# LITERATURE REVIEW

Road engineering involves the specification of design standards and the actual engineering design, field layout, construction and maintenance of forest roads and subsidiary structures such as bridges and culverts.

## 1. Forest Roads

Road construction is one of the most essential things which have been included in National Socio – Economic Development Plan in every tropical developing countries (Odier *et.al*., 1971; FAO, 1977). As a matter of fact, road facilitates people to travel from place to place. Furthermore, roads show the civilizations and indicate the economic status of the country (Odier *et.al*., 1971; Highway Department, 1978; Keller and Sherar, 2003). Thus, roads are built a thousand kilometers every year in developing countries. In Thailand, there are several organizations responsible for the constructions of road. However, many parts of the country nowadays are still lack of road for transportation. Each year the Royal Forest Department (RFD) builds approximately 400 kilometers of forest road, which cost more than 2 millions US dollars totally (Royal Forest Department [RFD], 1983; Puangchit, 1986; RFD, 2001). This is not included the road construction cost built by private section. So, every year the Thai Government spends a large amount of money in constructing roads in order to develop the country efficiently. Therefore a good road planning and design are needed.

### 1.1 The Essential of Forest Roads

Forest roads in developing countries are not built solely under the pressure of traffic or harvesting operations, but in order to meet a particular demand of integrated development actions. Forest roads provide possibilities to increase the accessibility of new forest areas, to apply new technology and civilization to the rural people. They are needed in reforestation, in watershed management and erosion control, and for recreational purposes. In the production system, forest roads reduce the capital costs and result to a low price products (Oregon State university, 1970; Odier *et.al*., 1971; Irwin and Brooks, 2000; Keller and Sherar, 2003). By mean of forest roads, the planning and management of national resources can be done very effectively.

The economy of developing countries is very sensitive to road Investments, which rapidly create entirely new trade. The construction or improvement of the forest road is rightly regarded as one of the most effective ways of promoting economic development of a country. While economic adaptation to development needs is one necessity, another is the adaptation of techniques in the light of the special conditions encountered, such as climate, geology, and nature of the soils, intensity and nature of traffic, structure and management of construction and maintenance services. Of forest roads in developing countries have a special character. Thus, the forest roads must be designed to meet the needs in order to ensure the best return for the efforts made.

### 1.2 Forest Road Terminology

In forest roads planning and design, it is necessary to understand the words road and way (Highway Department, 1978, 1982; Hoapetch, 1983; Thongshim, 1983). The overall road engineering terminology was shown in the Appendix D.

Road is the transportation route within district, province, community, or village, i.e. forest road.

Way means the transportation route between town to town, district to district or village to village, i.e. highway, and expressway.

Forest road can also be called forest way which means path or route path use for pulling logs as well as cart way and inspection way (Puangchit, 1986; RFD, 2001;).

### 1.3 Forest Road Classification

Most of the forest roads are used as a temporary way which was built by cutting and clearing trees to make path. In forestry work, roads can be broadly divided into 5 types.

1.3.1 Temporary Roads. Temporary road is the road that used for specific purpose for a certain time, i. e. for logging or hauling rock, or mine out of the forest. Generally, the concessionaires will construct this road under the control of the RFD. The RFD may do the road contraction in some cases, in order to lessen the disturbance of the nature.

Temporary roads are usually constructed in low land, mainly for logging purpose. The performance life of these types of roads are between 1-3 years. Since the road is just for temporary used, it is therefore recommended to try to build a cheap road, by avoid Access road. Access roads are permanent transportation links between forests and public roads. It is mainly for transporting from villages to forests, and from forests to towns or markets nearby. Access roads are usually constructed to be all – weather roads. They are trafficable for most of the year and are intended to be permanent roads.

1.3.2 Main Road. Main roads are usually laid in a straight short line, since it is a common roads with heavy traffic. Main road must have a good drainage. When the natural ground is soft, the surface should be covered stone to ease the transportation. The government organizations which responsible for this type .of road are : Highway Department, Civil Works Department or Provincial Administration Office. If the distance between main road and forest are very far, it is necessary for the Royal Forest Department to construct the separate road for forestry purpose directly. The width of forest road is about 5-7 meters, depends on the important of the road and amount of traffic (RFD, 2001). The width of crushed stone surface is 5 meters, and road shoulders are compacted with laterite soil.

1.3.3 Forest Cart Roads. This road is mainly for cart, and it should be used as sub main road. It is better to cover the road with laterite soil or sand. The width of this road is about 3-4 meters.

In the area where cart is not commonly used, people use animals such as buffaloes and cows to pull wood and bamboo directly. This type of road is called dragging road. If forest cart roads are available, the dragging roads are not recommended to be used, because rain in the rainy season will erode the road.

1.3.4 Bridle Paths. Bridle paths are constructed to be a short cut way from place to place. This road is mainly for horses, elephants, cows or other animals, and normally used for transportation where the construction cost of forest cart road is too high. Bridle paths will save the forest cart road from damaging by the animal trampling in the rainy season. The width of this road is about 2.5 meters.

1.3.5 Inspection Paths. This is the narrow road about l meter width, just enough for men to walk. The road is done by clearing the path, trees and branches within 75 centimeters distance must be cut away. The inspection path is normally used for inspecting inside forests or plantations, and is moreover used as a fire break. In case of the plantation, the inspection path must be well – planned already after the establishment. The principal of inspection paths is that it must be done in the cheapest way. The path must be connected to each part of the area, as well as the mountain ridges. The inspection paths should be included in the forest management plans, and clearly indicated in the map.

