle to run off the road onto sidewalks bringing calamity to pedestrians and passengers. Such road sections, where the drivers are inclined to misoperate their vehicles because of road geometry, need for the provision of guardfences.

For the roads, it is desirable to install guardfences on sidewalks at the sections where considerably high speed vehicles endanger pedestrians.

On a bridge with sidewalks, it is desirable to install sidewalk guardfences other than handrails of a bridge, in order to prevent vehicles from drop off.

The guardfences on sidewalks, where pedestrians jaywalk carriageway to jeopardize traffic and endanger themselves, are very effective.

(3) Selection of guardfence type

In selection of guardfences, information on merit and demerit of each type of guardfence will be of a great help. Characteristics of four types of guardfences are described in Table 2.3.1. This table suggests that careful and sound judgment are required in guardfence selection since each type has distinctive characteristics.

Table 2.3.2 is prepared for practical use so that engineers can easily get the information regarding which guardfence has a suitability for a certain road section. It is obvious that the final decision shall be made based on thorough field investigations and taking economical and social conditions into consideration.

Table 2.3.1 Characteristics of Various Guardfences

Type of Guardfence	Advantage	Disadvantage	Usage
Guardrail	- Appropriate rigidity and tenacity - Easy replacement of damaged part - Good visual guidance to drivers - Good adaptability to small-radius curve	- Easily stained	Roadside Median Sidewalk
Guard-pipe	- Good adaptability to small-radius curve - Good scenic view from passengers	- Difficulties in pipe connection	Sidewalk
Box-beam guardfence	- Good adaptability to narrow median - Good scenic view from passengers	- Difficulty to install to small radius curve	Median
Guard-cable	- Easy rehabilitation through reusing the steel cable - Better scenic view from passengers - Free placement of supporting posts - Allowable to differential settlement of posts	- Difficulty to install to small radius curve - Uneconomical to short section - Difficulty in repairment of cable terminals	Roadside Median
Rigit Guardfence	- Completely prevent run-off type of accident - Good lastingness for corrosion resistence	- Difficulty in construction and maintenance - Collision impact fully affect collided vehicle	Roadside Median

Table 2.3.2 Applicability of Various Guardfences to Specific Road Sections

Road Section of ... \ Type of Guard-fence	Guardrail	Guard-pipe	Box-beam Gurdfence	Guard-Cable	Rigid Guardfence
Small-radius (R=300 m) curve	◎	○			
Visual guidance need	◎				○
Good scenic view needed		○	○	◎	
Narrow median	○		◎	○	○
Big Differential settlement				◎	
Corrosion resistance needed	○	○	○	○	◎
Long tangent road	○	○	○	◎	
Bridge/Flyover					◎

Legent; ◎ : Highly Applicable
○ : Applicable

2.4 Delineator

Summary of Warrants

1. Post delineator

Post delineators may be installed along the following sections except where guardfences are installed:
- Curve sections of which radius is 300 m or less, and approaches to the curve.
- Sections where number of lanes or width of carriageway changes abruptly.
- Sections where there are many accident records of run-off type at nighttime or where found as necessary by engineering study to ensure safe traffic flow.

2. Raised pavement marker (Chatter-bar)

Series of raised pavement markers may be installed along:
- Curve sections of which curve radius is 150 m or less.
- Sections where center line crossing by vehicles is to be prohibited.
- Boundary of chevron marking which is drawn on the pavement near to rigid hazards, e.g, raised traffic island, pier in the carriageway, etc.

(1) Delineation of carriageways

Nighttime brings increase hazards to road users through limited visibility and night driving is considerably more hazardous than daytime driving. The main purpose of carriageway delineation is to assure safe driving at nighttime providing various visual information, especially when carriageway is not illuminated or the illumination is insufficient. Effective delineation improves the road safety and ease the driving task.

Substantial delineation treatments include the following:
- Post delineators.
- Raised pavement markers.
- Longitudinal pavement markings.
- Curbs.
- Guardfences.
- Colored pavements.
- Rows of luminaires.

Among these treatments, post delineators and raised pavement markers are taken up in this section, while other important delineation treatments such as guardfences, pavement markings and rows of luminaires are discussed in their respective sections in this chapter.

At present, BMA has not erected any post delineators on their road networks. Instead of that, small reflective buttons had been installed on curbs of medians for the delineation of medians, however, this idea was abandoned, since the reflection of this type of buttons could not be last for long time due to dusts.

On the other hand, DOH has erected a large number of so-called "guide posts", at curves, approaches to bridges and other selected places. The guide post, made of concrete in a shape of quadrangular column, painted in white and black zebra with the height of about 0.8m, is regarded as one form of post delineator when it is reflectorized at the top. Types of post delineators varies in shape and material, and some examples are illustrated in Figure 2.4.1.

Raised pavement markers, meanwhile, include various types employed for guidance of vehicles, as exemplified in Figure 2.4.2. While shape, color and material vary extremely, raised pavement markers may be roughly classified as follows:

- Non-reflective markers.
- Reflective buttons.
- Reflective raised bars (so-called "Chatter-bars").
- Reflective curb markers.
- Intersection identification markers.
- Other reflective markers.

From the standpoint of applications, several aims of raised pavement markers are listed as follows:

- To amplify longitudinal pavement marking.
- To restrain overtaking.
- To delineate curb line.
- To control vehicle speed.
- To channelize traffic.
- To identify intersection.
- To identify hazardous location.

As there is no established practice for the selection of raised pavement markers, engineers are requested to select an adequate type so as to get sufficient efficacy of them, considering the characteristics of each type.

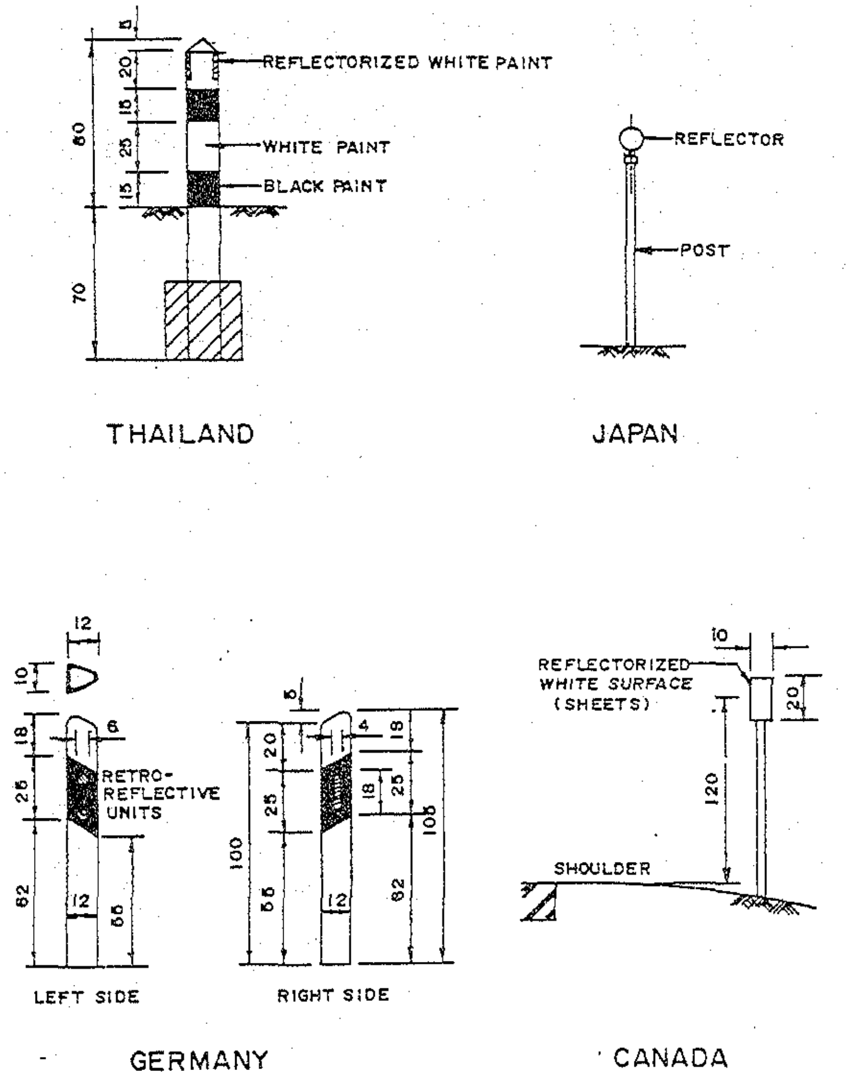


Figure 2.4.1 Various Post Delineators

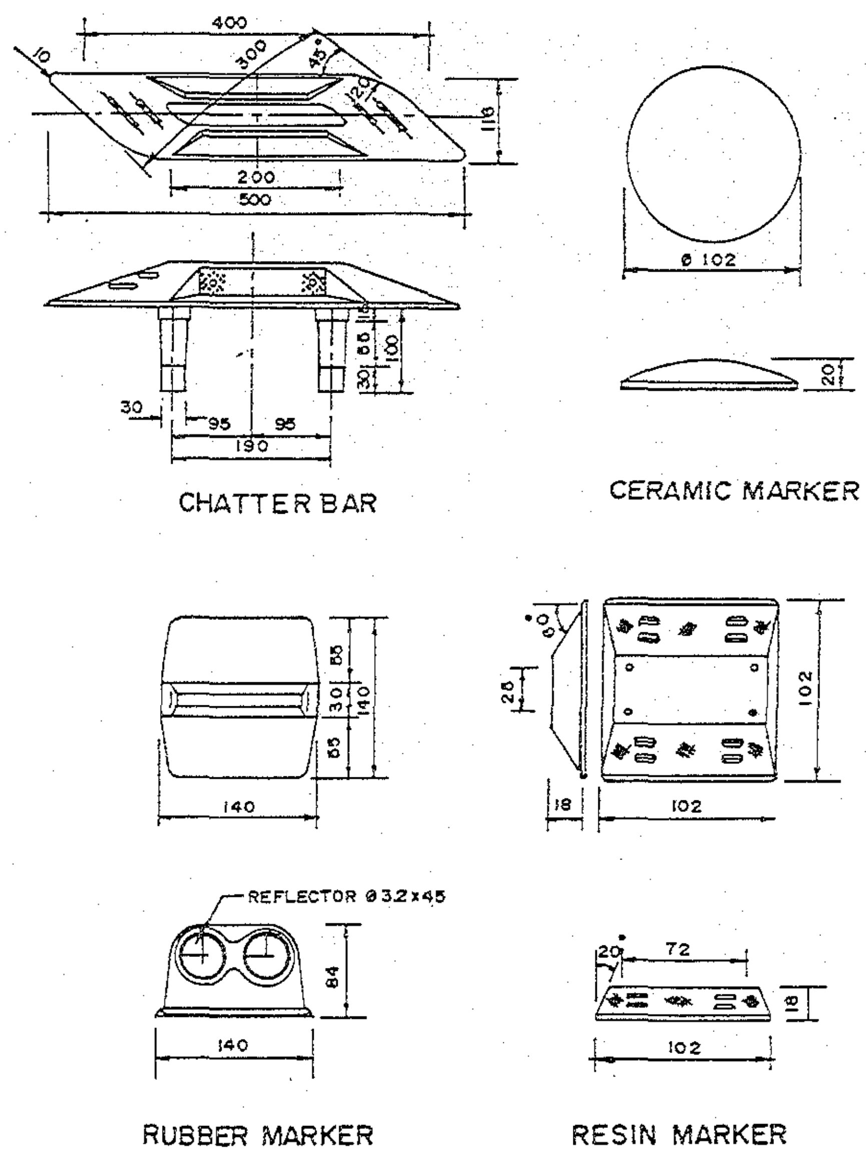


Figure 2.4.2 Various Raised Pavement Markers

UNIT : mm.

In this section, reflective raised bars will be mainly discussed since they are utilized and applied to various purposes and win general appreciation in Japan.

(2) Warranting conditions

1) Post delineators

Since non-reflectorized guide posts can be nothing but hazards to traveling vehicles at night, except when they are installed in illuminated area, following discussion will not apply to non-reflectorized guide posts. There are three types of road sections where delineators may be erected, which are:

- Horizontal or vertical curve sections.
- Sections where pavement width changes.
- Tangent sections.

As there is a part of common roles between guardfences and post delineators, the warranting conditions for post delineators shall be discussed, referring to those of guardfences. It should, however, be noted that delineators are not so effective when guardfences are installed, because guardfences have high visual guidance effect especially when they are reflectorized partially.

According to warrants of guardfences, they are to be installed at curve sections having radius of 200m or less or downgrades of 4% or more. As to post delineators, they can be applied more widely, because of their relatively low cost. Post delineators are generally recommended to curve sections having radius of 300m or less, while slopes are not necessarily provided with post delineators.

Post delineators are also to be installed along sections where number of lanes or width of carriageway changes abruptly because substantial guidance for drivers are needed peculiarly at such sections.

The installation of post delineators to tangent road sections is justified only when vehicle speed at night is relatively high and such installation is expected to effect a smooth and safe traffic flow or where are many experiences of run-off type accidents at nighttime.

2) Raised pavement markers (Chatter-bars)

Chatter-bars have been placed in various cases in Japan. They have two aspects in effectiveness, one is delineation effect by reflective unit, and the other is rumble effect which alerts inattentive drivers. Chatter -bars are very effective when applied to road sections where traffic is to be channelized and visually guided at nighttime.

As a small radius curve, vehicle running on inside lane often drives on a part of opposing lane to avoid intense centrifugal effect, which possibly leads to a disastrous head-on collision. Installation of chatter bars along center line at such small radius curve is very effective. This has been proved effective through the experimental work on Pibun Songkram Road in the previous JICA Study for DOH. The inclination to drive on opposing lane is related to "easiness of driving". Assuming that approaching speed is 60 km/hr, 150m of curve radius is considered as a minimum limit for easy driving according to lateral force calculation.

Even the tangent road sections sometimes should be divided physically along the center line. One case is undivided multilane road, and the other is section where overtaking is prohibited. Roads having 4 lanes or more are, in principle, to be divided by median to prevent intensive head-on collision accidents. Installation of chatter-bar are effective when construction of mounded and curbed median is restricted. Another effective use of chatter-bars is to stress the boundary of chevron markings. To mark clearly channelization at night and to alert careless drivers by rumble effect, the placement of chatter-bars along the boundary of chevron markings contributes to safety, especially when such markings are drawn closely to rigid hazards, e.g., raised traffic island, pier in the carriageway, etc.

(3) Application

1) Post delineators

a) Horizontal curve

In Japan, spacing of delineators at a horizontal curve is determined by the criteria shown in Figure 2.4.3 together with those of employed in DOH. Since both seem similar to each other, spacing criteria of DOH are considered as adequate.

From the visual standpoint, use of post delineators only on the outside of curve is effective enough. However, post delineators used on both side make the carriageway clearer. In this case, two-color system, white for left hand side and orange for right hand side from the driver, may be more effective.

b) Pavement width transition

Shortening of the spacing of post delineators in the area where the pavement width reduces will provide advance warning of change. Use of post delineators on both sides of the road may further emphasize hazardousness, and promote slower and more attentive approaches.

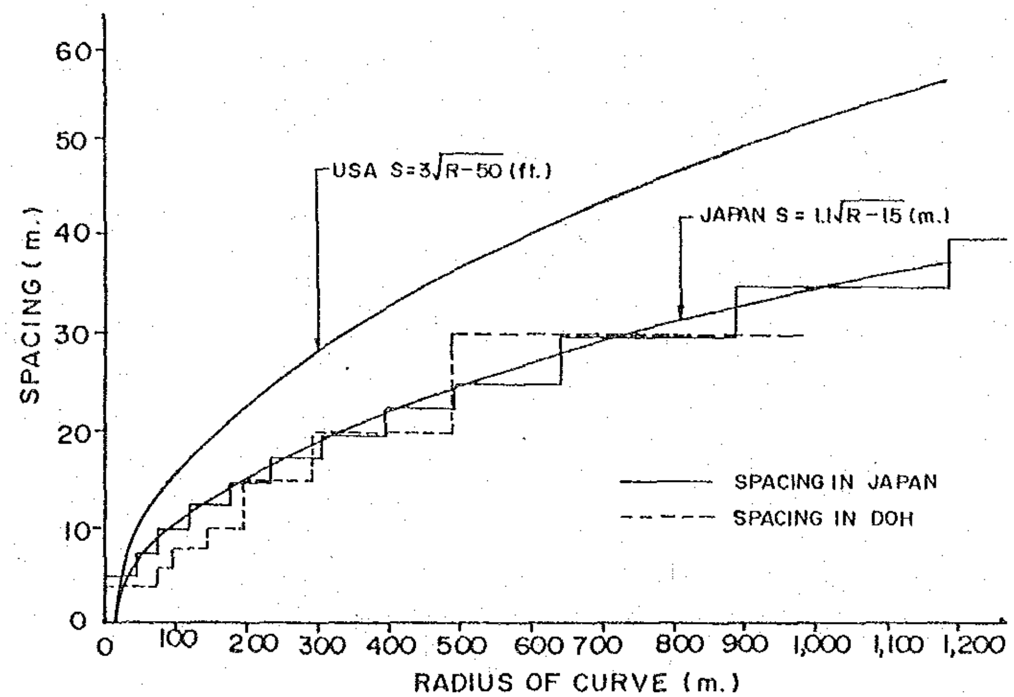


Figure 2.4.3 Spacing of Post Delineators

c) Tangent section

Post delineators should be installed along the left hand side of roads with a spacing of 40m.

