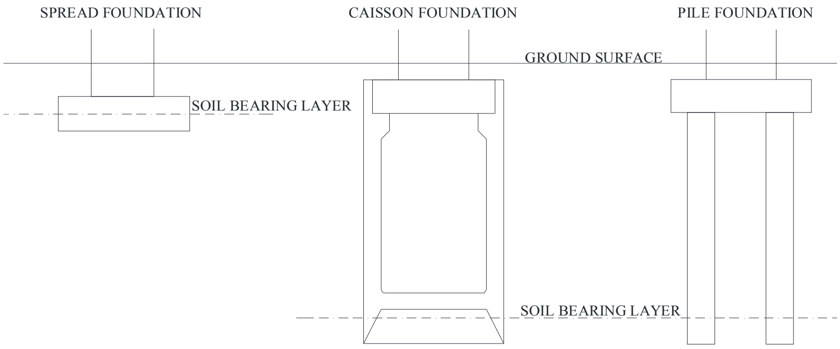


Figure 6.5.2 Outline Drawing of Foundation Type

1) **Pile foundation method**

There are various pile foundation methods.

The cast-in situ pile method is to form the pile by putting a cylindrical reinforcing bar assembled in situ into the excavated ground and subsequently pouring and solidifying concrete into the hole. The work method differs depending on the method of excavating the ground and is related to the pile length that can be constructed.

In the case of pre-fabricated piles, the length that can be constructed differs depending on the method (the embedded pile method, driving method) and the pile types (concrete pile, steel pipe pile, etc.). The pile foundation method requires that pipe placement and footing must be done in the dry condition. Namely, cofferdam construction is necessary when the piers are to be provided in the shallow-water channel. The conditions, etc. must be reviewed thoroughly beforehand when this method is to be employed.

Pre cast pile	Driving method	(Steel pipe pile, PHC pile, SC pile)
	Vibrohammer	(Steel pipe pile)
Embedded pile method	Inner excavation method	(Steel pipe, PHC pile, SC pile)
	Pre-boring pile method	(Steel pipe, PHC pile, SC pile)
	Steel pipe soil cement pile method	(Steel pipe pile)
Cast-in-place pile method	Mechanical excavation method	(All-casing method, reverse method, earth drill method)
	Manual excavation method	(Caisson foundation method)

Figure 6.5.3 Classification of the pile foundation method

2) **Caisson foundation method**

The caisson is a concrete or steel large box used for construction of an underwater structure, such as breakwater, etc., or underground structure. The caisson foundation method is widely employed for construction of the pier foundation in the port and harbor, ocean, or low-water channel of rivers.

The caisson foundation structure is characterized by three points as follows: the larger section than other foundation and large rigidity, with small displacement; horizontal resistance force and vertical bearing capacity expected to be large; and the possibility of utilizing the hollow internal space of caisson foundation as the underground structure after completion.

For the construction of river piers, in particular, this method offers a merit that there is no need of keeping the area around caisson dry cofferdam construction before putting the caisson.

The caisson method for the landside work for rivers is roughly classified into two as follows:

- Opened caisson method

The caisson main body constructed and placed on the ground is gradually sunken into the ground while the caisson internal space is manually or mechanically excavated. After arrival at the bearing stratum, the caisson main body is turned into the foundation structure.

- Pneumatic caisson method

In case that the opened caisson method is employed for the work in the soft ground or rivers where underground water is abundant, water or mud flows into the work site, making excavation extremely difficult. The pneumatic caisson method provides the chamber in the bottom of the main body beforehand. The compressed air is fed into this chamber to maintain it at high pressure, which enables excavation without allowing inflow of water and mud.

Therefore, special machine and equipment, such as the pressurization and decompression equipment, must be provided. Since the work is done under the high pressure condition, special care must be taken on the safety and health management of workers at work.