## 1.4 Social and Economic Aspects in Forest Road Planning

As the cost for road construction per kilometer is generally rather high, good planning must be considered with special care. Benefits and investments must be compared particularly. Although benefits can not be expected directly from the road construction, the necessity of the road must be however considered. If it is necessary to build the road, the next consideration is the types of road, the next consideration is the types of the roads which is needed, in order to define the standard of the road to be constructed. And finally the construction cost and expense must be considered. If the government can not fully support the construction, the road is also possible to build by the community or those who get benefits from the road (Odier *et.al.*, 1971; Highway Department, 1978; RFD, 2001).

One of the most important things that should always be kept in mind is the impact on the environment and the ecosystem where the road passed. Generally, road harm the nature by leading people and heavy machine to the forest (Cropper *et.al.*, 1997; Forman and Alexander, 1998). Careless instruction can cause great erosion that will generate higher expense than expected. Furthermore, it can also generate the serious accident on the road.

Economic analysis of the forest road construction can be done by analyzing the total expenses needed in the construction, which can be divided to; capital, maintenance costs, and administrative costs. The best road construction is the road that gives the lowest total cost, which include the best planning with the lowest cost for all data needed.

Although, forest roads are just a simple roads which are not so important to the development of the country. However, forest road can provide both direct and indirect benefits to the society, economics and stability of the country (Odier *et.al.*, 1971; RFD, 2001). which can be categorized as:

1.4.1 Increase production with low cost.
1.4.2 Natural resources can be used efficiently.
1.4.3 Provide rural development, i.e. leading civilization from city to village.
1.4.4 Provide better education, and public health.
1.4.5 Promote tourism.
1.4.6 Increase the stability of the country.

1.4.7 It is a primary road to be developed to a high standard road in the future.

## 1.5 Route Location

Route location is generally indicated road usage, as well as the investment and maintenance cost (Odier *et.al*., 1971; FAO, 1977). The wrong decision in route location will cause higher costs in construction and maintenance. Poor route locating also make it difficult to improve the road, and in that case, new construction route is probably cheaper and more economical.

First of all, it is necessary to find the best location for the road which can connect to every desired points. Several trial lines must be selected and comparing. The best route location is the route that gives the lowest investment with the lowest maintenance cost, and the most beneficial one.

The method of route locating (Yarwudhi, 2001) were listed as follows:

1.5.1 Specify Type and Standard of Forest Roads. Specify the type and the standard of the road which will be constructed, i.e. inspection – paths, dragging roads, forest cart roads, laterite soil or crushed stone road, single surface treatment, or double surface treatment. Then, define the standard and maximum gradient of the road.

Maximum gradient is the proportion between the different of height and horizontal distance, which can be indicated in degree, ratio, or percent; i.e. 3 degree, 1/10, or 5 %. Maximum gradient is the controlling factor for maximum loading of road. For instance, if the maximum loading of road in the horizontal is 6 tons, the maximum loading of road is only 4 and 2 tons at 5% and 10 % of gradient respectively. This gradient percentage is called percent of grade in forest road engineering. Generally, percent of grade in forest road engineering. Generally, percent of grade in forest road is not exceeded 12%. Exceptionally in the mountainous area the percent of grade is allowed to 16 % as maximum. If the percent of grade is high, special drainage must be applied to minimize the erosion.

Maximum gradients used in forest roads are:

- 6 % in flat terrain
- 10 % in hilly terrain
- 12 % in mountainous terrain
- 16 % in very steep terrain or watershed area

1.5.2 Site Examination. After types and gradients of the roads have been defined, the next step is site examining. Site examining is actually the primary selection for the best route, by avoiding the steep slope and the deep valley if possible. If topographic map or aerial photography is available, the survey will then be more convenient. All the details about construction site must be recorded accurately.

1.5.3 Obligatory Points. After careful site examining, the following step is to mark the obligatory points where the road must pass; i.e. villages, market places, substations, or nurseries. If is not necessary that road can be constructed through all the marked points due to the maximum gradient. If is there fore recommended not to mark too many obligatory points, since it increase the construction cost.

1.5.4 Deviations. In some cases, it is necessary to build the deviation roads to avoid obstacles, such as valleys, ponds, cliffs, or mountains, in order to save the construction costs. Deviations which increase the distance of the road less than 15 times of elevation is considered to be economic. For example to construct the deviation road of 150 m is better than construct the elevated road of 10 m. Moreover. The deviations can also lead to the view points, camping sites or some interesting places. The deviation roads should be constructed to avoid bridge construction or to get near to source of construction materials, such as rocks, and laterite soil site.

1.5.5 Hilly Terrain Route Alignment. The principles of hilly terrain route alignment are:

1.5.5.1 The Main Objectives of the Road. For instance, if the roads are between substations, the shortest ways must be considered. On the other hand, the inspection path must be deviated to every parts of the area.

1.5.5.2 Topographies. In the flat terrain, there can be several choices of the alignment, while in the mountainous or hilly terrains, the alignment are limited. Try to avoid the zigzag road if it is possible, since zig-zag road can easily cause accident. Beware of landslide in steep slope area. Alignment of the road should be done from high to low elevation. In wet area, the alignment should lay towards the south or southwest, so that the road is easily dried by sunlight. Big trees should be left for shedding in some cases.