2) Raised pavement markers (Chatter-bars)

a) Horizontal curve

Positive application of chatter-bars along the center lines of sharp curves will have a remarkable effect on safety improvement. Spacing of chatter-bars should comply with figures in Table 2.4.1.

Table 2.4.1 Spacing of Chatter-Bars

Curve Radius (m)	Spacing (m)
Less than 50	2
50 to 300	3
300 or more	4

b) Use as substitute for median

One effective usage of chatter-bars is to install along the center line to make it work as a simple median. The height of chatter-bar is about 5cm from the pavement surface, and it may give the vehicle running in considerable speed an intense rumble effect which discourage the driver to cross the center line.

Simple median comprised of chatter-bars, therefore, is useful and effective when it is applied to sections where separation of counter-directional traffics is retired. Figure 2.4.4 is a typical application for above usage.

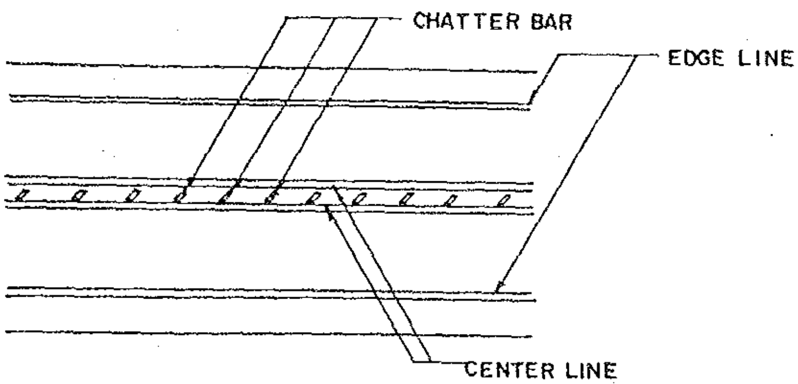


Figure 2.4.4 An Example of Simple Median Marking Use of Chatter-Bars

c) Enhancement of zebra markings

Zebra markings to channelize the traffic flow is one of the principal measures to enhance the safety and capacity of intersections. But as is often the case with the channelization only by markings, drivers tend to disobey his way indicated by means of zebra markings, and this leads to restricted efficiency of channelization. In such case, installation of chatter-bars along the boundary of zebra markings is recommended. Chatter-bars installed as indicated in Figure 2.4.5 will guide and delineate the way of drivers effectively through its rumble effect and optical guidance by reflective unit.

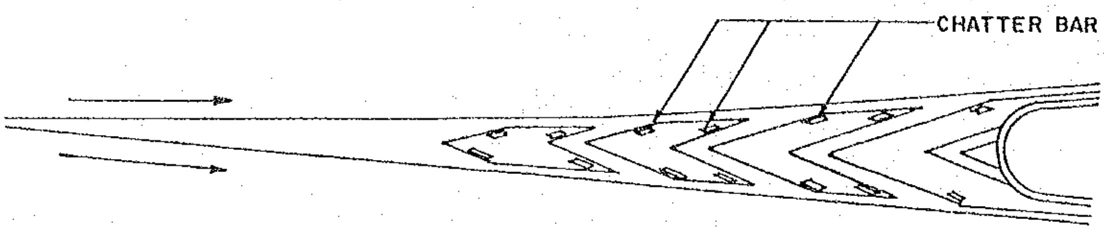


Figure 2.4.5 Enhancement of Channelization by Chatter-Bars

2.5 Sidewalk

<u>Summary of Warrants</u>

In sub-urban areas, sidewalks may be constructed at sections where traffic volume on outer lanes of both directions per day is 3,000 or more and pedestrian volume is 250 or more. For the roads in urban areas, it is desirable, regardless of the above traffic volume, to construct sidewalks on any road, when found necessary to do so and no land acquisition problems exist.

(1) General

In order to reduce the accidents at locations where their traffic volumes are high, it is a general practice to separate pedestrians from the vehicle traffic, by providing exclusive road spaces for pedestrians.

The construction of sidewalks for pedestrians does not only contribute to the safety of pedestrians, but also enhance the safety of vehicle traffic because it reduces reckless emergings of pedestrians. It can also contribute to improving the traffic capacity and travel speed.

Figure 2.5.1 illustrates conceptional cross section of a sidewalk.

(2) Warranting conditions

1) Basic frame of warrants

Construction of sidewalks are justified if there are requirement for segregation of pedestrians.

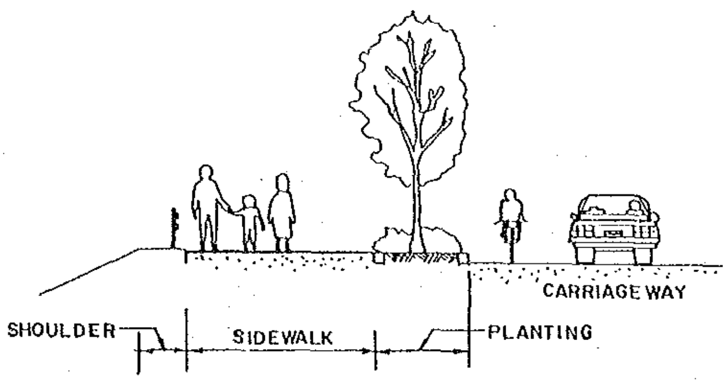


Figure 2.5.1 Typical Type of Sidewalk

2) Segregation of pedestrians

Whether pedestrians should be segregated or not shall be determined by considering pedestrian volume and traffic volume.

It may be considered rather dangerous if a pedestrian walking on a road is passed by vehicles every 30 seconds. When the speeds of vehicle and pedestrian are 60 km/hr and 4 km/hr, respectively, above situation is created by traffic volume of 260 veh/hr, which corresponds to approximately 3,000 veh/day.

On the part of a driver, every 15 second encounter with pedestrians may be hazardous. 35 persons per hour or 250 persons per day creates such condition.

When above two requirements on traffic volume are satisfied, sidewalk construction may be warranted. This warrant, however, should be applied only to roads in sub-urban areas because sidewalks in urban area should be considered not only from the traffic safety point of view but social requirements as well as city planning. Then, sidewalk construction in built up areas could be justified at the lower level of traffic volume than sub-urban area.

3) Paving the shoulders

Since the construction of sidewalks are costly, it is necessary to consider low-cost alternatives. The simplest method is to draw clear edge lines on carriageway and designate shoulders as sidewalks. Installation of raised pavement markers along the edge lines might make them clearer and safer. But when the shoulders are not paved, they ought to be paved. Paving the shoulders may make a safer condition not only for pedestrians but also for vehicles.

(3) Design information

1) Cross section

Following discussions deal with three components of cross section, i.e., pathway width, shoulder and vertical clearance.

a) Minimum width of pathway

Assuming the occupied width of a pedestrian as 0.6m, the unit width of a row of pedestrians (that may be called as a "lane") shall be 0.75m including marginal spaces.

The width of pathway is to be determined by traffic volumes as well as their moving patterns and the minimum widths of sidewalk is considered as 2.75 m. (Please refer to Figure 1.2.10)

On the other hand, it is quite difficult to decide the capacity of pedestrian traffic, because the pedestrian volume varies drastically, even in a five-minutes measuring duration, and additionally, pedestrian traffic changes its feature according to the trip purpose, sex and age. Therefore, final decision shall be made by concerned engineers, taking account of the characteristics of the pedestrian traffic as well as its volume.

b) Shoulder

Shoulder set out here has following multipurpose functions;
- To protect the main structure of pathway from erosion.
- To produce a space for the appurtenances (e.g. guardfences or traffic signs).
- To produce spaces for planting roadside trees.
- To make a lateral clearance for the use of stopping or passing each other.
- To improve the amenity for users.

Except for the spaces for planting roadside trees, 0.5m wide shoulder is enough for respective purposes in most cases. Planting spaces may require 1.0 to 1.5m. It can be said, however, that the width may be reduced to 0.25m on bridges or on the sections under specific restrictions.

c) Vertical clearance

The height of a pedestrian can be assumed less than 2.0m. Accordingly, minimum vertical clearance of 2.5m for the sidewalk is recommended.

2) Separation methods

There are varieties of measures to separate slow traffic from high-speed traffic. They vary from the simple one of edge line markings to the complete one of raised paths with a guardfences and roadside trees. Typical measures of separation are exemplified in Figure 2.5.2.

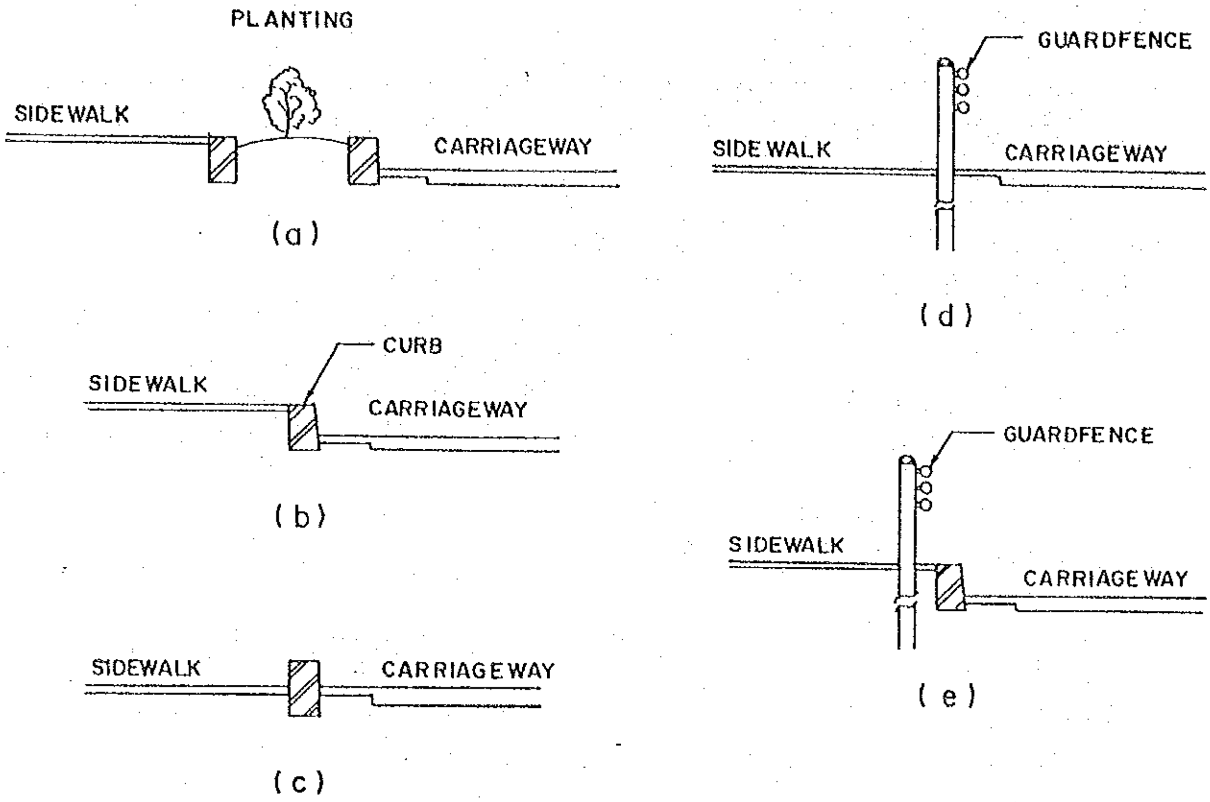


Figure 2.5.2 Various Methods of Slow Traffic Segregation

Summary of Warrants

1. Crosswalk
   - More than 100 pedestrians cross carriageway per hour.
   - A number of school children cross carriageway.
   - Designated as walking spaces within intersections.
   - Vehicle traffic makes it difficult for a number of pedestrians to cross carriageway.

2. Pedestrian Refuge Island

Pedestrian refuge islands may be installed at the sections where pedestrians can not cross carriageway in one movement of crossing and forced to wait for traffic gaps in the middle part of carriageway with 4 or more lanes.

Pedestrian refuge islands should, in principle, be installed in combination with crosswalks.

3. Pedestrian Overpass/Underpass

Pedestrian overpasses/underpasses, at mid-block sections or at non-signalized intersections, are warranted under the following conditions.

a) The number of crossing pedestrians per hour exceeds 100 persons at a peak hour, and the condition of traffic volume and width of carriageway meet the range indicated by the oblique line in Figure 2.6.1. (For the crossing of school children, Figure 2.6.2 should be used.)

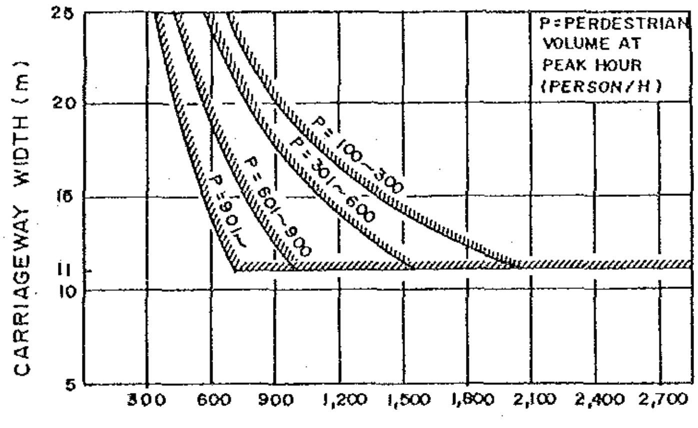


Figure 2.6.1 Warrant of Pedestrian Overpass/Underpass

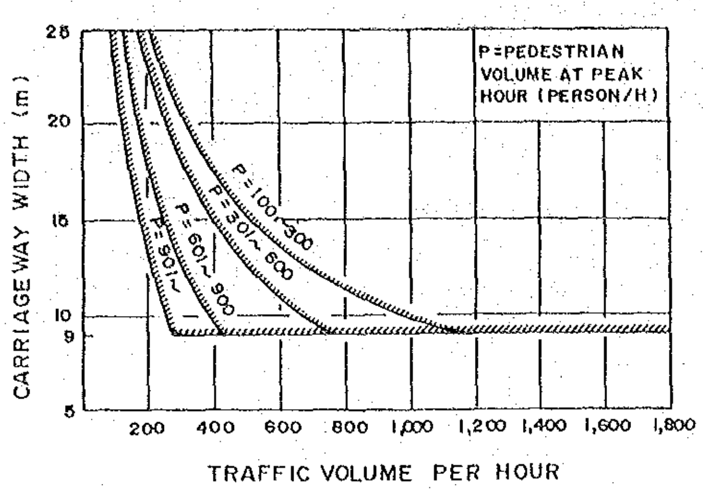


Figure 2.6.2 Warrant of Pedestrian Overpass/ Underpass for School Children

b) The following conditions are met:
- The width of carriageway exceeds 25 meters, and there are no proper space to construct median or refuge island where pedestrians can wait for traffic gap.
- Pedestrian volume is so heavy that vehicle traffic is affected to a large extent.
- No pedestrians are allowed to cross to ensure high running speed of vehicles on roads such as expressway; or
- When pedestrian volume is heavy at such as locations, within 200 meters from railway crossing, immediate vicinity of grade separated road, or sub-standard sight distance, where pedestrian safety cannot be kept by at-grade crossing.

(1) General

The main objective of crossing facilities is to ensure safety of pedestrians when they cross roads, through elimination or reduction of conflicts between vehicles and crossing pedestrians. The crossing facilities also contribute to minimize vehicle traffic delays which may be caused by disorderly movements of pedestrians on carriageways without them.

Crosswalks, refuge islands, pedestrian signals, and pedestrian overpasses/underpasses are well known and practical facilities for pedestrian crossing. Since the degree of effectiveness and obstruction to vehicles as well as construction costs varies with types of the facilities, careful considerations should be paid to select best suited facility at a given location.

Although, detailed discussions on the features of the crossing facilities are made in the following section, some of them, by the nature of complexity, are rather subjective but neither objective nor conclusive. It should, therefore, be noted that a final decision on selection of type and location of crossing facilities should be made by concerned engineers who is acquainted with road and traffic conditions at specific locations.