3) **Steel-pipe sheet pile (SPSP) foundation method**

Steel-pipe sheet pile consists of steel pipes connected via welded joint. The foundation with steel-pipe sheet piles connected and closed in circular or elliptical cross patterns is called the steel-pipe sheet pile foundation. This type of foundation enables economical and rational design and construction of pier foundation because steel-pipe sheet piles function as both the foundation piles and the wall for cofferdam.

- The steel-pipe sheet pile has following merits:
- Higher bending rigidity and vertical bearing force than pile foundation
- Enables construction work with higher safety and reliability under poor ground and construction conditions than the caisson method
- Enables economical foundation structure because the optimum section can be easily secured for the design load

Below shown is the comparison of merits and demerits of construction work in rivers among the pile foundation (steel pipe soil cement pile method), caisson method (opened caisson and pneumatic caisson methods), and steel-pipe sheet pile method.

(2) Foundation ground

1) **Selecting the bearing stratum**

The quality bearing stratum is the one that can support the load from the foundation. No specific description can be made on the bearing stratum because it differs depending on the importance of structure, scale of load acting on the foundation. Target stratum is as follows:

- Rock mass
- Clayey soil with the N value of 20 or more (unconfined compression strength "qu" of $0.4N/mm^2$ ($4kgf/cm^2$) or more)
- Sand and gravel strata with the N value of 30 or more

The following points must be taken into account when the bearing stratum is to be selected:

- In sand and gravel strata, due care is necessary because the N value when the gravel is hit tends to be excessively higher.

- If the stratum is considered the quality bearing stratum, the bearing capacity or settlement must be reviewed when the stratum is thin or there is a weak or compression strata exist below the bearing stratum.

2) **Considerations for the soft ground**

Though there is no clear definition, the soft ground may often refer to the clayey soil stratum with the N value of 2 or less and the sandy soil stratum with the N value of 10 or less.

The following points must be taken into account when the foundation is planned in the soft ground:

- Liquefaction and fluidization of sandy soil stratum
- Lateral movement of abutment
- Negative skin frictional force in the course of consolidation settlement

Liquefaction of the sandy soil stratum

When the groundwater level is 10 m or less from the site ground surface and when the alluvial saturated sandy-soil stratum is located at 20 m or less from the ground surface liquefaction may occur during earthquake. If such possibility exists, the low efficiency FL for liquefaction should be calculated. The soil stratum for which the calculated value is 1.0 or less is considered to suffer liquefaction.

For the sandy soil stratum which is considered to develop liquefaction, reduction of the soil constant must be made.

Lateral movement of abutment

This is a phenomenon in which the abutment develops mainly the substantial displacement in the bridge axis, inclination, and settlement of the back embankment under the effect of eccentric load during or after construction.

Where there is any possibility of lateral movement, the lateral movement judgement criteria (I value) must be calculated. As a reference, with I values of 1.2 or more, it is determined that the abutment may suffer lateral movement. In such an event, it is necessary to consider the methods of enhancing the resistance force of abutment by means of soil improvement or by increasing the rigidity of foundation structure, or the method of reducing the eccentric load.

Negative skin friction in the course of consolidation settlement

The caisson foundation or pile foundation to be provided in the ground where the consolidation settlement is expected must be considered by taking into account the effects of negative skin frictional force (N: negative friction). Due attention must be paid on the negative frictional force because this force acts as a load instead of acting as a help to the bearing capacity.

6.6 DESIGN METHODOLOGY

6.6.1 Introduction

This section provides an overview of the design methodology adopted in this Manual to achieve the objectives listed below.

(1) Design Objectives

The most suitable functional bridge structure for a particular site is one which best achieves the following objectives:

- Structural strength and stability

- Serviceability
- Durability
- Ease of Construct ion
- Financial acceptability
- Aesthically Pleasing form

To achieve these objectives a design process is used as described below.