1.5.5.3 Marketplaces or Community Areas. Avoid aligning the road straight through the markets or communities, by making the small separate roads instead.

1.5.5.4 Existing Roads. Use the existing road as the sub main road or part of the new road to save the construction cost. However, the after – effected must be carefully considered.

1.5.5.5 Construction Materials. Alignment of the road should be close to the source of construction materials, such as stone quarry and laterite soil quarry, so that it is easy to utilize.

1.5.5.6 Bridge Construction. In case that bridge is needed, both ends must be flattened at least 20 meters long, to minimized the damages of the bridge by vehicles. Avoiding curve on the bridge because it easily cause accident. On the hillside, it is recommend that cutting into the hill rather than filling the hillside, since it easily causes erosion and it is not so economic.

1.5.6 Flat Terrain Route Alignment. In flat terrain, the alignment must be as straight as possible. The road should be higher than maximum water level. The side ditches should be constructed parallel to the road and drained to the stream or water way. When the road lay across the stream, it is important to choose the site where strong foundation can be placed. If the horizontal curve is necessary, the radius must be long enough to make uneasy turn. Avoid alignment through agricultural area, low – land, muddy area or across the stream. Trees along the roadside must be cut away. The width of the roadsides must be about an average of tree height. However, in the area where heavy storm is common, the distance of roadside should be 1.5 times of tree height

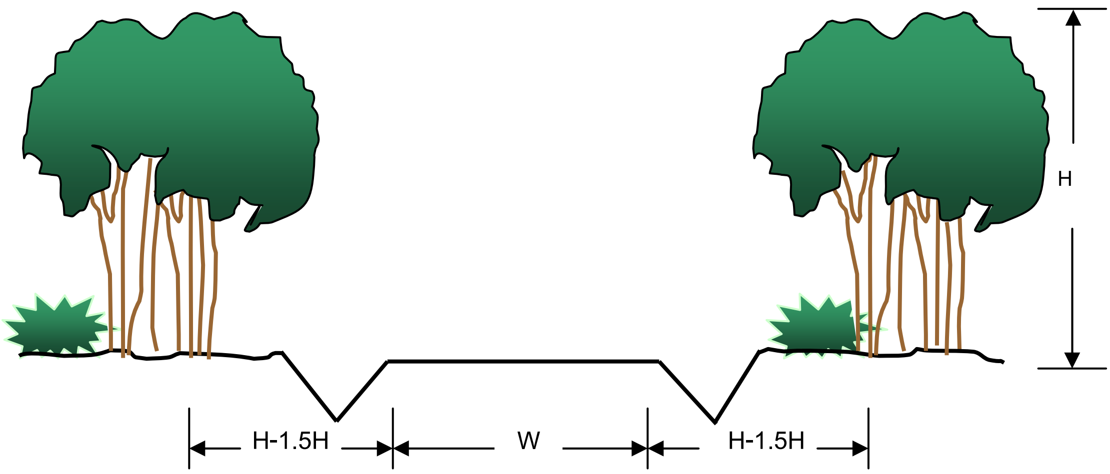



Figure 1 Road alignment in rainy tropical forest area.
Source: Odier *et.al.*(1971)

## 1.6 Design of Forest Roads

The layout and design of forest roads have a direct influence on its construction cost, and maintenance cost. It may increase or decrease road accidents and control the performance and durability of the road. Road design is how to define right of way, road grades, curvatures, and pavement thickness by considered traffic volume, type of vehicle, safety, comfortable and worthwhile. The procedure can be divided into planning, route surveying, designing and construction. The first two topics were already mentioned in the planning of forest road construction, the last two topics will be described here on.

1.6.1 Geometric Design As known that road design is how to specify width, surface thickness, slope, route alignment, vertical and horizontal curve of road for the most useful of road users. It is necessary for the designer to know the vehicle speed, nature of dynamics of vehicle, human reaction time, centrifugal force, curve lay out and nature of surface construction material. All these factors will be discussed in the following topic.

1.6.1.1 Control Factors of Road Design. In designing road, the following factors must be taken into account.

(1) Topographic Conditions. Design standard of the road varies to topographic characteristics such as flat or rolling conditions, hilly or mountainous conditions.

(2) Soils, Drainage and Climatic Conditions. Considering of soil properties, detachment characteristics, and drainage condition; as well as temperature and rainfall intensity of the area.

(3) Land Use Features. Whether the surroundings are forest land, watershed area, plantation, farm, garden, devastated forest, arboretum or animal grassland.

(4) Economics Factors. The possibility of investment and community status must be considered.

(5) Environmental Factors. Side effects to ecosystem around the road are very important for the design steps.