Executed in the following discussions is the pedestrian signal which will be reviewed together with traffic signal.

(2) Warranting conditions

1) Crosswalk

Crosswalks are a part of carriageway designated as a walking spaces for pedestrians to cross carriageway safely. It is particularly desirable to indicate crosswalks by pavement markings so that they are visible by day and by night. The clearly marked crosswalks will attract pedestrians and warn vehicle drivers when they approach to crosswalks.

It is noteworthy that crosswalks accompanied with adequate safety devices like flashing beacons, street lightings and warning signs are more effective. Installation of sidewalk guardfences plays an important role to make crosswalks effective, when they are properly erected so as to guide pedestrians into crosswalks preventing jaywalkings.

There are no definitely accepted warrants for painted crosswalks, but they should be based upon;

- Pedestrian volume crossing roads.
- Traffic volume and running speed.
- Accident frequency.
- Use as school crossings.

For pedestrian volume, crosswalks are generally warranted at locations where there are at least 100 crossing pedestrians per hour. To ensure sufficient traffic gaps for 100 pedestrians per hour, the maximum traffic volume can be estimated at about 450 vehicles per hour. The minimum intervals of crosswalks should be decided based upon the requirement of smooth vehicle traffic flow. Although there exist conflicts between pedestrian safety and smooth traffic flow, the minimum interval of around 200m seems to be a reasonable compromise for the conflicts.

2) Pedestrian refuge island

Pedestrian refuge islands are safety zones built in the middle of the carriageway for the exclusive use of pedestrians, where there are heavy vehicle traffic volume and heavy volume of pedestrians who would face difficulty and danger in crossing a wide carriageway at one movement. With the provision of refuge islands, in the middle part of the carriageway, pedestrians can safely wait for traffic gaps sufficiently long enough to complete the crossings.

Pedestrian refuge islands may also be desirable for wide streets where intersections are controlled by traffic signals, to reduce the necessary clearance period in accordance with traffic movements without creating a dominant gaps for pedestrians to cross the street.

To increase effectiveness of pedestrian refuge islands, it is preferable to provide a combination of some adequate devices like crosswalks and street lightings.

3) Pedestrian overpass/underpass

The pedestrian overpass is the most effective means to attain the safety of road crossing pedestrians, since it completely separates pedestrians from vehicles on carriageways.

However, its high construction cost often restrains the installation of overpasses/underpasses, and pedestrians sometimes prefer crosswalks because of longer walking distance and extra loss of energy for up and down of stairways.

Pedestrian overpasses/underpass, therefore, may be justified at extremely hazardous locations where there are heavy traffic volumes and pedestrian volumes, and there are high frequency of accidents involving pedestrians which can not be solved by some simpler or more economical ways.

A comprehensive evaluation of a crosswalk and a pedestrian overpass/underpass, should be made prior to the the installation of a pedestrian overpass/underpass. The most fundamental factor in the study is the "time gap" of the traffic flow, during which pedestrians can cross carriageway at grade. There exists the following equation between time gap and number of crossing pedestrians.

$$G = \frac{W}{V} + t + f(n) \qquad \ldots\ldots(1)$$

where G' : necessary time gap for pedestrians to cross carriageway (sec),

W : width of carriageway (m),

V : walking speed of pedestrians (m/sec),

t : pedestrian's reaction time (sec) (usually negligible)

f(n): some sort of function
n = pedestrian volume per day.

From the results of various studies and experiences, the above equation can be simplified as follows;

$$G = \frac{W}{1.3} + 2(N-1) \qquad \text{......(2)}$$

where N is number of pedestrian rows.(See Table 2.6.1)

Table 2.6.1 Number of Rows for Pedestrian

Number of Pedestrians (persons/hour)	Number of Rows
100 - 300	1
301 - 600	2
601 - 900	4
901 -	6

Note: Prepared based on the assumption that pedestrian cross carriageway by five abreast in a row.

Meanwhile, the probability that the number of vehicles which arrive at a certain road section: (TG/3600; T = traffic volume/hr), can be assumed to follow the Poison's distribution.

When traffic volume per hour is T, provided that one vehicle in each direction of road is requested to stop for crossing pedestrians during the time period of G, the traffic volume of T under which G occurs once every 60 seconds, can be obtained from the following equation.

$$P(k) = \frac{e^{-TG/3600}(TG/3600)^k}{k!} \quad (k=0,1,2,..) \qquad \text{......(3)}$$

From the equations (2) and (4), and Table 2.6.1, a warrant for pedestrian overpasses/underpasses can be proposed as shown in Figure 2.6.1.

$$\sum_{k=0}^{2} P(k) = \sum_{k=0}^{2} \frac{\left(\frac{TG}{3600}\right)^k \cdot e^{-\left(\frac{TG}{3600}\right)}}{k!} \leqq \frac{G}{60} \qquad \text{......(4)}$$

In this figure, the minimum width of carriageway is defined as 11m to ensure the utilization of pedestrian overpasses/underpasses. For these road sections, however, it is desirable to install adequate devices to prevent pedestrians from jaywalkings.

(3) Planning methods

1) Crosswalk

a) Type of markings for crosswalk

There are three kinds of pavement markings for crosswalks, namely, zebra markings with white colour paint, two parallel solid lines with white colour paint and two parallel doted lines with road studs. The zebra markings are superior to other types of marking in visibility of crosswalks' existence.

b) Planning conditions

It is desirable to plan crosswalks in the following manners.

- The standard width of crosswalks should be 4.0m. The width may be increased or decreased according to pedestrian volume, but the minimum width be 3.0m.
- Pedestrians to cross the road in one movement.
- Stop lines shall be painted in association with the crosswalk markings.
- The minimum interval of crosswalks shall be 200m in urban area and 300m in the other area with exception of the areas in the vicinity of schools, hospitals, and where pedestrian volume is heavy enough to justify installation of other crosswalks in spite of the above minimum intervals.

2) Pedestrian refuge island

It is desirable to plan pedestrian refuge islands in the following manners.

- The minimum width of refuge islands shall be 2.0m,
- Refuge islands should be protected from direct collisions by vehicles by means of guardfences, curbstones and the like.
- Refuge islands should be provided with adequate devices by which the vehicle drivers approaching to or passing by refuge islands, could be warned of the existence of refuge islands. The following are main

warning devices;

a. Pavement markings.
b. Traffic signs.
c. Delineators.
d. Flashing beacons.
e. Raised pavement markers.
f. Street lightings.

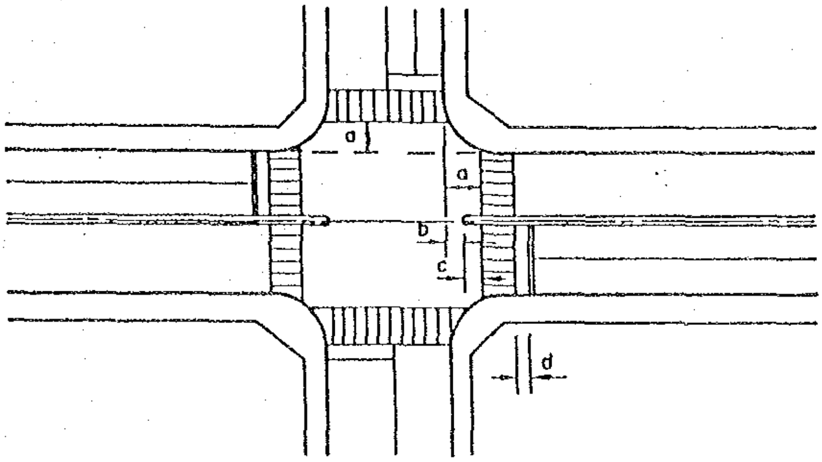


Figure 2.6.3 Crosswalk Planning at Intersection

3) Pedestrian overpass/underpass

Because a pedestrian overpasses/underpasses are permanent structures and their construction costs are high, it is, unlike other crossing facilities, very hard to remodel a pedestrian overpasses/underpasses in accordance with the change of pedestrian volume in the future.

Therefore, a thorough study on overpasses/underpasses especially as to structural dimensions is strongly required in advance of construction. The following are standards for overpass designs.

a) Width of footpath

The necessary width is theoretically given by the equation.

$$W = \frac{Q}{V \times D}$$

where,

W : Effective width, (m)
Q : Pedestrian volume, (person/min.)
V : Walking velocity, (m/min.)
D : Space for one pedestrian, (m^2/person)

The minimum width of footpaths, of pedestrian overpasses shall be 1.5m, but 2.0m when bicycles, baby carriages and wheelchairs are expected to use the overpasses (see Table 2.6.2).

b) Width of stairway and slopeway

The width of stairways and slopeways shall be at 1.5m and 2.0m, respectively, and a minimum of 1.2m and 1.7m, respectively under very special conditions (see Table 2.6.2). As for stairways with slope, the minimum width of portion of slope shall be 0.6m as a standard.

c) Stairway

The gradient of stairways shall be 1:2 as a standard. Landing shall be provided at half way of stairways in the case that height is more than 3 meters.

Table 2.6.2 Width of Pedestrian Overpass

Method for rise and fall	Minimum width of footpath	Minimum width of stairway or slopeway	
		rule	reduction
Stairway	1.5	1.5	1.2
Slopeway	2.0	2.0	1.7
Stairway with slope	2.0	2.1	1.8

2.7 Street Lighting

Summary of Warrants

1. Continuous Lighting

Continuous lightings in urban areas are warranted where:
- ADT is 25,000 vehicles or more.
- Adjacent areas have high illumination levels, which interferes with driver's visibility.
- Pedestrian volume at night is considerably heavy.
- Road sections shorter than 1 km which are located between two lighted sections.

Continuous lightings in rural area may not be warranted.

2. Specific Lighting

Specific lightings are warranted at:
- Intersections where traffic signals are warranted and installed.
- Crosswalks where pedestrian signals are warranted and installed.
- Sections where cross section abruptly changes.
- Sharp bend or steep gradient.
- Toll plaza and its approaches.
- Sections where number of accidents at night time is much more compared with daytime.
- Sections where studies indicate that street lightings may be expected to significantly reduce the night accident rates.

Summary of Design Factor for Street Lighting

1. Average Road Surface Luminance

Table 2.7.1 Recommended Average Road Surface Luminance

(Unit : cd/m^2)

Roadside Condition / Road Class	A	B	C
Major Trunk Roads	1.0 (0.7)	0.7 (0.5)	0.5 (-)
Major Roads Minor Roads	0.7 (0.5)	0.5 (-)	0.5 (-)

Note: Values in parentheses are applied to roads where median is furnished with glare screen.

2. Light Distribution Type

Table 2.7.2 Selection of Light Distribution Type

Road Class \ Roadside Condition	A	B	C
Major Trunk Road	semi-cut-off	cut-off	cut-off
Major Road Minor Road	semi-cut-off	semi-cut-off	cut-off

(1) Function of lightings and visual information

Nighttime brings increased hazards to road users through limited visibility. Night driving is considerably more hazardous than day driving. The main purpose of street lightings is to assure safe driving at nighttime providing increased visibility so that drivers can perceive the following important information as clear as in the daytime.

- Positional information : Required for steering and speed control
- Situational information : Required for changes in speed, direction and lateral positions.
- Navigationa information : Required for selecting a route to a destination.

In order to give sufficient visual information to the drivers at night, street lightings should be designed properly in terms of brightness, uniformity of light, glare and so forth.

However, it would not be appropriate to furnish street lightings to the whole road network in BMA area, because installation and operation of lightings are costly. Therefore, an effective street lighting system should be planned prior to the installation of any lighting units. The word "effective" used here has two facets as noted below:

- Superiority over other alternative measures such as delineators, pavement markings, guardfences, etc.
- Efficient lighting design comprising selection of light source, placement and height of luminaires, glare control and some other important elements.

The requirements for street lighting installation vary with sites according to visual information elements specifically needed. For example, a certain road sec-tion may need clear road geometry among other, while another section may require to light up pedestrians. Some of these sections may be substituted by other safety devices with lower costs than street lightings.

(2) Warranting conditions

As remarked in the preceding section, determination whether street lightings should be provided or not is to be made through extensive studies. The general principles for lighting installation are that priority shall be placed (1) where a study indicates that street lightings are expected to remarkably improve the nighttime safety, or (2) where there are many road users who get benefits from street lightings.

There are two types of installation for street lightings, i.e., continuous lighting and specific lighting. When luminaires are placed successively along a certain length of mid-block section,usually more than 0.5 km, such an illumination method is called "continuous lighting". On the other hand, "specific lighting" is a general term for the lighting for specific sites such as intersection, bridge, toll plaza, etc.

1) Continuous lighting

Continuous lightings in urban area are generally approved for creation of traffic safety, better environments and crime prevention.

Benefits from reduction of accidents are deemed to increase proportionally to traffic volume. A road with more than 25,000 daily traffic volume is expected to yield enough benefit from continuous lightings. But even when traffic volume is less than 25,000 per day, some road sections may require continuous lightings where there are considerably heavy pedestrian volume at night and are assumed to create dangerous situations.

2) Specific lighting

Intersections generally create complicated traffic flows that produce very hazardous spaces for road users. Crosswalks are also dangerous spots where pedestrians and vehicles frequently meet. Therefore, intersections and crosswalks need to be clearly seen by drivers at points with enough distance to assure proper response of drivers.

Warrants of traffic signals (including pedestrian signal) require certain amounts of traffic volume for installation of them. Accordingly, the street lightings at intersections and crosswalks where traffic signals are warranted and installed are expected to bring enough economic benefits.

At nighttime, visual information on road alignment and geometry are essential for safe driving. Road sections where alignment or geometry of road changes abruptly, may be considered to be illuminated. Such sections include:

- Curve or bend with insufficient sight distance.
- Road section having poor continuity of horizontal alignment.
- Steep gradient.
- Road section where number of lanes or carriageway width reduces suddenly.

Besides above, road sections where number of accidents at nighttime are much more compared with daytime, are generally as seriously dangerous at night and need for lighting.

In the preceding paragraphs, typical locations which should be lighted are discussed. However, whether a location shall be illuminated or not is, in principle, a matter of engineer's judgment. This leads to a conclusion that sections where a study indicates that street lightings are expected to significantly reduce the nighttime accidents shall be warranted.

(3) Design of street Lighting

1) Road and area classification

Lighting facilities should be designed taking account of the road class and brightness of surrounding area.

Roads discussed in this section are classified into three categories as following:

a) Major trunk road
   The part of road system which serves as the most principal network mostly for through traffic flow.

b) Major road
   The part of road system which serves as the principal network mostly for through traffic flow and supplements the network of major trunk roads.

c) Minor road
   The part of road system which serves traffic between major trunk roads or major roads and access roads.

This classification is derived from the functional characteristics of road system discussed in section 1.2. Besides, condition of roadside area shall be classified according to the degree of glare as follows:

a) Roadside Condition A
   Vehicle traffic is continuously affected by roadside illumination.
b) Roadside Condition B
   Vehicle traffic is intermittently affected by roadside illumination.
c) Roadside Condition C
   Vehicle traffic is scarcely affected by roadside illumination.

2) Quality of street lighting

There are four fundamentals which influence the quality of street lightings, i.e.:

- Average road surface luminance.
- Luminance uniformity.
- Glare.
- Visual guidance.

a) Average road surface luminance

Contrast is one of the most important contributors to nighttime visual performance. The recognition of objects is mainly based upon discernment of brightness (luminance) differences between an object and its background. For night conditions, an obstacle may appear as a dark area against bright background (silhouette) or it may appear as a bright area against a dark background (reverse silhouette). Illumination is essential to enhance the discernment by silhouette.

Specification of street lightings of MEA (Metropolitan Electricity Authority) has criteria as to average road surface illumination requirements that are shown in Table 2.7.3. Values of illumination are converted to those of luminance and indicated in parentheses. In fact, there are still many road sections under the old standard, and MEA intend to improve street lightings of these sections accordingly.

Table 2.7.3 Current Average Illumination (Luminance) Requirements

Road Width	New Standard	Old Standard
More than 8 m	18 lx (1.2 cd/m^2)	8 lx (0.5 cd/m^2)
Between 4 m to 8 m	10 lx (0.7 cd/m^2)	6 lx (0.4 cd/m^2)
Less than 4 m	6 lx (0.4 cd/m^2)	1 lx (0.1 cd/m^2)

Note : Conversion from illumination to luminance is done assuming that pavement is asphalt concrete. (15 lx = 1 cd/m^2)

According to the researches and experiments conducted in Japan, the minimum requirement of average road surface luminance (reference luminance) is 1 cd/m^2 when the luminance uniformity is kept to 0.4, while CIE (The International Commission of Illumination) has recommended 2 cd/m^2. MEA specification requires about 1.2 cd/m^2 for "major roads", which is a medial value of Japan and CIE. However, considering the high cost and expenses required for lighting facilities, 1 cd/m^2 is recommended as the reference luminance. Moreover, Japan has lots of practices with the reference luminance of 1 cd/m^2 which proved to be enough for street lighting.