(2) Design Process

The overall purpose of the design process is to invent a structure which will satisfy the above objectives. The design process is iterative in nature. It begins with a definition of the problem and moves to a useful solution after many intermediate trials and modifications. This process is illustrated in Figure 6.6.1.

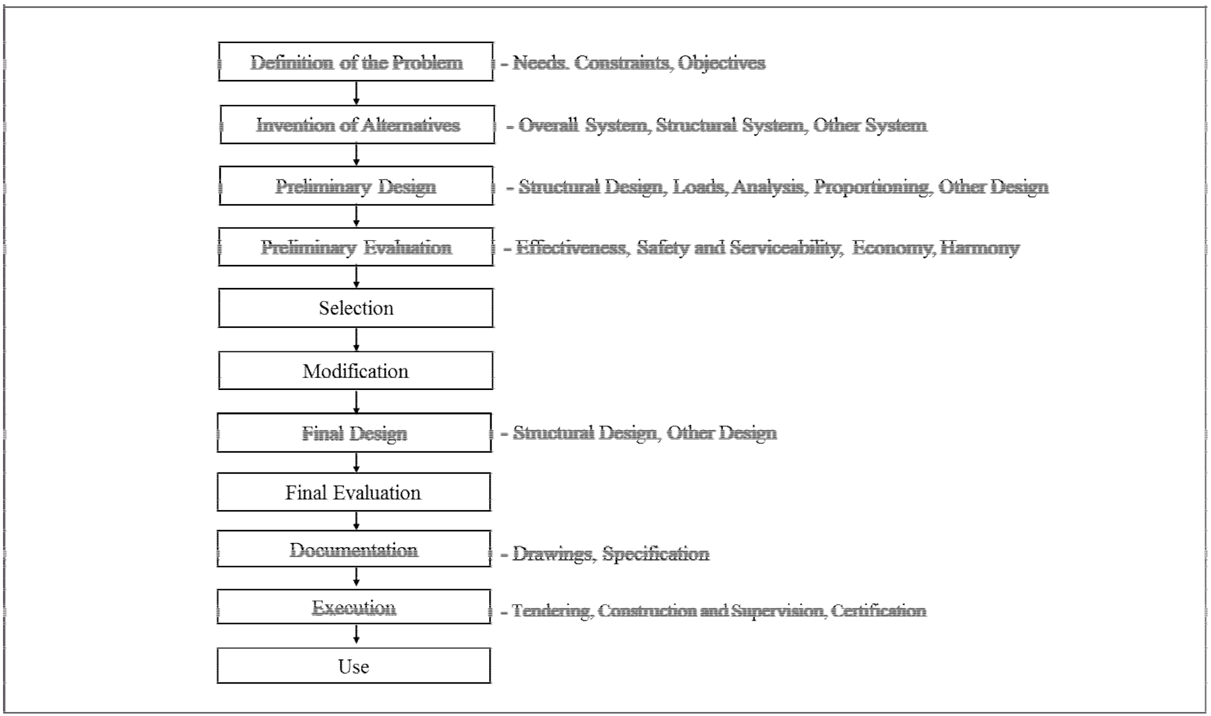


Figure 6.6.1 The Design Process

The major factors in this process are dealt with in this Manual as follows:

1) **Selection of Structural Form**

The definition of site conditions and design constraints and the invention of viable alternatives from which the final structural form is chosen is the first major factor in the design process and are discussed in Section 6.1-6.5. A bridge structural system consists of a superstructure and substructure. All feasible superstructure types must be considered in the preliminary phases of the project. All distances and weight limits should be verified by the Designer in the area. Prior to the submission of the Span Arrangement, the Designer shall meet with the Client to discuss the span arrangement alternatives that shall be included in the submission.

2) **Design Philosophy**

There are two basic approaches for ensuring structural safety allowed by the Bridge Code. These two design philosophies are known as "Working Stress Design" and "Limit States Design".

They both give similar answers, but they use different design load values and a different description of the safety factor.