1.6.1.2 Vehicles and Design Speed. In constructing a road, the designer must have all data about the traffic volume, type of vehicle, wheel load for each type of expecting vehicles which going to use that route. Designer must keep in mind that the road will be constructed for heavy truck or personal car. Normally, forest roads use the standard of 18 tons heavy truck as the designing criteria. The design speed is generally the maximum speed that the vehicles can run safely on the road under the certain condition. The design criteria depend on area characteristics, transportation conditions, climatic conditions and the classifications of road. The design speed of forest road at the present are as follow:

| **Topographic conditions** | **Design speed** (km/hr) |
|---|---|
| Flat terrain | 40 - 60 |
| Hilly terrain | 35 - 40 |
| Mountainous terrain | 25 - 35 |

1.6.1.3 Horizontal Alignment. Driving speed relates very much to curve alignment, drivers can control vehicles to run through road curve with safety by one maximum speed. If exceed this speed, they will outrun from the road. Curve lay out concerning to curve design computation, thus the essential of curve design is not only for safety of drivers, but also increase the efficiency of the road and decrease maintenance cost. The road curve can be circular, spiral or mixed curves. Curve design is to define radius of curve for corresponding design speed. Generally, standard of designed curve specify minimum safety curve. Minimum turning radius for circular curve can specify by following formula:

$$R = \frac{V^2}{127.4(e+f)} \qquad \text{. . . . . . . . . . . . . . . . (1)}$$

Where: R = safety minimum turning radius (m)

V = turning speed (km/hr)

e = Super elevation rate (m/m)

maximum e = 0.10 m/m

f = friction coefficient factor between tire and traffic surface. In laterite soil surface road with rainy and slippery condition f = 0.06

R values used in curve design for forest road are shown in Table 1 Road super-elevation. Normally, road surface will be constructed as slope for draining. Slope surface depends on construction material, i.e. 4% for laterite soil. Road surface inclines from center line to the sides, while the surface of turning curve inclines from side to side, because of the resistance to centrifugal force.

Table 1 Forest road design configuration

| Description | Topographic characteristics | | | Remarks |
|---|---|---|---|---|
| | Flat | Hilly | Mountain | |
| Min. embankment height above HWL (m) | 0.30 – 0.50 | - | - | 5 years cycles |
| Design speed (km/hr) | 40 – 60 | 35 – 40 | 25 – 35 | |
| Min. radius (m) | 75 – 110 | 40 – 75 | 25 – 35 | |
| Max. gradient % | 8 | 10 | 12 | max. allowable up to 16% in watershed area |
| Surfacing thickness (m) | | | | |
| a. laterite or graveled | 0.20 | 0.20 | 0.20 | Vary to |
| b. surface treatment | 0.025 – 0.03 | 0.025 – 0.03 | 0.03 – 0.05 | CBR value |
| Shoulder width (m) | | | | |
| a. laterite | None | None | None | |
| b. surface treatment | 0.50 | 0.50 | 0.50 | |
| Carriageway width (m) | | | | |
| a. traffic < 50 vpd | 4.50 | 4.50 | 3.50 | |
| b. traffic < 100 vpd | 4.50 – 5.50 | 4.50 – 5.00 | 3.50 – 4.50 | |
| c. traffic > 100 vpd | 6.00 – 8.00 | 5.00 – 6.00 | 4.50 – 5.00 | |
| Right – of – way (m) | 20 | 20 | 15 – 20 | |
| Non passing sight distance (m) | 110 | 30 | 30 | |
| Super-elevation rate ( m/m ) | 0.10 | 0.10 | 0.10 | |

Table 1 (Continued)

| Description | Topographic characteristics | | | Remarks |
|---|---|---|---|---|
| | Flat | Hilly | Mountain | |
| Widening (m) | 1.0 | 1.0 | 1.0 | |
| Crown slope (%) | | | | |
| a. laterite | 4 | 4 | 4 | |
| b. surface treatment | 3 | 3 | 3 | |

Sources: Odier *et.al*. (1971); Royal Forest Department (1983)

Inclining of traffic surface called super-elevation which can be defined by height per horizontal length i.e. S.E. = 0.10 m/m means to elevating the surface up to 10 cm per 100 cm surface width.

In addition, road consists of horizontal curve and vertical curve up and down due to topographic condition. Main purpose of vertical curve design is to provide adequate length for safety in case of sudden stop at different speed. Good curve lay out must correlate with horizontal curve lay out. Putting two types of curve at the same place should be avoided, since many accidents can occur easily. Vertical curve can be defined into two types, crest curve and sag curve. Vertical curve design should consider road elevation which must be higher than flood level, and adequate drainages. Avoid surplus excavation, and fill, in order to save construction cost. Length of vertical curve can be defined by the relationship between sight distance, various of grade, height of obstacle and distance from road surface to eyesight. In crest vertical curve, stopping sight distance is shown in Figure 2, and passing sight distance is shown in Figure 3.