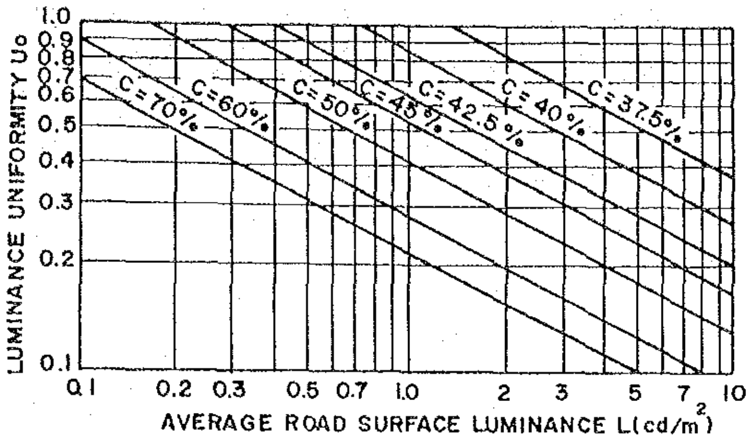
Table 2.7.1 indicates the recommended reference luminances according to the road classification and roadside condition, where the reference luminance is re duced to 0.5 cd/m^2 which is presumed to be the absolute minimum value to maintain the minimum visibility.

b) Luminance uniformity

Uniformity of luminance is required to provide visibility and visual comfort to the driver. Recognition of obstacles are easy in the area with higher luminance, while it is difficult in the area with lower luminance. Difficulty is derived not only from lower luminance but from the deterioration of visual acuity caused by the light dispersion in the driver's eyes, when the uniformity of brightness is not maintained.

Uniformity ratio is generally expressed as L_{min}/L, where L_{min} is the minimum local luminance and L is the average luminance of the whole carriageway. Relationship between object visibility and luminance uniformity is shown in Figure 2.7.1, indicating a great influence of luminance uniformity. It is generally approved that uniformity ratio of

0.4 is proper for the minimum criterion. Appropriate uniformity of road surface luminance is attained by proper placement of luminaires.



NOTE: C IS "LUMINANCE RATIO", DEFINED AS FOLLOWING:

$$\frac{\text{OBJECT LUMINANCE}}{\text{AVERAGE ROAD SURFACE LUMINANCE}} \times 100\ (\%)$$

Figure 2.7.1 Thresholds of Object Recognition with Regard to Road Surface Luminance and Luminance Uniformity

c) Glare

There are two kinds of glare; discomfort glare and disability glare. Discomfort glare gives the psychological sense of discomfort, while disability glare induces the deterioration of physiological faculty of sight, inducing the light dispersion in eyes which becomes "noise" in sight information. Since enough limitation of discomfort glare can minimize the influence of disability glare, consideration can be concentrated on discomfort glare.

Distribution of glare is affected by mounting height and number of luminaires as well as by the type of lighting apparatus, including cut-off, semi-cut-off and non-cut-off. Cut-off types is suitable for principal road for which limited glare is needed because glare is controlled restrictively for this type. Semi-cut-off type is appropriate for the road where surroundings are comparatively bright, because the light distribution is not so limited as the cut-off type. Non-cut-off type is not generally suitable for street lightings. Table 2.7.2 is prepared for selection of the light distribution type.

d) Visual guidance

Drivers need to perceive or know beforehand the information about the change of road alignment and geometry. Longitudinal lane markings and post delineators can give, of course, such information. Appropriately arranged lighting facilities also produce an outstanding visual guidance, while street lightings arranged improperly may mislead the drivers. Effective placement method of luminaires shall be discussed later.

3) Street lighting design

a) Light source

Selection of light source should be done taking various aspects into account, i.e., efficacy, lamp life, stability to temperature, color rendering, etc. Following lamps are generally utilized for street lighting purpose:

- High-pressure sodium lamp.
- Low-pressure sodium lamp.
- Mercury vapor fluorescent lamp.
- Metal halide lamp.
- Fluorescent lamp.

Characteristics of these lamps are summarized in Table 2.7.4. Considering the features of each lamp, Table 2.7.5 is prepared for selection of light source.

Adoption of low-pressure sodium lamp has advantages of relatively high efficacy and accordingly low operation cost, but also has disadvantages such as lack of color rendition and relatively short lamp life. On the other hand, high-pressure sodium lamp is characterized by improved color rendering, long lamp life and high efficacy. Therefore, introduction of high - pressure sodium lamp seems to be reasonable.

b) Arrangement of luminaires

The position of luminaire is determined by mounting height, overhang, inclination angle and placement type. Figure 2.7.2 shall be referred to for the explanation below.

Table 2.7.4 Characteristics of Typical Light Sources

Item \ Lamp	High-Pressure Sodium	Low-Pressure Sodium	Mercury Vapor Fluorescent	Metal Halide	Fluorescent
Wattage (W)	220	35	400	400	40
Luminous Flux (lm)*	40,000	4,600	21,000	30,000	3,000
Efficacy(lm/W)	87	78	47	65	55
Lamp Life (hr)	12,000	9,000	12,000	9,000	10,000
Light Color	Hazy Orange	Orange	White	White	White
Color Rendering	Average	Bad	Good	Good	Good
Dimming	Possible	Impossible	Possible	Impossible	Possible
Minimum Temperature for Usage (C°)	-20	-20	-5	-5	5
Maximum Starting Time	8	20	8	8	Negligible
Maximum Re-Starting Time	3	Negligible	10	15	Negligible

*Standard value use for design computation of roadway lighting.

Table 2.7.5 Suitability of Lamps

Road \ Lamp	High-Pressure Sodium	Low-Pressure Sodium	Mercury Vapor Fluorescent	Metal Halide	Fluorescent
Expressway	◎	◎	○		
Inter-City Road	◎	○	○		
Urban Road	◎		◎	○	
Commercial street			◎	○	◎
Road in Residential Area			◎		○

Legend; ◎ : Recommended ○ : Suitable

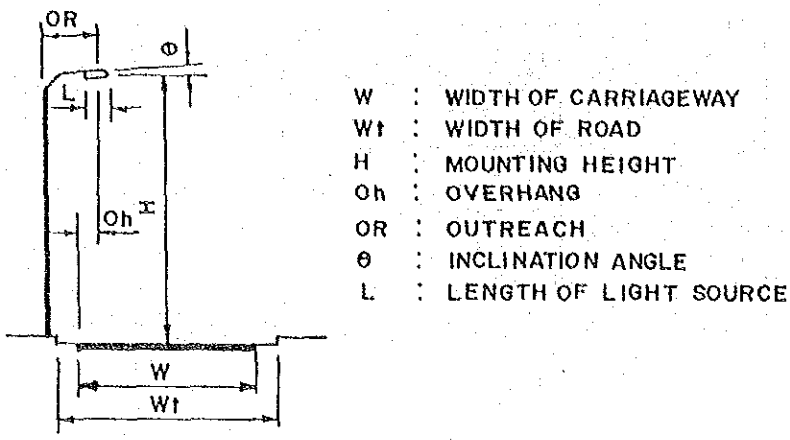


Figure 2.7.2 Basic Dimension of Luminaire

Mounting height of luminaire

Generally speaking, the higher luminaire is, the weaker the glare comes out. Also, higher luminaire gives the improved uniformity of luminance, while total construction cost increases. Mounting height of 10 to 15 m is generally regarded as economical.

Overhang

If the road surface is dry, greater overhang produces higher average road surface luminance. But when the road surface is wet, luminance of road edges or shoulders will be reduced drastically. Then, smaller overhang is appropriate considering the wet season.

Inclination angle

Larger inclination angle can improve the brightness and luminance uniformity to some extent, but more than that, it increases the discomfort glare. Generally, less than 5 degree is adopted.

Placement of luminaire

Basic types of placement comprise one-side placement, staggered placement, opposite placement and median placement, which are illustrated in Figure 2.7.3.

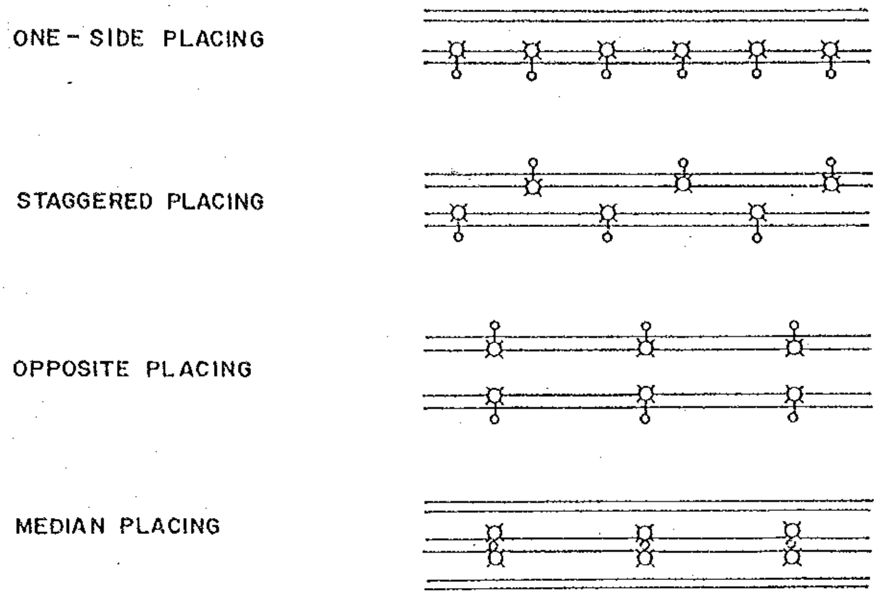
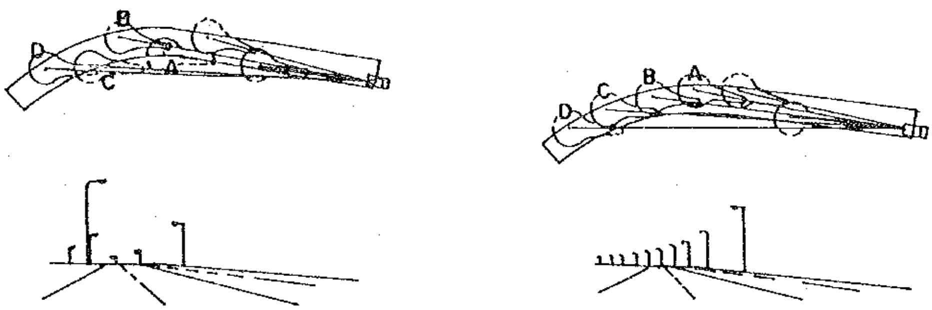


Figure 2.7.3 Typical Luminaire Placing Arrangements

When the continuous lighting system is planned at a curve section, visual guidance effect of luminaires should be considered. As to the type of placement, staggered placement is not adequate. On the contrary, application of one-side placement to the outer edge of the curve is generally recommended because of its good visual guidance effect. Comparison of perspectives from the driver's eyes is shown in Figure 2.7.4.

c) Design criteria for luminaire positioning

Mounting height, overhang and inclination angle of luminaire shall be conformed to Table 2.7.6.



(a) STAGGERED PLACING AT A CURVE (b) ONE-SIDE PLACING AT A CURVE

Figure 2.7.4 Light Placing at a Curve

Table 2.7.6 Mounting Height, Overhang and Inclination Angle of Luminaire

Luminous Flux of a Light Source (lm)	Mounting Height(m) H	Overhang (m) Oh	Inclination Angle (deg.) θ
Less than 15,000	8 or more	$-1 \leqq Oh \leqq 1$ (lamp length $< 0.6m$) $-1.5 \leqq Oh \leqq 1.5$ (lamp length $\geqq 0.6m$)	5 or less
15,000 - 30,000	10 or more		
30,000 or more	12 or more		

Practical mounting height and spacing of luminaire are determined by carriageway width, type of luminaire placement and type of light distribution. These can be obtained from Table 2.7.7.

As for the luminaire spacing along the outer edge of the curve, the criteria specified in Table 2.7.8 shall also be satisfied.

Table 2.7.7 Mounting Height and Spacing of Luminaire

Light Distribution / Height and spacing / Type of placement	Cut-Off		semi-cut-off	
	Mounting Height(m) H	Spacing (m) S	Mounting Height(m) H	Spacing (m) S
One-Side Placement	$\geqq 1.0W$	$\leqq 3.0H$	$\geqq 1.1W$	$\leqq 3.5H$
Medium Placement	$\geqq 1.5W$	$\leqq 3.5H$	$\geqq 1.7W$	$\leqq 4.0H$
Staggered Placement	$\geqq 0.7W$	$\leqq 3.0H$	$\geqq 0.8W$	$\leqq 3.5H$
Opposite Placement	$\geqq 0.5W$ $\geqq 0.7W$	$\leqq 3.0H$ $\leqq 3.5H$	$\geqq 0.6W$ $\geqq 0.8W$	$\leqq 3.5H$ $\leqq 4.0H$

Note; W is width of carriageway.

Table 2.7.8 Spacing of Luminaires along Outer Edge of Curve

Curve Radius (m) / Mounting Height	300 or more	250 to 300	200 to 250	Less than 200
No more than 12m	35 or less	30 or less	25 or less	20 or less
More than 12m	40 or less	35 or less	30 or less	25 or less

d) Design method of street lighting

For the design of continuous lightings, it is possible to calculate desirable spacing of luminaire and luminous flux by the following formula.

$$\frac{F}{S} = \frac{W \times K \times L}{N \times U \times M}$$

where:

F : Luminous flux (lm)
S : Spacing of luminaire (m)
W : Carriageway width (m)
K : Conversion factor of illumination to luminance ($lx/cd/m^2$)
L : Reference luminance (cd/m^2)
N : Coefficient by the type of placing
One side or staggered placement -- N = 1
Opposite placement --------------- N = 2
U : Utilization factor
M : Maintenance factor

The utilization factor can be obtained from the Figure 2.7.5. In this figure, the horizontal axis is the ratio of carriageway width and mounting height of luminaire.