These two approaches are discussed in Section 6.6.2. For the good reasons stated in this Section, the "Limit States Design" approach is used throughout this manual.

Recently, international community mostly adpotes the limit states design (LSD) as shown in Table 6.6.1. The Eurocode was scheduled to convert to the LSD format in early 2010. The U.S. and the European Union LSD design codes use a calibration coefficient to convert from tabulated strength properties in allowable stress design (ASD) to reference design values in LRFD. Japan also recently transitioned to the LSD format for its bridge design code.

All codes use the same basic structural equations for flexure and shear, but they use different adjustment factors to modify reference design values or specified strength values. All codes consider the ultimate limit states (ULS) and service limit states (SLS).

Table 6.6.1 International Bridge Design Codes

Region/ country	**ISO**	**United States**	**Euro**	**Japan**
Code	ISO 2394	AASHTO LRFD Bridge Design Specifications	Eurocode	Standard Specification of Highway bridge
Design Methodology	Partial factors format	LRFD (Load Resistance Factor Design)	Partial factors format	Partial factors format
Year	1986	1994	2007	2017

All respective bridge design codes have dedicated sections for each type of material (wood, steel, and concrete, including resistance values) and design factors (loads, load factors, and analysis methods). The bridge designer shall provide a national annex that includes nationally determined parameters (NDPs) with respect to load duration, partial factors for material properties, deflection limits, damping ratios, and other geographically specific data (i.e., climate, earthequaque, snow loads) and all the requirements must exceed the minimum requirements set by each bridge design code.

3) **Design Loads**

Loads on Bridges

All loads that are expected to be applied to the structure shall be considered in the bridge design. These loads shall include but not be limited to permanent loads, live loads, water loads, construction loads, wind loads, ice loads, earthquake effects, earth pressure, vehicular collision force, force effects due to superimposed deformations, friction forces and vessel collision forces. These loads are summized in Section 6.7.

Load Combination

In Limit States Design a given design load has three separate values as follows:

- a nominal value
- a probable maximum value called the "normal" value
- a probable minimum value called the "relieving" value

The normal and relieving load values are found by factoring the nominal load as described in Section 6.9.

4) **Analysis Methods**

Analysis involves the idealization of the structure and foundation under the action of the design loads as a numerical model. From this model the individual member forces and deformations and the overall structural stability can be calculated.

6.6.2 Design Philosophies

The Bridge Code allows either "Working Stress Design" or "Limit States Design" to be used, in the design process.

(1) Working Stress Design

"Working Stress Design" is an elastic approach which is used to assess strength or stability by limiting the stresses in the structure to permissible stresses of about one half of the actual strength of the structure under working loads.

These permissible stresses are obtained after making some allowances for the non-linear stability and material affects on the strength of isolated members and are in effect expressions of their ultimate strength divided by a safety factor, SF:

Working stress $\leq$ Permisslble stress = ultimate stress / SF

1) **Non-Uniformity of Safety Factor**

One major criticism of the working stress design method is the lack of efficiency in the achieving a consistent level of safety when the safety factor is applied to the material alone. This statement is best illustrated by the following example.

Two reinforced concrete retaining walls are constructed. One restrains water the other earth and traffic loads. Both walls are designed by the working stress method and therefore will have the same safety factor. However, both will have a different actual margin of safety due to the certainties in occurrence of the loads acting on the wall.

In order to minimize this inconstancy many codes of practice stipulate load combinations with different factors for each load in the comqination i.e. a "Hybrid Working Stress Design".

2) **Conclusion**

In spite of any deficiencies, the working stress method is simple and conservative and for this reason its use has been allowed in the bridge codes. However because of its lack of efficiency noted above and because all new bridge codes are moving to a Limit States approach and because it is already well understood, it has not been used in the Design Manual.

(2) Limit-States Design Method

“Limit States Design” is the term used to describe a design approach in which all of the ways a structure may cease to function are taken into account.