# STOPPING SIGHT DISTANCE ON CREST VERTICAL CURVES

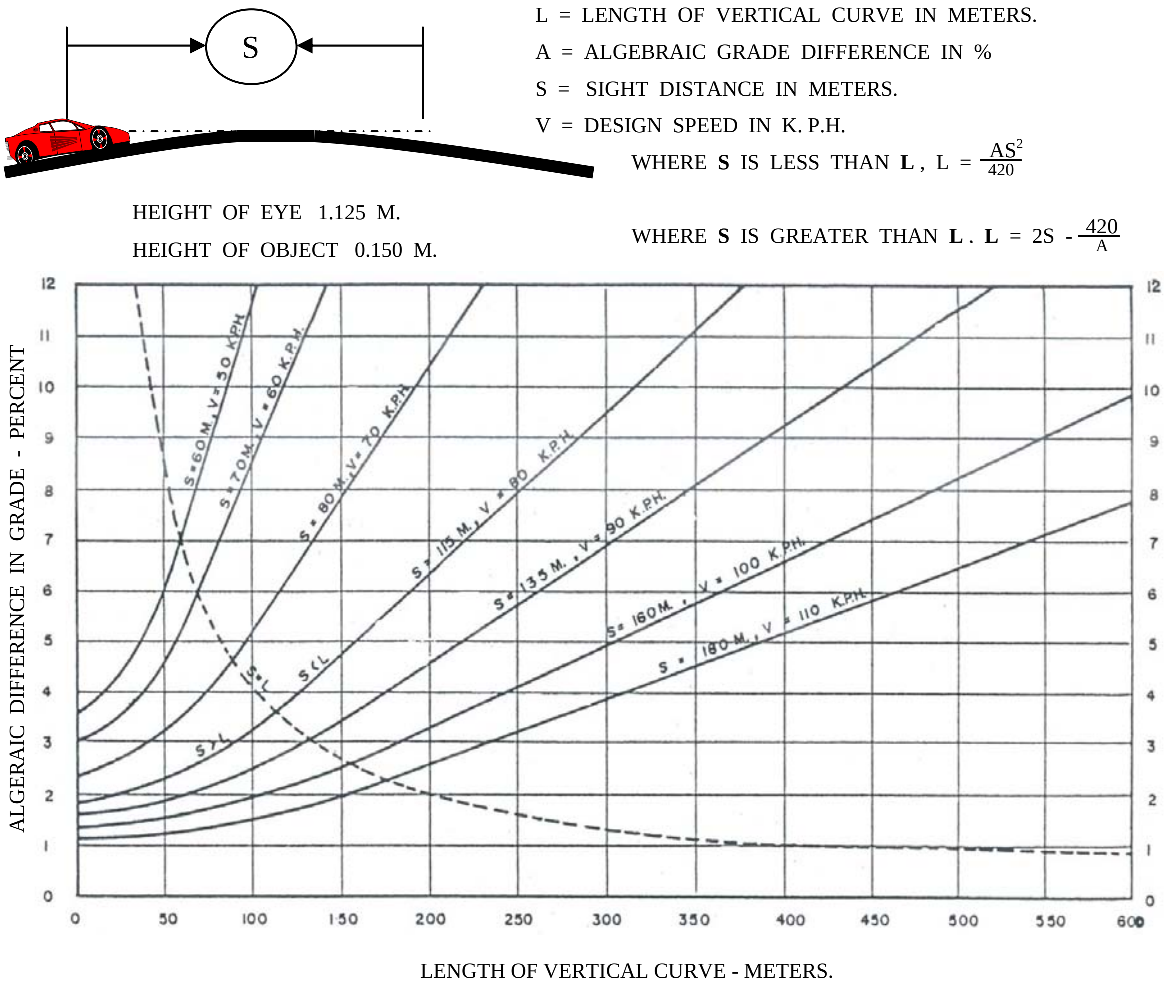
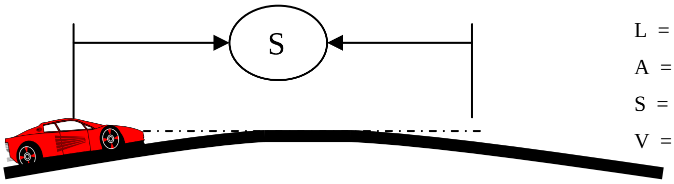



Figure 2 Design chart for stopping sight distance of crest vertical curve.

Sources: Trapsukmuuay (1982); Hoapetch (1983)

# PASSING SIGHT DISTANCE ON CREST VERTICAL CURVES




HEIGHT OF EYE 1.125 M. ABOVE PAVEMENT

HEIGHT OF OBJECT 1.35 M.

L = CURVE LENGTH IN METERS.