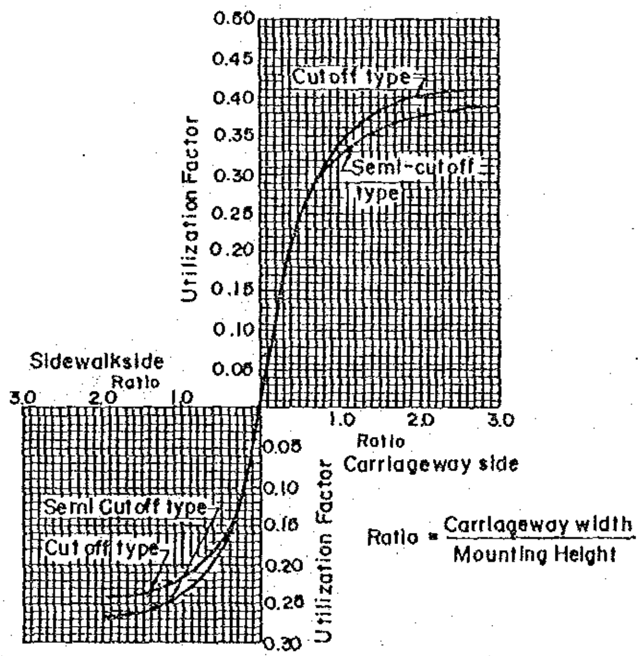


Figure 2.7.5 Relation Between Utilization Factor and Ratio of Carriageway Width and Mounting Height of Luminaire

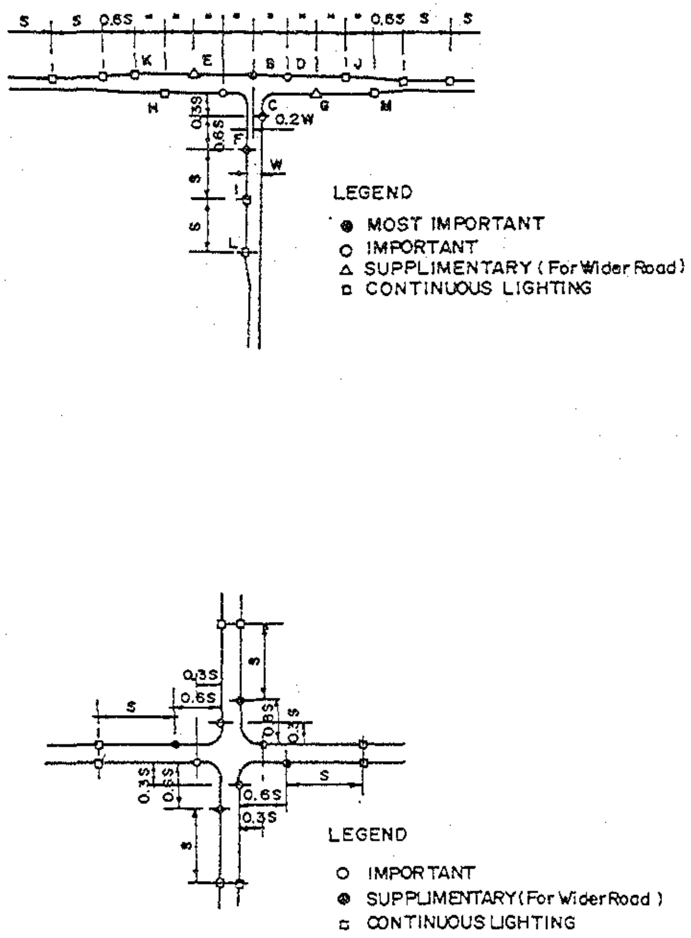


Figure 2.7.6 Typical Luminaire Arrangement (Intersection)

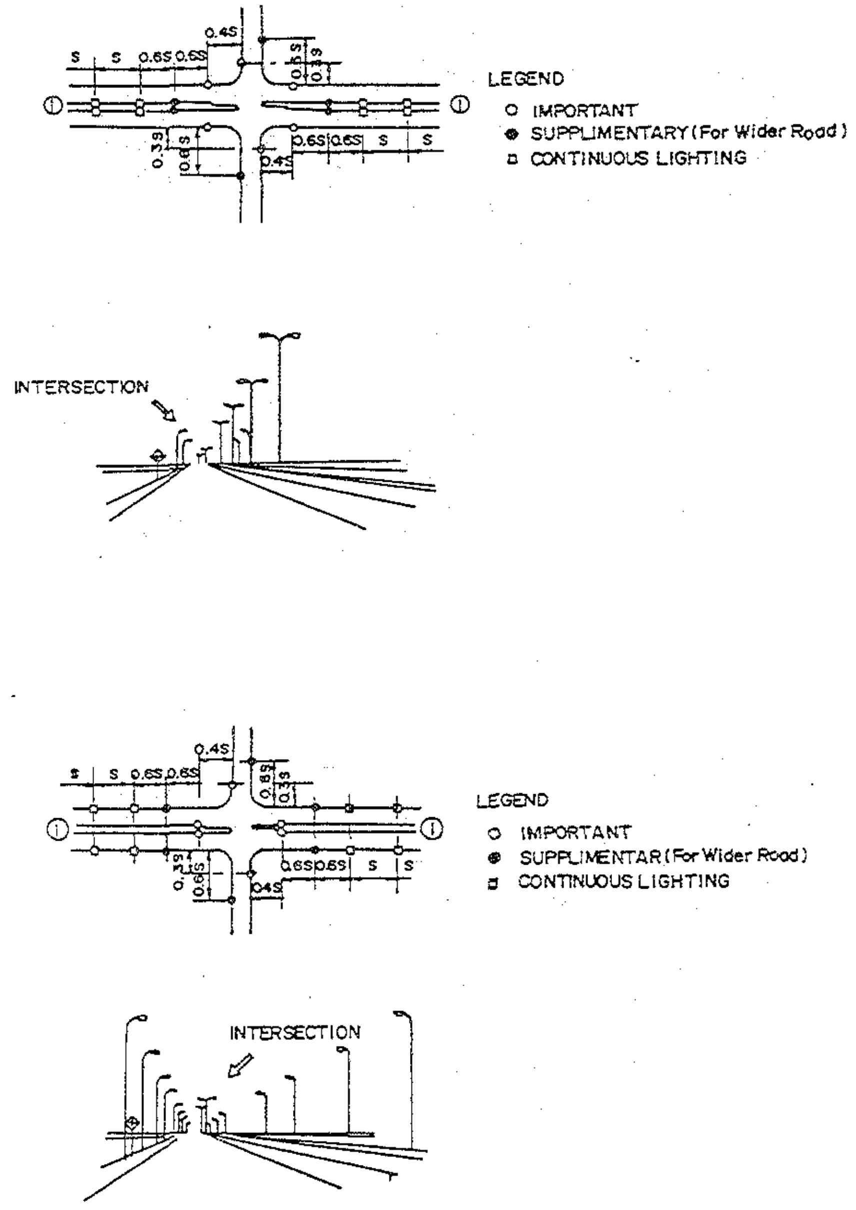


Figure 2.7.7 Typical Luminaire Arrangement (Indication of Intersection)

Maintenance factor is the diminution rate of reference luminance due to the decline of luminous flux capacity and contamination on luminaires. For the continuous lightings, 0.65 - 0.75 is used as the maintenance factor depending on traffic condition, road condition, etc.

4) Arrangement of luminaires for specific lighting

a) Intersection

Luminaires at intersection should be placed so that the driver approaching to the intersection can easily recognize the vehicles and pedestrians in and near the intersection, and besides, the existence of the intersection can draw an attention of the driver from a distance.

Figure 2.7.6 shows examples of luminaire arrangement at a T-intersection and a cross intersection. The luminaire placements in this figure are determined so as to illuminate the turning vehicles clearly in particular. When the road has a median, two kinds of typical luminaire arrangement can be considered, as shown in Figure 2.7.7. If continuous lightings are furnished along the median, opposite placing of luminaires at the intersection is recommended because such an arrangement gives the approaching drivers an information of the existence of an intersection. On the contrary, if continuous lightings are furnished along both sides of carriageway, the median placing at an intersection is recommended.

b) Crosswalk

Lightings at crosswalks should be furnished so that pedestrians are clearly lightened up. To assure the safety of pedestrians, they must be recognized by drivers from a distance of minimum 50 m, and this can be realized by illuminating the 35 m zone ahead from the crosswalk. In addition, to lighten the crosswalk itself is not considered effective because the silhouette effect is impaired, unless the crosswalk is directory illuminated.

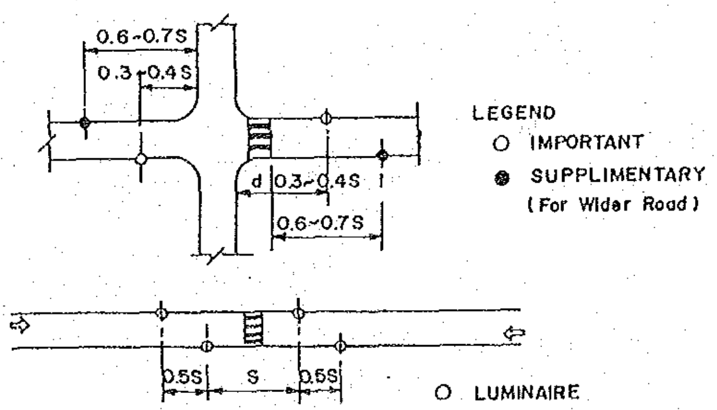


Figure 2.7.8 Typical Luminaire Arrangement (Crosswalk)

c) Pavement width transition

Specific lightings at pavement width reduction are exemplified in Figure 2.7.9. Identification of such a hazard is to be made easily.

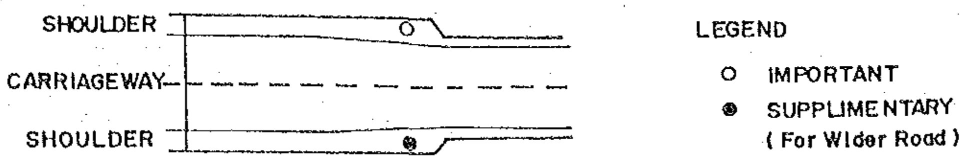


Figure 2.7.9 Typical Luminaire Arrangement (Width Transition)

d) Other places

Specific lightings at a curve are explained in preceding paragraph. Lightings for other places such as bridge, gradient, toll plaza, rest area, etc. can also be correspondingly applied in the same manners as discussed above.

5) Maintenance of street lighting

In order to secure the effectiveness of luminaire, it is desirable to carry out the routine maintenance of street lightings especially for the following items.

- Lighting conditions.
- Reference luminance.
- Lamps.
- Dirt on lamps.
- poles and foundation.

In addition, since many roadside trees have been planted in Bangkok, it is also necessary to trim branches of these trees in order to secure the reference luminance.

2.8 Traffic Signal

Summary of Warrants

1. Pretimed Signal

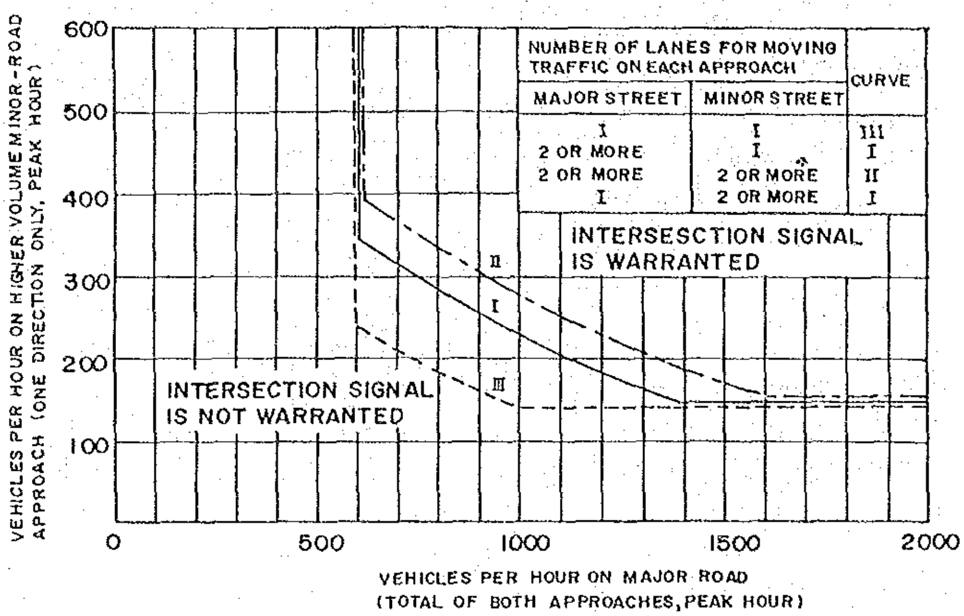


Figure 2.8.1 Warrant for Traffic Control by Pretimed Signals

2. Semi-Traffic-Actuated Signal

Table 2.8.1 Warrant for Traffic Control by Semi-Traffic-Actuated Signals

	Vehicle per hour on major road (total of both approaches)	Vehicle per hour on higher-volume minor road approach (one direction only)
Peak hour traffic volume	900 or more	100 or more

3. Pedestrian Signal

Table 2.8.2 Warrant for Traffic Control by Pedestrian Signals

	Vehicle per hour on the street (total of both directions)	Pedestrian per hour on the crosswalk crossing the road
Peak hour traffic volume	650 or more	200 or more

4. Accident Prevention

Table 2.8.3 Warrant for Traffic Accident Prevention by Traffic Signals

	Accidents Preventable by Traffic Signals
Number of Accidents within a 12-month Period	5 or more

(1) Function of traffic signal

1) Purpose of traffic signal installation

Traffic signals assign alternately the right-of-way to the competing traffic movements at the intersection by light of red, amber and green, and thus they ensure an orderly flow of traffic.

Traffic signals have following advantages when they are well-designed, effectively placed and properly operated:

- They can maintain orderly traffic flows and increase the traffic capacity of the intersection.
- They can reduce the total delay of vehicles at heavy traffic intersection, and relieve vehicles on minor road and pedestrians from suffering extraordinary delay to cross the main road.
- They can reduce the frequency of certain types of accidents.

Following three paragraphs present detailed explanations as to the aforesaid features of traffic signals.

2) Traffic capacity of signalized intersection

It is obvious that the signalization at low-traffic-volume intersection reduces the traffic capacity of the intersection. But when the traffic volume at the intersection exceeds a critical volume, traffic signals can increase the capacity of traffic at the intersection as far as the intersection is not saturated with traffic.

The maximum number of crossing vehicles per hour during the green phase of the signal is called as "saturation flow rate". Although the saturation flow rate varies with the number of lanes and volumes of right and left turning vehicles, or pedestrians at the intersection, the constant value of 2,200 PCU per hour for one lane can be applied practically for any intersection in Bangkok. The quotient obtained by dividing the design traffic volume at each approach by its saturation flow rate shows the ratio of the 'effective green time' to the cycle length required for handling the design volume.

Usually, one phase covers two approaches or more and the maximum of the above ratios of these approaches, is called the "degree of saturation of the phase". The sum of the saturation degrees of all the phases is called the "saturation degree of an intersection".

The saturation degree of an intersection is the ratio of the sum of the minimum necessary green periods of all phases to the cycle length; if this value exceeds 1.0, it means that the intersection is oversaturated in the view of traffic capacity, and that the intersection cannot handle the design volume.

In this case, more sophisticated countermeasure should be considered, such as coordinated signal control system, grade separation or one-way system.

3) Delay at signalized intersection

Signal control can eliminate the delays to minor-road vehicles waiting for acceptable gaps, but it will cause vehicles on a major-road to suffer some delays while waiting for a green light. It should be noted that the substitution of a signal for stop control by traffic signs and pavement markings does not always reduce the total intersection delays.

Relation between traffic volume entering an intersection and an average delay is shown in Figure 2.8.2 *, in which it is evident that at reasonably low levels of traffic volume, the stop control is preferable to the signalized control when the total delays at the intersection is a primary concern.

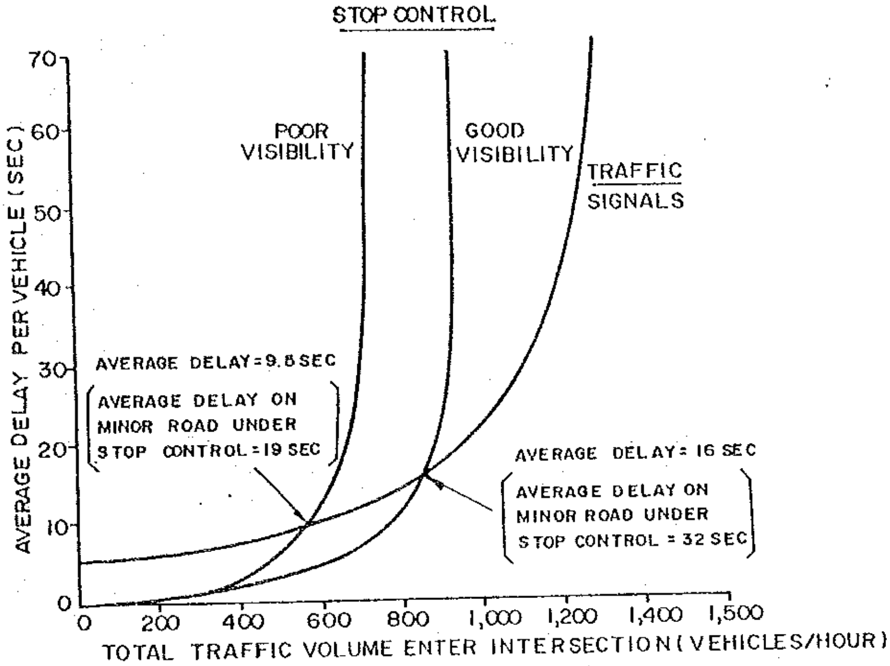


Figure 2.8.2 Relationship between Traffic Volume Entering Intersection and Delay of Vehicle

4) Effect of traffic signals for safety improvement

Installation of traffic signals usually reduces accidents substantially, though rear-end collisions tend to increase slightly in many cases. However, the installation of two or more signal displays to each approach can prevent the increase of rear-end collisions.

Pedestrian signal displays with sufficient duration for crossing are useful to prevent pedestrian accidents. Separated vehicular turning phases together with provision of exclusive turn lanes are effective in avoiding right turn vehicle accidents.

According to accident data before and after installation of traffic signals on Lat Phrao Road (DOH Route 336) under the previous JICA Study for DOH, the number of traffic accidents was reduced by about 50%. This reduction rate agrees generally with the experiences in other countries.

* F.V. Webster and J.G. Wardrop, "Capacity of Urban Intersections", Sixth International Study Week Traffic Engineering, Saltzburg, 1962.

(2) Warranting conditions

In this study, warrants on installation of traffic signals are proposed for the following three types of signal systems, i.e., pretimed signal, semi-traffic-actuated signal, and pedestrian signal. A criterion of installing signals for accident prevention is also proposed.

1) Warrant of pretimed signals

A pretimed signal is operated by a fixed-timing program which has been determined by taking into account traffic volumes of approaches, and vehicle composition as well as the geometric characteristics of the intersection.