1) **Different levels of loading and ways of failure**

Such failure events are usually grouped into two main categories (or limit-states):

- ultimate or collapse limit-state and;
- serviceability limit-state

Ultimate Limit-state

Violation of the ultimate limit state occurs when safety of the structure is endangered through:

- unlimited deformation
- overturning
- instability

Serviceability limit-state

The serviceability limit state is a less serious condition related to deflection, cracking and spalling, durability and vibration. The design level of these actions is chosen so that they:

- do not make the bridge unfit for use
- do not cause public concern
- do not significantly reduce the service life of the bridge

2) **Uniformity of Safety Factor**

In limit-states design the margin of safety is more uniformly applied throughout a structure through the use of partial safety factors. Unlike working stress design in which the safety factor is applied to the material alone, in. limit-states design the safety factor is split between the load and the material allowing the uncertainties in each to be accounted for i.e.

Strength reduction factor × nominal capacity ≥ load factor × nominal load

using Code terminology :

$$K^R \times \text{nominal capacity} \geq K^U \times \text{nominal load}$$

or

$$R' \geq S'$$

In theory, these partial factors are determined from statistical analysis as illustrated in Figure 6.6.2 below.

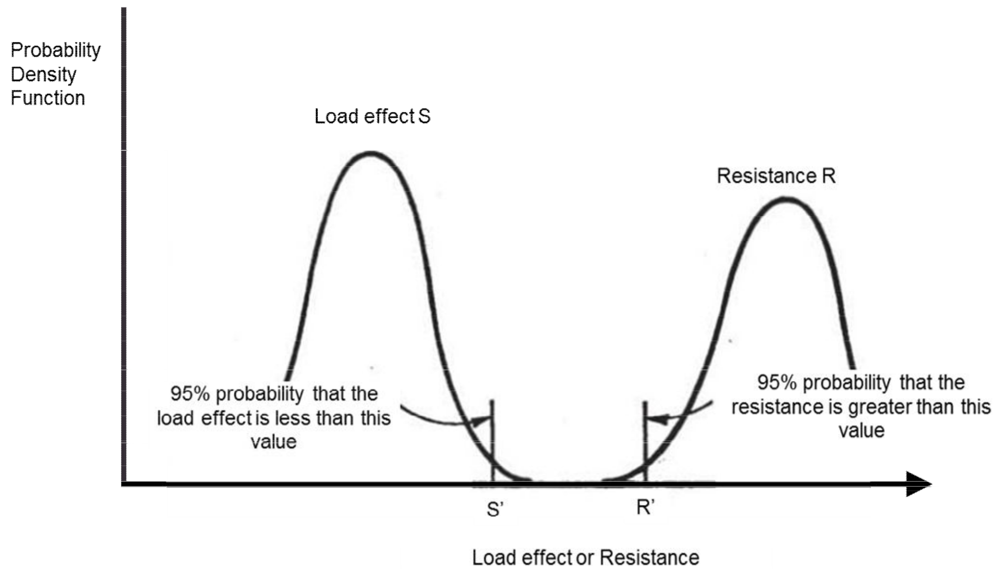


Figure 6.6.2 The statistical meaning of partial factors

In practice and in view of the lack of actual load and capacity data a semi-probabilistic approach partly based on statistical analysis and partly based on correlation with previous designs has been used in the Code. The load factors for various load combinations, and permanent loads are given in Table 6.9.1 and Table 6.9.2.

(3) Conclusion

It is now generally recognized that a Limit States Design philosophy is a more rational approach than the Working Stress Design approach. Designs produced by application of Limit States principles will, in the main, be more economical and will result in bridges of more uniform capacity or strength reserves. For this reason the limit-state design method is used exclusively in the Design Manual.