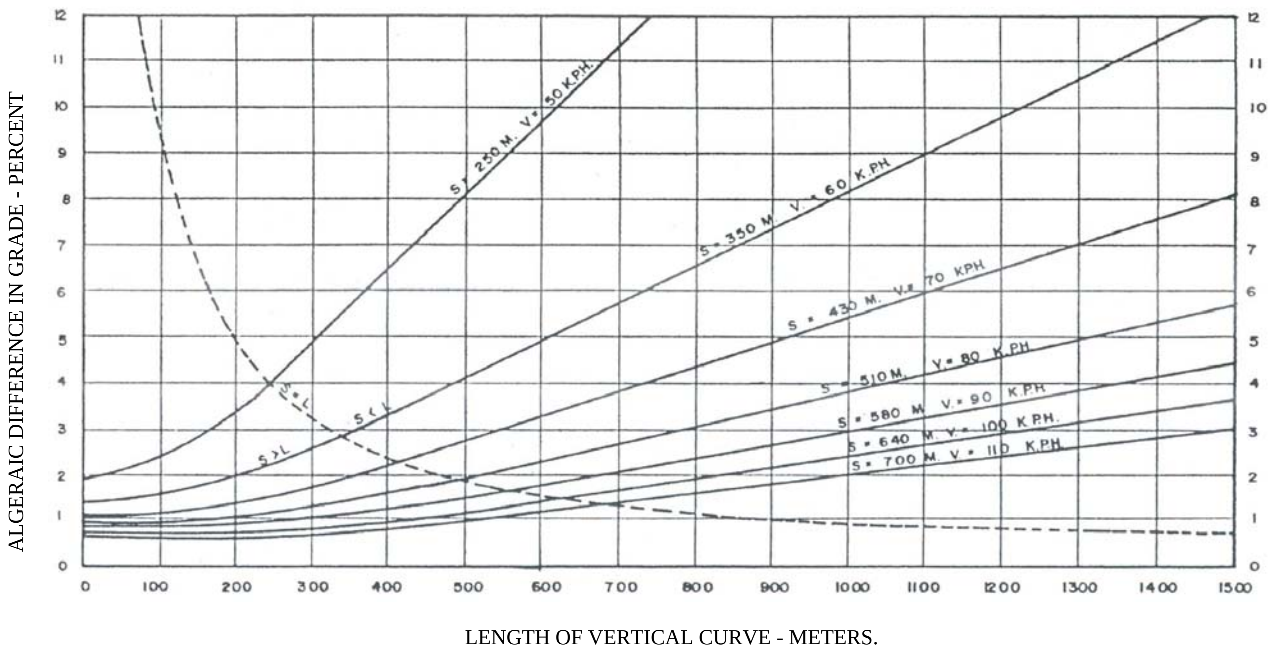
A = ALGEBRAIC GRADE DIFFERENCE IN %

S = SIGHT DISTANCE IN METERS.

V = DESIGN SPEED IN K. P.H.

WHERE **S** IS LESS THAN **L** , **L** = $\frac{AS^2}{988}$

WHERE **S** IS GREATER THAN **L** , **L** = $2S - \frac{988}{A}$




<u>Figure 3</u> Design chart for passing sight distance of crest vertical curve.

Sources: Trapsukmuuay (1982); Hoapetch (1983)

Another design is sag vertical curve, the purpose of this curve is to provide adequate stopping distance with safe in nighttime when the driver usually see through the front beams or headlight. This is the most dangerous case for sag curve. Headlight sight distance can be defined by chart in Figure 4.

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# HEADLIGHT SIGHT DISTANCE ON SAG VERTICAL CURVES

L = CURVE LENGTH OF IN METERS.

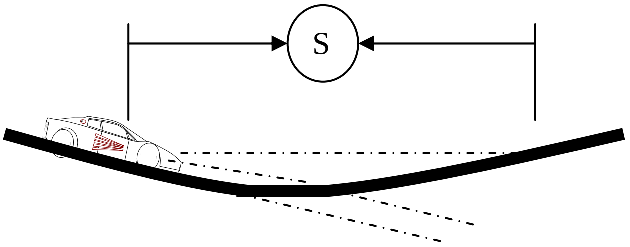
A = ALGEBRAIC GRADE DIFFERENCE IN %

S = SIGHT DISTANCE IN METERS.

V = DESIGN SPEED IN K. P.H.

WHERE **S** < **L** , **L** = $\frac{AS^2}{152+3.5S}$

WHERE **S** IS GREATER THAN **L** , **L** = $\frac{152+3.5^S}{A}$



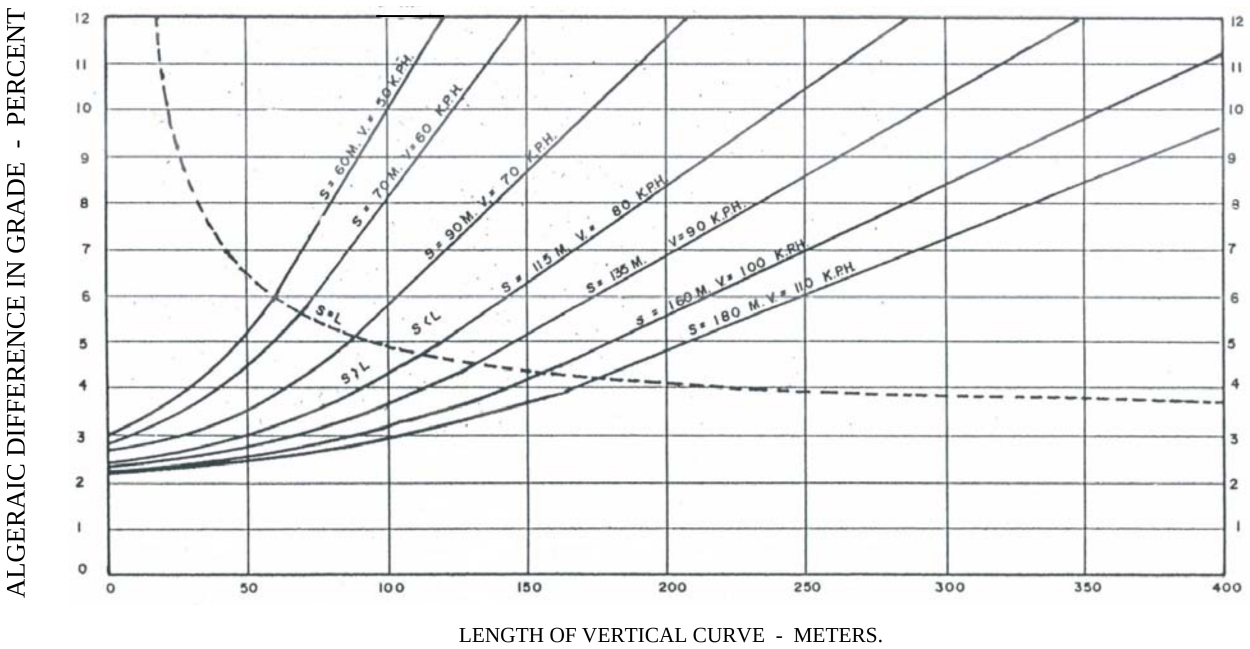




Figure 4 Design chart of headlight sight distance for sag curve.