On condition that traffic volume remains within a certain level at intersections, it is possible to handle traffic smoothly by traffic regulations such as stop control. When traffic volume exceeds this level, it becomes difficult to guarantee a smooth flow of traffic and the resulting traffic congestion may induce traffic accidents.

According to the simulation carried out for a non-signalized intersection where the major road has 4 lane and minor road has 2 lane, the maximum traffic capacity at the intersections can be calculated by the following formula.

$$M = \frac{Ne^{-\lambda L}}{1 - e^{-\lambda L'}}$$

Where:

M : Vehicles per hour on higher-volume minor-road approach (one direction only, vehicles/hr.)

N : Vehicles per hour on major road (total of both approaches, vehicles/hr.)

λ : N/3600 (vehicle/sec.)

e : Base of the natural logarithm

L : Headway of vehicles at the intersection from major road (sec.)

L' : Headway of vehicles at the intersection from minor road (sec.)

The value of L in the formula is determined by running speed and crossing movement, both of which depend on the types of roads and characteristics of the area. Supposing that 85 percentile running speed is about 50 - 60 km/hr, the value of L is estimated at about 6 seconds.

Value of M is the maximum traffic capacity in the case for stop control at the intersection where major road has 4-lane and minor road has 2-lane. At the other types of intersections, the value of M is obtained by considering the fact that the wider the road is, the smoother the flow of vehicles becomes.

Figure 2.8.1 shows warranting condition for pretimed signals proposed in this study.

2) Warrant of semi-traffic-actuated signal

A semi-traffic-actuated signal utilizes vehicle detectors only on the minor approaches. This type of control may be applied at the intersections where vehicles on minor approaches cannot cross the major road safely without traffic signals.

In this study, warranting conditions for semi-traffic-actuated signal are worked out based on the experiences in Japan, and the results are shown in Table 2.8.1.

3) Warrant of pedestrian signal

As for a traffic signal of which primary objective is to control crossing pedestrians, it is necessary to consider the volume of pedestrian, the width and the traffic volume of approaches.

In this study, the subject is focused on the road whose carriageway is from 9 to 12 m wide with crosswalks. In such road, a minimum traffic volume that makes pedestrian crossing difficult is said to be from 650 to 700 vehicles/hr.

Table 2.8.2 shows warranting conditions for pedestrian signals which have been determined by taking the empirical examples of other countries into account.

In addition, minimum duration of signal phase for crossing pedestrians can be calculated by the following formulas.

- Intersection/crosswalk with limited number of pedestrians for each cycle.

$$T = \frac{L}{V}$$

where;

T : Minimum duration required for pedestrians to cross carriageway (sec.).

L : Length of crosswalk (m)

V : Velocity of pedestrian (m/sec.).
Actually, 1 m/sec. is utilized as the velocity

- Intersection/crosswalk with a number of pedestrians for each cycle.

$$T = L + \frac{P}{F \times W}$$

where;

T : Minimum duration required for pedestrians to cross carriageway (sec.).

L : Length of crosswalk (m)

P : Number of waiting pedestrians for each cycle (person)

F : Flow rate of crossing pedestrians. (person/m/sec.)

W : Width of crosswalk (m).

There is no uniform figure for the flow rate of crossing pedestrians, however, based on experiences in Japan, the following figures can be utilized as the flow rate depending on walking purposes.

* for commuting - 0.92
* for shopping - 0.69
* for amusement - 0.72
* other purpose - 0.52

4) Warrant for traffic accident prevention

When traffic signals are installed at intersections, rear-end collisions may increase but serious accidents such as head-on collisions and pedestrian accidents etc. may be reduced. There are some evidences to suggest that a substantial number of accidents can be prevented by traffic signals. Traffic signals are essential when other less restrictive measures fail to reduce the accidents.

In this study, to ensure traffic safety at intersections with the history of traffic accidents, warranting conditions based on accident data are proposed in reference to the examples in other countries. (Table 2.8.3)

(3) Selection of signal control systems

There are two types of traffic control system, i.e., independent control and coordinated control.

a) Independent control system

The independent control by traffic signals, in principle, may be applied to intersections where the section distance between neighboring intersections is generally long for the platoon of the traffic to disperse over the section.

(Pretimed Control)
- single-program control
- multi-program control

(Traffic-Actuated Control)
- semi-traffic-actuated control
- full-traffic-actuated control

The pretimed control operates with a time table in which the cycle length and intervals are predetermined and fixed. Single-program control, the most simple control system, applies constant parameters around the clock. The multi-program control, on the other hand, is operated by variable parameters of cycle length and intervals. These parameters change throughout the time of the day, and the switchover of parameters are carried out automatically by the built-in clock.

Traffic-actuated control is the type in which the length of the green period varies according to the fluctuation of traffic volumes on approaches. The change in traffic volume is detected by using vehicle detectors. In this system, the length of green period is prolonged by detecting vehicles on approaches.

The one is which the time intervals of all signals are changed in accordance with the traffic flows on all approaches, is called "full-traffic-actuated", and the other in which only a traffic fluctuation on a minor approach is reflected upon the allocation of time splits of the signal is called "semi-traffic-actuated control".

The following is the summary of selection method for independent control types.

- Where crossing roads are major roads and their traffic volumes are relatively heavy, multi- program control is proper.
- Where an major road with heavy traffic volume and a minor road carrying low traffic volume cross each other, semi-traffic-actuated control is proper. In this case, it is desirable to install a push button signal for pedestrians to cross the major road. If pedestrian crossings are frequent on the major road (more than 1 person per 1 minute), the multi-program control is generally desirable.
- Where two roads of which traffic volumes are relatively low intersect, single-program control is proper. However, if there are few crossing pedestrians (less than 1 person per 1 minute), full-traffic-actuated control may be desirable. When full-traffic-actuated control is adopted, it is desirable to install push button signals for pedestrians.

b) Coordinated control system

The coordinated control system is effective and applicable to extensively developed road network in urban area, since linked traffic signals can be coordinated according to the traffic flow.

(Pretimed Control)
- single-program control
- multi-program control

(Traffic-Actuated Control)
- semi-traffic-actuated control
- full-traffic-actuated control

(Traffic-Adjusted Control)

The operational characteristics of pretimed control and traffic-actuated control is almost as same as the independent control system, although several linked traffic signals are controlled by this system.

Traffic-adjusted control is the type in which the length of green period varies according to the fluctuation of traffic volume in the specific location of linked section or area. In fact, progressive system and area traffic control system is under this control system.

(4) Placement of signals

According to this specification of signals, the placement of signal displays is set out as indicated in Figure 2.8.3. The placement is planned on the premise that the type of signal is pedestal or overhang type. This signal placing method is characterized by nearside positioning of primary signal (hereafter called Method A). On the other hand, the placing method indicated in Figure 2.8.4 is of farside positioning of primary signal which is overhang type (hereafter called Method B). Method B has several advantages, i.e., smaller number of signal displays needed, high visibility from approaching vehicles and less expensive installation cost. Method A is widely prevailing in Thailand, but its inferior visibility from high speed approaching vehicles encourages the adoption of overhand type signals, and accordingly, superiority of Method B can be stressed. Therefore, the introduction of Method B is desirable at intersections where approaching speeds are high, and required visibility from a distance.

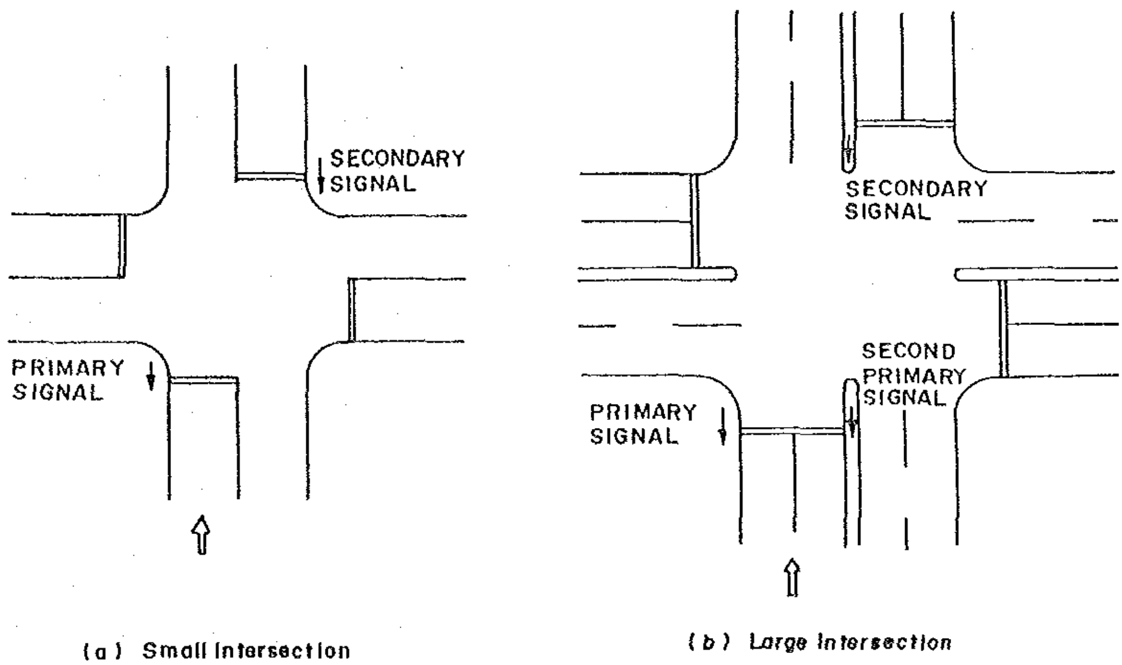


Figure 2.8.3 Standard Placement of Signal Display (Method A)

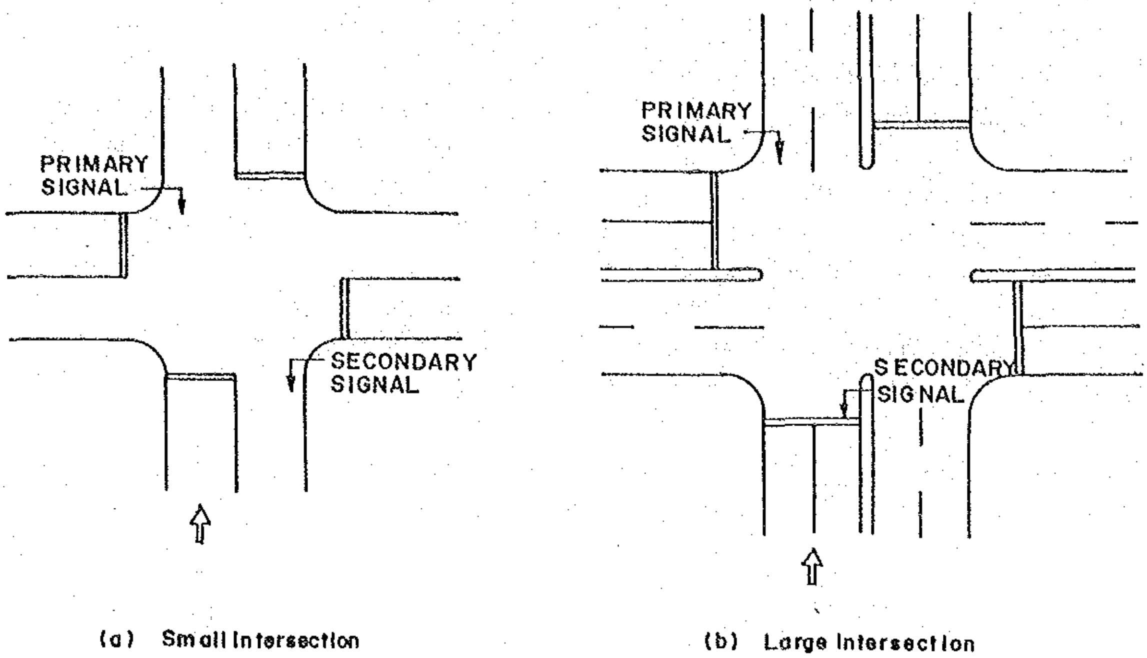


Figure 2.8.4 Standard Placement of Signal Display (Method B)

Following paragraphs explain the signal placing method (Method B) for practical application.

1) Signals for vehicle traffic

a) Primary signal

- To be installed at far-left location of the intersection, facing exactly opposite to the running direction.
- When an approach is split and channelized by traffic islands, each channelized lane is to be considered as an approach.

b) Secondary signal

- To be installed at near-right location of the intersection. Generally it is attached to backside of the primary signal for the opposite direction.
- To be installed at median strips, when the approach has more than 3-lane and median strip is 1 m wide or more.
- Secondary signal for minor road is omissible when the width of minor road is less than 5.5 m, heavy vehicles are few and visibility is well secured.

c) Advance notice signal

- When necessary due to insufficient sight distance at locations such as curved section, an advance notice signal is required at about 50 m on this side of a spot where primary signal or secondary signal can be seen. It is desirable that an advance notice signal is of flashing amber color type, and attached with a sign to indicate existence of traffic signals ahead.

2) Pedestrian signal

Pedestrian signals shall be positioned so as to provide maximum visibility at beginnings of crossings, and to avoid to be an obstacle in the pedestrian flows. Placement at far-side right or left end of crossing areas may meet this requirement.

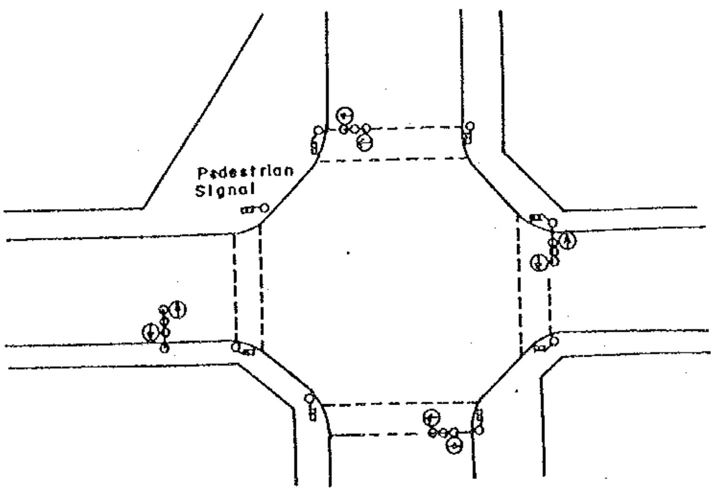
(3) Enhancement of Visibility

Visors should be used on all signal displays to aid in directing the signal indication specifically to approaching traffic, as well as to reduce the impaired visibility resulting from external light entering the optical units.

Also, when the visibility of signals are obstructed by the sunlight at dawn or sunset, following betterments should be taken into consideration; i.e., use of back-plates, relocation of primary signals, installation of secondary signals.

Based upon the aforementioned instructions, typical placement plans of traffic signals at intersections are shown in Figure 2.8.5.

(a) TYPICAL INTERSECTION



(b) DEFORMED INTERSECTION

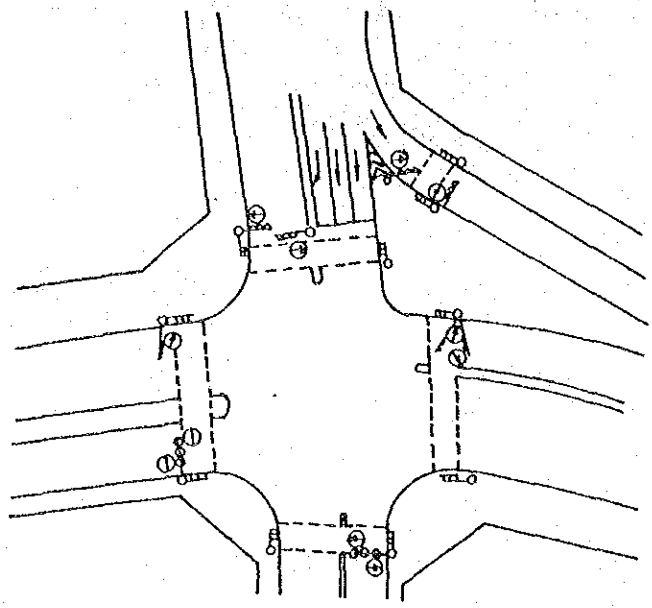


Figure 2.8.5 Examples of Signal Arrangement

2.9 Traffic Signs

A review was made on the "Standard for production and installation of reflective traffic signs" (hereinafter referred to as Manual) that are currently in use by the Traffic Engineering Division (TED) of BMA.

(1) Regulatory signs

Although, the Manual specified the location for installation of each sign individually, respective usage of traffic signs at appropriate spacing should be considered when a certain control applies on zone basis such as maximum speed control in community zone.