6.7 LOADS ON BRIDGES

6.7.1 Permanent Loads

Permanent loads are those that remain on the bridge for an extended period of time, perhaps for the entire service life such loads include:

- Dead load of structural components and nonstructural attachments (DC)
- Dead load of wearing surfaces and utilities (DW) and future overlays and planned widenings.
- Dead load of earth fills (EV)
- Earth pressure load (EH)
- Earth surcharge load (ES)
- Locked-in erection stresses (EL)
- Downdrag (DD)

6.7.2 Vehicular Live Load

AASHTO LRFD specification recommends vehicular live loading on the highways of bridges or incidental structures, designated HL-93, consist of a combination of the:

(1) Design truck

(2) Design tandem

(3) Design lane

(1) Design truck

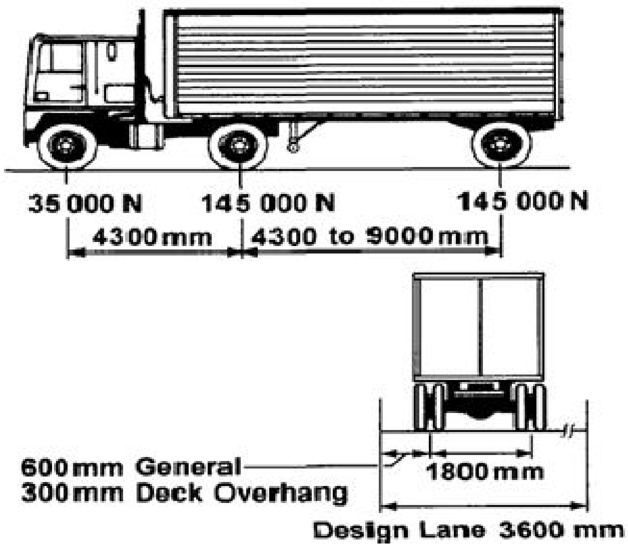


Figure 6.7.1 Design Truck

The design truck (shown in Figure 6.7.1) is a model load that consists of front axle weighs 35 kN, and the drive axle of 145 kN is located 4300 mm behind, and the rear trailer axle is also 145 kN and is positioned at a variable distance ranging between 4300 and 9000 mm.

(2) Design tandem

The second configuration is the design tandem and consists of two axles weighing 110 kN each spaced at 1200 mm.

(3) Design lane

The third load is the design lane load that consists of a uniformly distributed load of 9.3N/mm and is assumed to occupy a region of 3000 mm transversely. This load is the same as a uniform pressure of 3.1 kPa applied in a 3000 mm design lane.

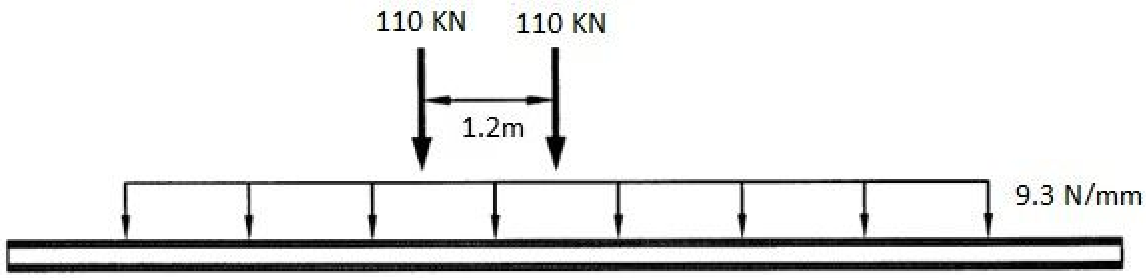


Figure 6.7.2 Design Tandem and Design Lane Load

Application of Design Vehicular Live Loads [A3.6.1.3.]

- The load effects of the design truck and the design tandem must each be *superimposed with* the load effects of the design lane load.
- For both negative moment (tension on top) between points of contra-flexure under a uniform load on all spans, and reaction at interior supports, 90 percent of the effect of two design trucks spaced a minimum of 15000 mm between the lead axle of one truck and the rear axle of the other truck, combined with 90 percent of the effect of the design lane load. The distance between the 145 kN axles of each truck shall be taken as 4300 mm.