Sources: Trapsukmuuay (1982); Hoapetch (1983)

1.6.2 Forest Road Cross Section Road cross section should be designed by classification of the road and correlation with road width. Road structural element terms of road cross – section were shown on Figure 5.

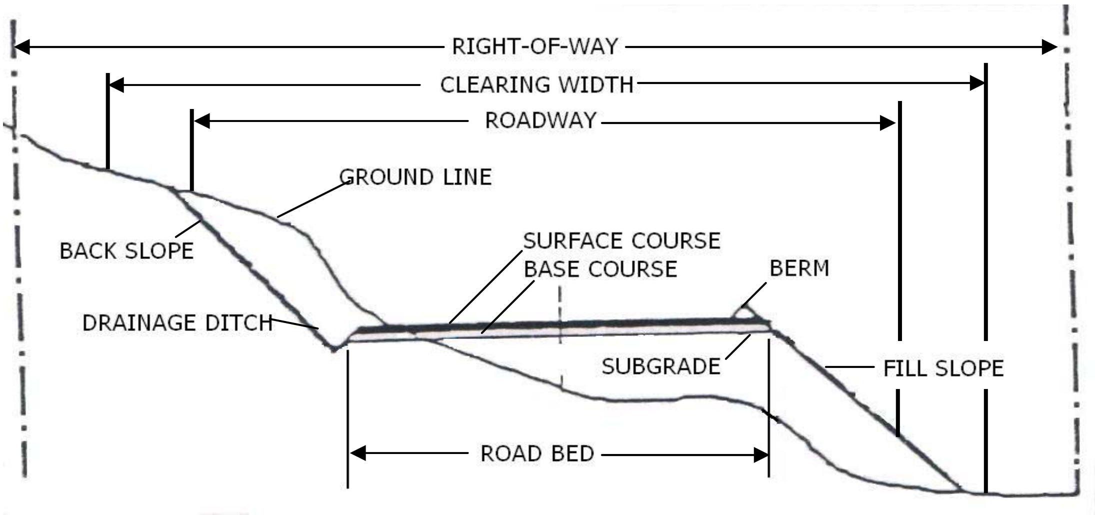



Figure 5 Road structural elements.
Source: Schiess *et.al*. (1982)

1.6.2.1 Right of way. Road must have an adequate right of way for traffic surface expansion in the future. Forest road need 10 – 20 meters at each side of the road to be right of way.

1.6.2.2 Carriageway width. Depending on designed speed, traffic volume and type of the road. Forest road specify 2 types of carriageway width, 4.50 meters for sub main road and 6.0 meters for main road.

1.6.2.3 Formation width. Formation width is the summation of carriageway and road shoulders.

1.6.2.4 Super elevation rate and road widening. To reduce centrifugal force while driving through curve.

1.6.2.5 Drainage. For rapidly drain of traffic surface and always keep traffic surface dry.

1.6.3 Forest road Drainage Structures Drainage is the most important factor in forest road performance. The ability of road drainage indicate road efficiency and performance period. Generally forest road damages caused by drainage failure are up to 90%, e.g. inadequate settlement of earth – filled, side – slope failure, road surface erosion and road surface deformation caused by poor material, settlement and failure of road – bridges, road erosion around culvert put in flooding. Those damages make higher annual repairing cost, and are sometime higher than construction cost.

Types of water which must be drained out from forest road are;

1.6.3.1 Surface Water. Surface runoff from rain must be drained by side ditches, culvert and crown slope. The 4% crown slope is for liberated surface drain.

1.6.3.2 Under Ground or Seepage Water. Upraise water caused by under ground water pressure or capillary, can damage road embankment. The economical way to prevent this type of water is to provide sand drain, sand interceptor wall or perforated pipe from embankment.

1.6.3.3 Side Ditches. Small opened channel cut beside embankment for interception and drained water, preventing flood over embankment of water upraise near top level of embankment. Side ditches can be in shape of trapezoidal, V – shape or U – shape, depends on topographic conditions and volume of drained water. V – shape side ditch easily failed and shall owed, so it is not generally used. In case of high slope, steep side ditch slope, cause high velocity of water running in side ditch and cause high erosion. Thus the protection must be provided by:

- Sodding. Grass root generally hold soil particle and reduce water velocity to low detach.
- Lining. Lining ditch with concrete, asphalt or mortar rock riprap to protect earth ditch which is natural soil from water erosion.
- Check dams. Construct a small wall or wire in ditch channel to reduce water speed

1.6.3.4 Design of check dams length. Velocity of water inside ditch is the cause of erosion, therefore the controlling of water velocity can lessen erosion. check dam spacing can be calculated by this formula

$$V = \sqrt{2gh} \qquad \text{……………………………..…(2)}$$

Therefore:

$$L = \frac{100\ h}{S} \qquad \text{or} \qquad h = \frac{SL}{100}$$

Substitute in (2) then $$V = 2g\sqrt{2g\frac{SL}{100}}$$

$$L = \frac{V^2}{0.02gS} = \frac{V^2}{0.196S}$$

where: V = water velocity m/sec

g = gravity acceleration = 9.81 $m/s^2$

h = elevation different between two ditches check

S = bed slope of ditch in percent

L = distance between two ditches check in meter

1.6.3.5 Site Inspection for Drainage Structures Design. Topographic data around water way must be investigated to collect data for structural design. The following site detail list must be included.