In this application, supplemental directional signs are effectively used together with corresponding regulatory signs.

The spacing of regulatory signs should be decided taking into account various factors such as driving speed, drivers' behavior and visibility of signs which depends largely on the situations of roads and its vicinity. However, it should be noted that excessive installation of signs invite drivers' disrespect to them.

The standard spacing being practiced in Japan is shown in Table 2.9.1. The standard spacing seems to have been determined to be applicable even under less favorable circumstances in terms of visibility. Thus, when the better visibility along highways is maintained, it is appropriate to enlarge the standard spacings in Table 2.9.1.

Table 2.9.1 Standard Spacing of Regulatory Signs

Type of Signs	Highway		Expressway
	Urban area	Rural area	
No-Passing	200 m	400 m	800 m
Maximum speed	200 m	400 m	800 m
Minimum speed	-	800 m	800 m
No stopping or standing	100 - 200 m	400 m	800 m
No-Parking	100 - 200 m	400 m	800 m
No crossing of Pedestrian - with guardfence - without guard-fence	 150 m 100 m	 150 m 100 m	 - -

(2) Warning signs

Adequate warning signs provide vehicle drivers with great assistance by noticing existing or potentially hazardous conditions, the use of which, however, should be carefully investigated and kept to a minimum because excessive installation often results in disrespect and depreciation of signs themselves.

1) Intersection ahead sign

Since the necessity of this warning sign is governed by the actual road or traffic conditions, it is recommended that more emphasis be given to those locations as shown below through deliberative field investigations besides the locations specified in the Manual in terms of road type or traffic volume.

- When the existence of intersection or its traffic situation is not recognizable from drivers of high speed vehicles or roads with short sight distance due to geometrical or road side condition.
- When stop sign is not distinct at the approach of stop-controlled intersection.
- At hazardous intersections with high accident number.

2) Curve signs

At road having a curve section, curve signs will be effectively applied for indicating existence to a curve ahead.

3) Advance distance

The manual prescribes the advance distance of warning signs, which varies from 100 m up to 250 m according to the type, whereas dominant distance is 200m - 250m.

These distances may also be applicable to fairly high approaching speed. For the cases with lower approach speed, reduced advance distance of 60 - 100m is recommended. The value will be obtained from the formula in the following subsection.

(3) Guide signs

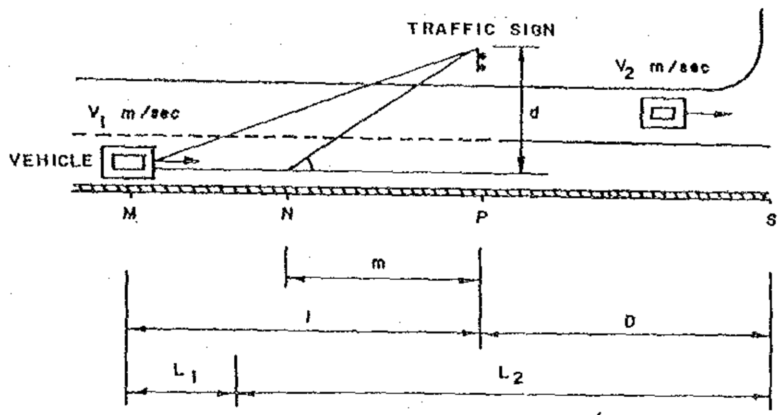
1) Guide signs at intersection

Guide signs at intersection are commonly composed of junction assembly, and destination and direction signs. In Bangkok, however, these guide signs are seldom used except roads under DOH and ETA. Since traffic routes in Bangkok are rather complicated due to the one-way road network, it is recommended to install guide signs near major intersections in order to secure smooth traffic flows as well as to prevent traffic accidents.

2) Advance distance

Some consideration on the advance distance are required especially for destination and direction signs, the adequate location of which varies with the size of characters and the vehicle approach speed.

In the following, a general method is introduced for calculating the advance distance of guide signs. Figure 2.9.1 illustrates the inter-relationship of vehicle, sign and intersection.



M : READING POINT (THE DRIVER FINISHES READING THE SIGN)
N : VANISHING POINT (THE SIGN VANISHES FROM THE DRIVER'S SIGHT)
P : SIGN LOCATION
S : INTERSECTION OR CORRESPONDING HAZARDOUS POINT
D : ADVANCE DISTANCE
d : TRANSVERSE DISTANCE OF SIGN BOARD (OUTER EDGE)
m : DISTANCE OF THE VANISHING POINT FROM THE SIGN
l : READING DISTANCE
L_1 : DISTANCE FOR PERCEPTION AND REACTION
L_2 : DISTANCE FOR CHANGING LANE AND REDUCING SPEED

Figure 2.9.1 Illustration of Sign Location

In this illustration, the following conditions should be satisfied for the driver to be able to maneuver the vehicle safely before the point S.

$$D + \ell \geqq L_1 + L_2 = 2.5V_1 + (n-1).V.t + \frac{V_1^2 - V_2^2}{2\alpha} \quad (1)$$

$$\ell \geqq m = d/\tan\theta \quad (2)$$

where,

- V_1 : prevailing speed (m/sec)
- V_2 : speed at S (m/sec)
- n : number of lanes
- α : deceleration rate (1.0 - 2.5 m/sec^2)

In eq. (1), perception and reaction time is taken as 2.5 sec. and when applying for guide signs, the distance should be increased by about 30m for the glance reading of the sign. The distance required for a single lane change (second term in eq. (1)) may also be approximately 150m from the research[1] conducted in Japan.

In eq. (2), the angle is taken as 10 degree for horizontal angle and 7 degree for vertical when applied for overhead or overhang type signs.

The key value in eq.(1) lies in the reading distance which is also obtained as a function of the character type, letter height and moving speed, as follows;

$$\ell = \frac{20}{3} .k.R.h(h \leq 45 \text{ cm})$$

where;

k : factor by the character
for alphabet k = 1.2
for Thai k = 0.8

R : dynamic legibility coefficient
R = 1.0 for V = 0 km/hr.
= 0.91 V = 49 "
= 0.87 V = 60 "
= 0.82 V = 80 "

h : letter height (cm)

The factor adopted for Thai character is estimated by comparing the research results on the legibility of Thai place-names conducted by Saraithong[2] and Hualthanom[3] .

1) N. Kurimoto, T. Kaji, "A Study on Methods of Allocation and Placements for Highway Guide Signs", Report of PWR1, Vol. 161-2, Feb.1984.

(Example for Destination and Direction signs)

Conditions;

$h = 25cm$, $V_1 = 80km/hr(22.2m/sec)$, $V_2 = 20km/hr(5.6m/sec)$

$\alpha = 1.5m/sec^2$, $n = 1$, $d = 10m$

$$\ell = \frac{20}{3} \cdot 0.8 \cdot 0.82 \cdot 25 = 109.3 \text{ m}$$

$$D = L_1 + L_2 - \ell$$
$$= (2.5 \times 22.2 + 30) + \frac{(22.2)^2 - (5.6)^2}{2 \times 1.5} - 109.3$$
$$= 85.5 + 153.8 - 109.3 = \underline{130.0 \text{ m}}$$

$$m = 10/\tan 10° = 56.7m < 109.3m$$

(4) Variable traffic sign

For the road sections where the reversible lane operation are introduced, it is recommended to install overhead variable traffic signs together with adequate lane line markings.

The desirable distance between two variable traffic signs is 500m in the urban area and it is also necessary to install additional variable traffic signs at locations of 5m to 30m distance from intersections.

Figure 2.9.2 illustrates an example of variable traffic sign installation indicating transition of the center line.

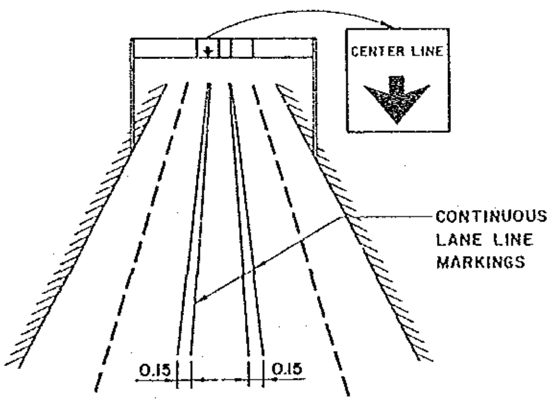


Figure 2.9.2 Installation of Variable Traffic Sign Indicating Transition of the Center Line

2) P. Saraithong, "Optimum Design of Thai-character Highway Signs", Thesis No. 163, SEATO Graduate School of Engineering, 1967.

3) S. Hualthanom, "Analysis of the effect of Duration of Exposure on Glance Legibility of Thai-character Highway Signs", Asian Institute of Technology, 1968.

2.10 Pavement Markings

A review was made on the "Standard for pavement markings by reflective thermoplastic" (hereinafter referred to as Manual) that are currently in use by the Traffic Engineering Division (TED) of BMA.

(1) Longitudinal Markings

1) Width of Markings

The width of longitudinal markings is standardized to be 10 cm in general which is adequate for normal condition, but it will be effectively widened up to 20 cm where special attention of drivers should be called to form an orderly flow at hazardous mid-block section or intersections.

At this case, attention should be paid for the introduction of anti skidding pavement markings, which is described in Appendix 2.10.1, if several accidents occurred due to skidding on pavement markings.

(2) Markings at intersection

1) Right-turn lane transition

The following formula, adopted in the Manual for calculating the length of converging lanes at pavement width transition section, will be applicable for obtaining suitable transition length to provide right-turn lane at intersection.

$$L = K \times V \times W$$

where,

L : Taper Length (m)
V : Prevailing or design speed (km/hr)
W : Width of transition (m)
k : Coefficient,
(0.6) for normal mid-block section
(1/3-1/2) for approach of intersection
(1/6) for entrance of turning lane at intersection

2) Others

There are some controls in which markings are also recommended in addition to primary regulatory signs such as NO U-turn sign and speed limit signs.

Some other useful markings are shown below.

- Symbol marking to guide right turn vehicles at the center of intersection (see Fig. 2.10.1).
- Symbol marking for advance notice of crosswalk.

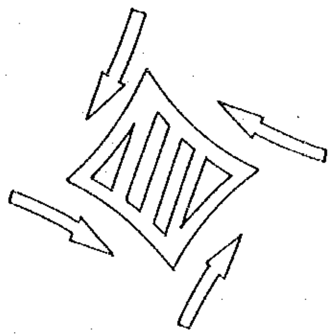


Figure 2.10.1 Guide Marking for Right Turn Vehicle

APPENDICES

Road

Construction in 1984

No	Road Name (length ≧ 100m)	Content	Standard Name	Engineer Name	Reason why you depend on the standard
		1) Cross section 2) Alinement 3) Grade 4) Vertical Clearance			
		1) - ditto - 2) " 3) " 4) "			

Bridge

Construction in 1984

No	Bridge Name (span ≧ 10m)	Contents	Standard Name	Engineer Name	Reason why you depend on the standard
		1) Load (dead, live) 2) Cross section 3) Alinement 4) Grade 5) Vertical clearance			

Pedestrian Bridge

Construction in 1984

No	Pedestrian Bridge name	Contents	Standard Name	Engineer Name	Reason why you depend on the standard
		1) Load (dead, live) 2) Cross section 3) Alinement 4) Grade 5) Vertical Clearance			

Pavement

Construction in 1984

No	Road Name (area≧300m²)	Type	Content	Standard Name	Engineer Name	Reason why you depend on the standard
		As or Co	1) Construction 2) Overlay 3) Reconstruction			
			1) 2) 3)			

Traffic Safety

Contents	Agency Name	Standard Name	Remark
1) Traffic sign 2) Pavement marking 3) Pedestrian crossing 4) Guard fence 5) Traffic signal 6) Street lighting			

BMA JICA Study Team

Questionnaire　　　　　　Design Standard

Name of the standard / Structure	Own Standard	AASHTO	Other (full name of the standard)	Project by Project Basis
Road (Geometric) Design speed Sight distance Horinzontal alinment Vertical alignment Cross section Vertical clearance				
Bridge Geometric (ditto) Load				
Pedestrian bridge Geometric Load				
Pavement Construction Maintenance				
Traffic Safety Facilities Traffic signal Pedestrian crossing Street lighting Guard fence Traffic sign Pavement marking				

Classification of Japanese roads

Express-way or not	Type (Area)	Class	Design speed (km/h)	Access control	Design traffic volume : (vehicles/day) Over 30,000	30,000 – 20,000	20,000 – 10,000	Less than 10,000	Remarks
Express-ways	1 (Rural)	1	120	F	N.E. in level terrain				
		2	100	F,P	N.E. in mountainous terrain	N.E. in level terrain			
					E. in level terrain				
		3	80	F,P		N.E. in mountainous terrain		N.E. in level terrain	
					E. in mountainous terrain		E. in level terrain		
		4	60	F,P				N.E. in mountainous terrain	
							E. in mountainous terrain		
	2 (Urban)	1	80	F	N.E & E. except the center of Metropolis				
		2	60	F	E. in the center of Metropolis				

Express-way or not	Type (Area)	Class	Design speed (km/h)	Access control	Design traffic volume : (vehicles/day) Over 20,000 vehicles	20,000 – 10,000	10,000 – 4,000	4,000 – 1,500	1,500 – 500	Less than 500	Remarks
Roads other than Express-way	3 (Rural)	1	80	P,N	N.H in level terrain						
		2	60	N	N.H. in mountainous terrain	N.H in level terrain					
					P.M. in level terrain						
		3	60 50 40	N		N.H. in mountainous terrain		N.H. in level terrain P. in level terrain			
					P.M. in mountainous terrain			M. in level terrain			
		4	50 40 30	N				N.H.& P. in mountainous terrain			
									M. in level terrain		
								M. in mountainous terrain			
		5	40 30 20	N						M. in level terrain or mountainous terrain	1-lane road
	4 (Urban)	1	60	P,N	N.H.						
					P.M.						
		2	60 50 40	N				N.H.			
							P.M.				
		3	50 40 30	N				P.			
								M.			
		4	40 30 20	N						M.	1-lane road

Note : N.E. : National Expressway
E. : Expressway other than National Expressway
N.H. : National Highway P. : Prefectural Road
P.M. : Prefectural or Municipal Road M. : Municipal Road

F : Full control of acces
P : Partial control of access
N : Non control of access

Source : Explanation and Application of the Road Structure Ordinance, 1983 (Japan Road Association)

Appendix 1.2.2

AASHTO - A Policy on Geometric Design of Highways and Streets, 1984

Functional Highway Systems in Urbanized Area

1) Urban Principal Arterial System
2) Urban Minor Arterial System
3) Urban Collector Street System
4) Urban Local Street System

Appendix 1.2.3

STTR (Short Term Urban Transport Review, October, 1985)

2.1.3 Road hierarchy

1) Primary Roads
2) Secondary Roads
3) Distributor Roads
4) Access Roads

Appendix 1.2.4

DOH : Minimum Design Standards for Primary Highways (Rural)

Design Feature	Flat and Moderately Rolling	Rolling and Hilly	Mountainous
Design Speed K.p.h. (3)	80-100	60-80	50-60
Maximum Gradient % (4)	4	6	8
Right of Way m. (5)	← 60-80 →		

ETA:F/S, The Second Stage Expressway

Appendix 1.2.5

SYSTEM ADOPTED DESIGN SPEED

Category	Recommended Standard (km/h)	ETA's Standard for 1st Stage Expressway System (km/h)
Expressway, throughways	80	80
Interchange, all ramps	50	50
On/off Ramp, diagonal type	50	30 - 50
On/off Ramp, loop type	40	

Appendix 1.2.6

Design Vehicle Dimensions (AASHTO)

Design Vehicle Type	Symbol	Overall			Overhang		WB_1	WB_2	S	T	WB_3
		Weight	Width	Length	Front	Rear					
Passenger car	P	1.3	2.1	5.8	0.9	1.5	3.4				
Single unit truck	SU	4.1	2.6	9.1	1.2	1.8	6.1				
Single unit bus	BUS	4.1	2.6	12.2	2.1	2.4	7.6				
Articulated bus	A-BUS	3.2	2.6	18.3	2.6	2.9	5.5		1.2[a]	6.1[a]	
Combination trucks											
Intermediate semitrailers	WB-40	4.1	2.6	15.2	1.2	1.8	4.0	8.2			
Large semitrailer	WB-50	4.1	2.6	16.8	0.9	0.6	6.1	9.1			
"Double Bottom" semi-trailer - full-trailer	WB-60	4.1	2.6	19.8	0.6	0.9	3.0	6.1	1.2[b]	1.6[b]	6.4
Recreation vehicles											
Motor home	MH		2.4	9.1	1.2	1.8	6.1				
Car and Camper trailer	P/T		2.4	14.9	0.9	3.1	3.4	1.5	5.5		
Car and boat trailer	P/B		2.4	12.8	0.9	2.4	3.4	1.5	4.6		

a - Combined dimension 7.3 split is estimated.

b - Combined dimension 2.7, 1.2, split is estimated.