(1) Cross sectional surveying in road way center line that intersect with the water way.

(2) Elevation surveying upstream and downstream of water way from intersection point.

(3) Measuring of skew angle of road way and water way for pier design without obstruction to running water.

(4) Others data surveying e.g. average rainfall, slope, watershed area, characteristics and type of plant covering in that area, etc.

1.6.3.6 Measurement of current water velocity in water way. Current water velocity can be measured not only by special device but also by simple type of set up device as shown in Figure 6.

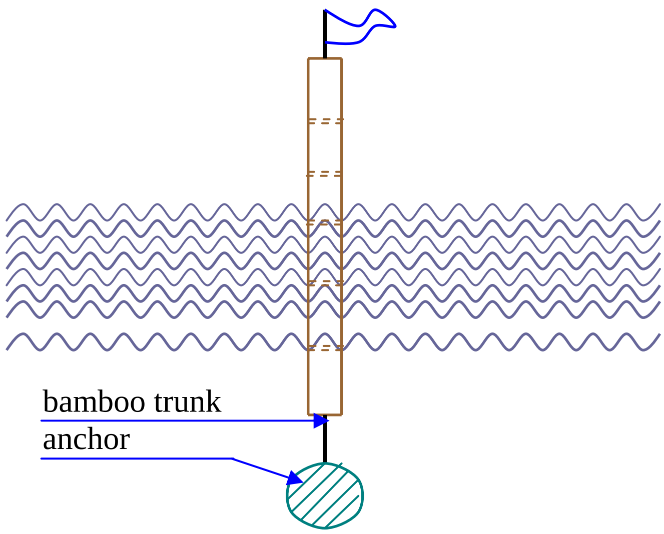



Figure 6 A simple device for measuring water current.

Sources: Odier *et.al*. (1971); Puangchit (1986)

The principle is that floating the device in the running water from one point to another point and measure distance between two points. Record the observation floating time of the device between two points, average current velocity can be calculated.

1.6.3.7 Calculation of water drainage volume. Use the formula below to compute volume of running water flowing into road embankment to find the optimum size of drainage structure that will not damage the embankment. Drainage structure can be reinforced concrete circular pipe, box culvert, bridges, etc.

Equation for water volume calculation

$$Q = 0.278\ C\ I\ A \quad \text{……………………………( 3 )}$$

where: Q = runoff volume or discharged ($m^3/s$)

I = rainfall intensity of the area (mm/hr)

A = catchments area ($km^2$)

C = flow factor; vary to slope characteristics of area

steep slope = 1.0 valley slope = 0.6 – 0.9

mild slope = 0.4 – 0.5 flat slope = 0.3

Knowing volume of runoff water, cross sectional area of water way drainage structure can be calculated by formula below.

$$A = Q/V \quad \text{……………………………( 4 )}$$

Where: A = sectional area of water way drainage structure ($m^2$)

V = unerodible water velocity (m/s)

Desirable max. V = 2 m/s

1.6.3.8 Type of road drainage structures. Drainage structures generally used in road construction are reinforced concrete circular pipe, reinforced concrete box culvert and reinforced concrete bridges or timber bridges.

1.6.3.9 Reinforce concrete pipe culvert (R.C.P.). There are two types of reinforce concrete circular pipe culvert of R.C. pipe, mounted type and bell type. Normal sizes in used are 40, 50, 60, 80, 100, 120, 150, cm. inside diameter and 1.00 meter long. Load resisting between 0 – 9 meters of earth fill depth from top of pipe. Deeper earth fill need special reinforced concrete design.

1.6.3.10 Box culvert. Box culvert, is sometime known as siphon, is usually in square shape of rectangular opening. The sizes of 1.2 x 1.2 m to 3.6 x 3.6 m, are most popular and easy to construct. Box culvert is good for medium water way which is not suitable for a large number of circular pipes and unreasonable to construct bridge (PCA, 1964; Punmia *et.al*., 1992; The Engineering Institute of Thailand, 1995; Keller and Sherar, 2003). Box culvert can stand earth filled weight more than 0 – 9 m height, depending on design criteria.

1.6.3.11 Reinforce concrete bridges. A large water way and transportation purposed water way which need an opening channel, is necessary for bridge construction. Timber bridge can be constructed for temporary road which will be change to R.C. bridge in future (Mckenzie, 2000; Keller and Sherar, 2003). For R.C. bridge, steel reinforcement can be normal steel for span length of 5 – 10 m. Longer span length, prestressed concrete is preferable. Span length can be allowed up to 30 – 50 meters. For span length greater than 50 m, special design is needed depending on topographic conditions.

Two types of R.C. bridge foundation are; spread footing for good natural foundation e.g. dense sand, and pile footing or caisson for soft foundation or bridge (The Engineering Institute of Thailand, 1995, 1997a).