WB_1, WB_2, WB_3, are effective vehicle wheelbases.

S is the distance from the rear effective axel to the hitch point.

T is the distance from the hitch point to the lead effective axel of the following unit.

Source ; AASHTO - A POLICY on GEOMETRIC DISIGN of HIGHWAYS and STREETS 1984

Appendix 1.2.7

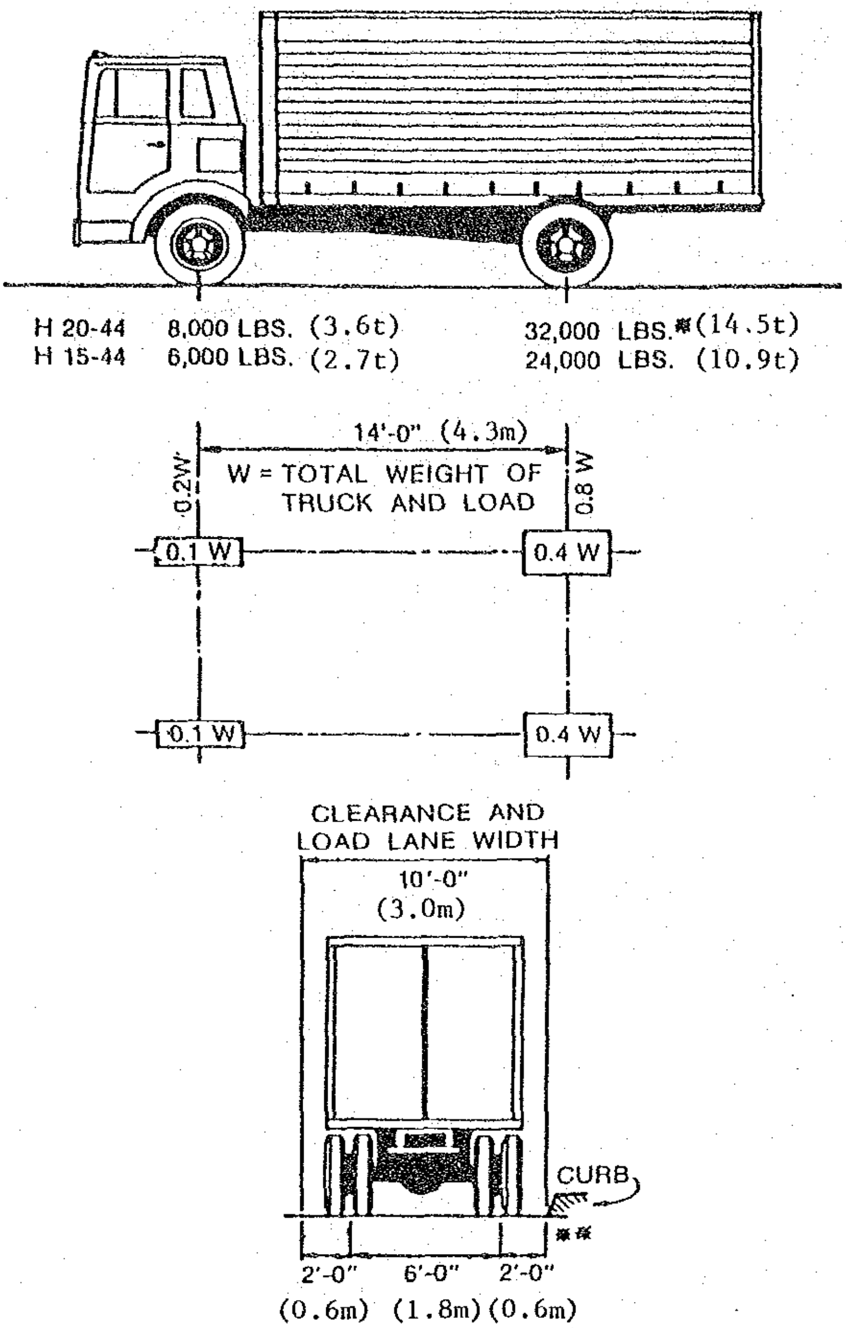
Minimum Turning Radii of Design Vehicles, (AASHTO)

Design Vehicle Type	Passenger Car	Single Unit Truck	Single Unit Bus	Articulated Bus	Semi-trailer Intermediate	Semi-trailer Combination Large	Semi-trailer Full-Trailer Combination	Motor Home	Passenger Car with Travel Trailer	Passenger Car with Boat and Trailer
Symbol	P	SU	BUS	A-BUS	WB-40	WB-50	WB-60	MH	P/T	P/B
Minimum turning radius (m)	7.3	12.8	12.8	11.6	12.2	13.7	13.7	12.8	7.3	7.3
Minimum inside radius (m)	4.7	8.7	7.1	6.4	6.1	6.0	6.9	8.7	1.7	3.0

Unit weights of materials

Material	Unit weight (kg/m^3)
Steel, cast steel and forged steel	7,850
Cast iron	7,250
Aluminum alloys	2,800
Reinforced concrete	2,500
Prestressed concrete	2,500
Concrete	2,350
Cement mortar	2,150
Timber	800
Bituminous material (for water-proofing)	1,100
Asphalt pavement	2,300

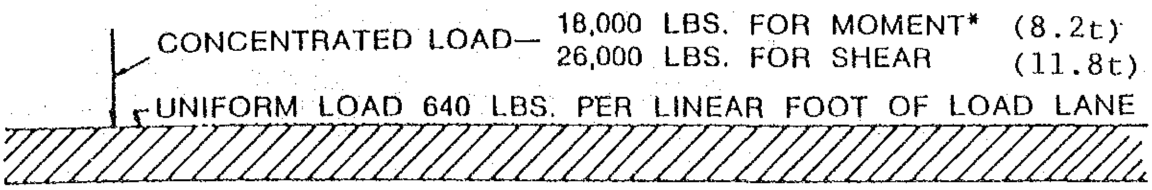
Source: Specifications for Highway Bridges
(Japan Road Association)



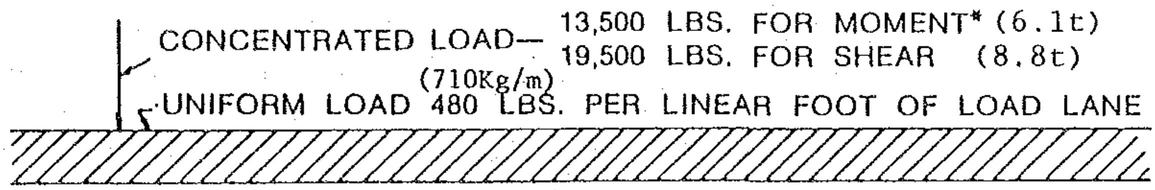
*In the design of timber floors and orthotropic steel decks (excluding transverse beams) for H 20 loading, one axle load of 24,000 pounds or two axle loads of 16,000 pounds each spaced 4 feet apart may be used, whichever produces the greater stress, instead of the 32,000-pound axle shown.

**For slab design, the center line of wheels shall be assumed to be 1 foot from face of curb. (See Article 3.24.2.)

Standard H Trucks
(Standard Specifications for Highway Bridges : AASHTO, 1983)



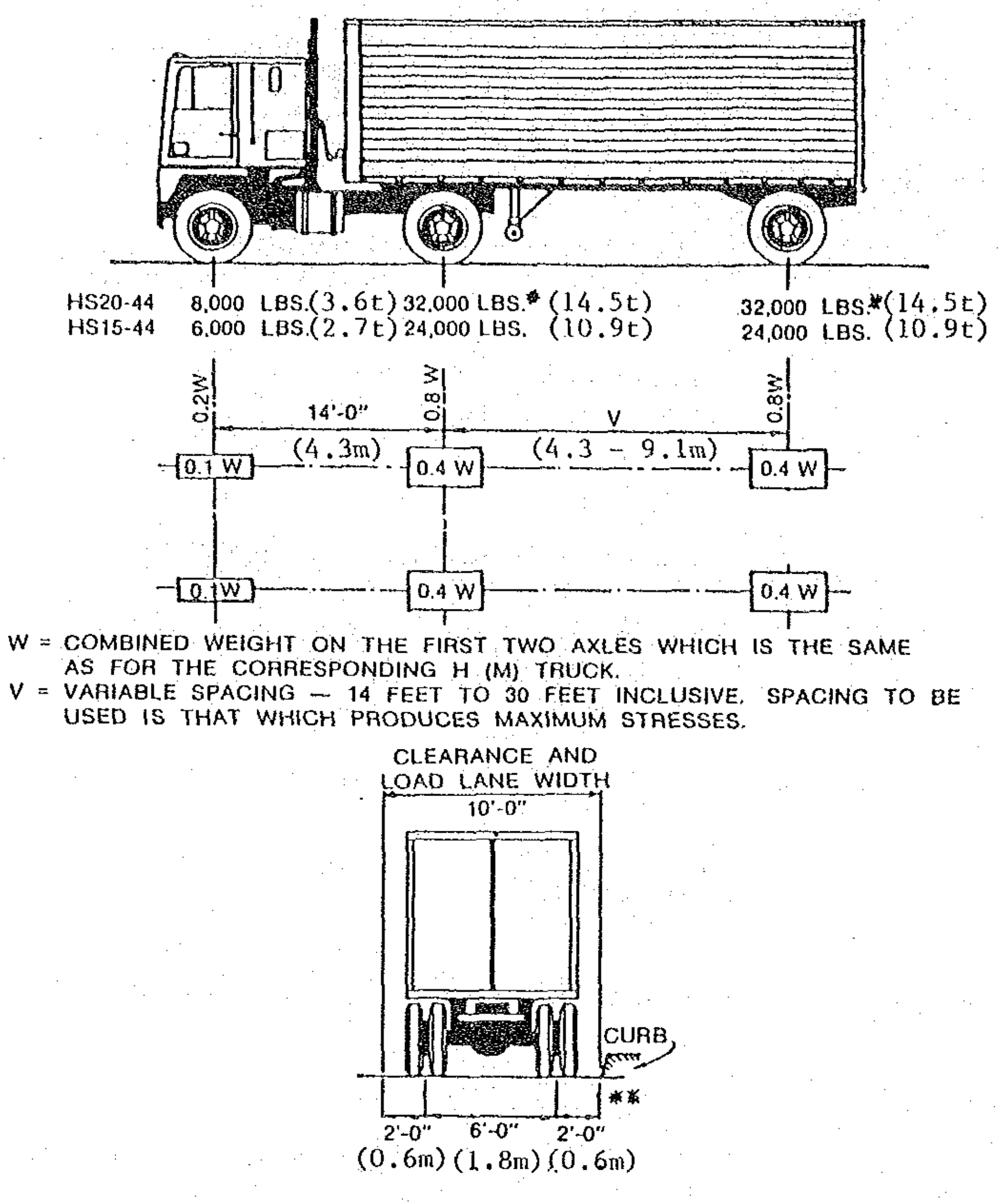
H20-44 LOADING
HS20-44 LOADING



H15-44 LOADING
HS15-44 LOADING

*For the loading of continuous spans involving lane loading refer to Article 3.11.3 which provides for an additional concentrated load.

Lane Loading
(Standard Specifications for Highway Bridges : AASHTO, 1983)



*In the design of timber floors and orthotropic steel decks (excluding transverse beams) for HS 20 loading, one axle load of 24,000 pounds or two axle loads of 16,000 pounds each, spaced 4 feet apart may be used, whichever produces the greater stress, instead of the 32,000-pound axle shown.

**For slab design, the center line of wheels shall be assumed to be 1 foot from face of curb. (See Article 3.24.2).

Standard HS Trucks

(Standard Specifications for Highway Bridges: AASHTO, 1983)

Skidding on Pavement Marking

1. Skid resistance on pavement markings

Coefficients of skid resistance on several markings were tested in Japan in 1975 and 1976, as shown in Figures 1 and 2. Figure 1 shows test results just after markings were painted. Figure 2 shows test results, 17 months after markings were painted. Following Figure 1 skid resistance coefficient, just after painting, at 40 - 60 km/h speed, on cold painted markings without beads is 0.22 and with beads in 0.28. On deposited marking it is 0.21 without beads and 0.35 with beads. On the other hand, ordinary cement concrete pavement is 0.55 and sand mixed marking is 0.56, and sand spreaded marking is 0.72. Skid resistance coefficient on cold painting is very small. Deposited marking with beads is slightly higher, but compared with ordinal cement concrete pavement, it is clear that the surface of markings is very much slippery. Following Figure 2, 17 months after painting, condition of skid resistance is almost same.

As the conclusion, coefficient of skid resistance on cold painting is very small, and on deposited painting is slightly higher but compared to ordinal pavement surface, it is half or 2/3. These show that the surface of marking is very slippery at wat condition.

2. Counter measures for slipperyness of markings

2.1 Counter measure for marking materials

From the view point of slipperyness, deposited painting is better than cold painting. If possible, sand (abrasive material such as silica sand, etc.) mixed marking will be recommendable but it is more expensive.

2.2 Counter measure for marking system

Marking should be painted for traffic safety. But from the view point of slipperyneww, very wide marking must not be used, especially where vehicle will run in curved way. For example, as for zebra marking at pedestrian crossing in intersection, wide marking more than 50 cm should not be used.

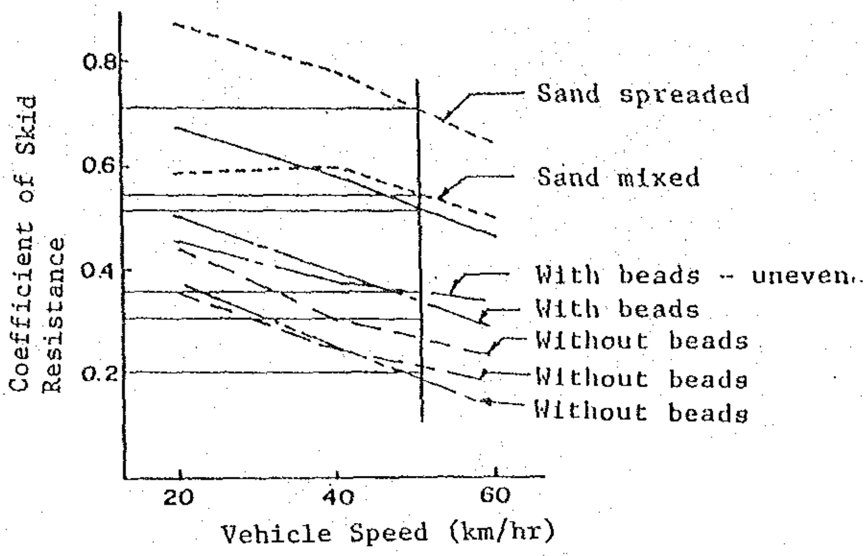


Figure 1 Coefficient of Skid Resistance on Pavement Markings Just After Painting

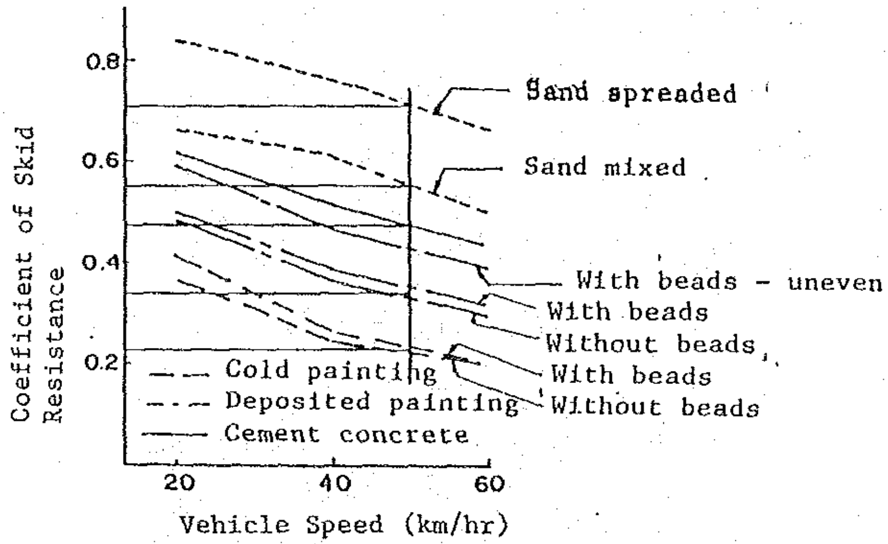


Figure 2 Coefficient of Skid Resistance on Pavement Markings 17 Months After Painting

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