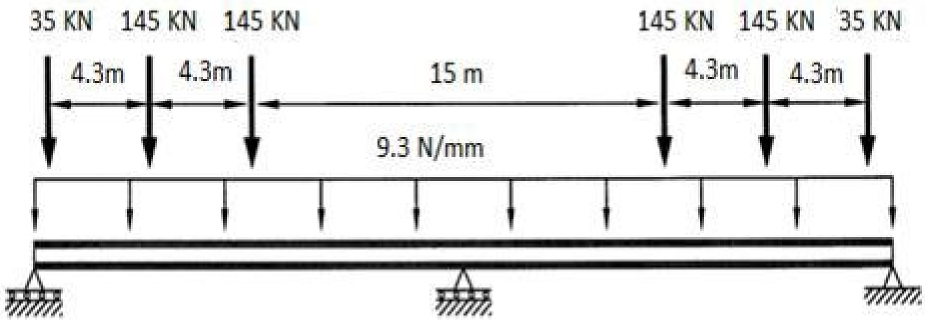


Figure 6.7.3 Application of Design Vehicular Live Loads with multi-spans for maximum negative moment

Deck and Railing Loads

The deck must be designed for the load effect due to the design truck or the design tandem, whichever creates the most extreme effect. The two design vehicles should not be considered together in the same load case. The deck overhang, located outside the facia girder and commonly referred to as the cantilever, is designed for the load effect of a uniform line load of 14.6 N/mm located 300 mm from the face of the curb or railing. The traffic barrier system and the deck overhang must sustain the infrequent event of a collision of a truck. The deck overhang and railing design is confirmed by crash testing as outlined in AASHTO [A13.7.2]. The appropriate multiplier to be used prior to superposition is shown in Table 6.7.1.

Table 6.7.1 Load Multipliers for Live Loads

Live load Combination	Design Truck	Design Tandem	Two Design Trucks or Tandem with 15m Headway	Design Lane
1	1.0			1.0
2		1.0		1.0
3			0.9	0.9

6.7.3 Dynamic Loads

The dynamic load allowance (IM) is an increment to be applied to the static wheel load to account for wheel load impact from moving vehicles. Dynamic effects due to moving vehicles may be attributed to two sources:

- Hammering effect is the dynamic response of the wheel assembly to riding surface discontinuities, such as deck joints, cracks, potholes, and delimitations, and
- Dynamic response of the bridge as a whole to passing vehicles, which may be due to long undulations in the roadway pavement, such as those caused by settlement of fill, or to resonant excitation as a result of similar frequencies of vibration between bridge and vehicle.

Table 6.7.2 Dynamic Load Allowance (IM)

Component	IM (%)
Deck joints-all limit states	75
All other components	
• Fatigue and fracture limit states	15
• All other limit states	33

All other components in Table 6.7.2 include girders, beams, bearings (except elastomeric bearings), and columns. These factors are to be applied to the static load as

$$UL+I = UL\,(1 + IM)$$

Where UL+I is the live-load effect plus allowance for dynamic loading, UL is the live-load effect of live load, and IM is the fraction given in the Table 6.7.2.

6.7.4 Centrifugal Force

As a truck moves along a curvilinear path, the change in direction of the velocity causes a centrifugal acceleration in the radial direction. AASHTO [A3.6.3] gives an expression for the force on the truck directed toward the center of the curve (outward on the bridge) as following equation.

$$CE = CW$$

$$\text{Where } C = f\left(\frac{v^2}{Rg}\right)$$

$f = 4/3$ for combinations other than fatigue and is $f = 1.0$ for fatigue;

v the highway design speed in meters/second,

R radius of curvature of traffic lane in meters, and

CE applied at the assumed center of mass at a distance of 1800 mm above the deck surface.

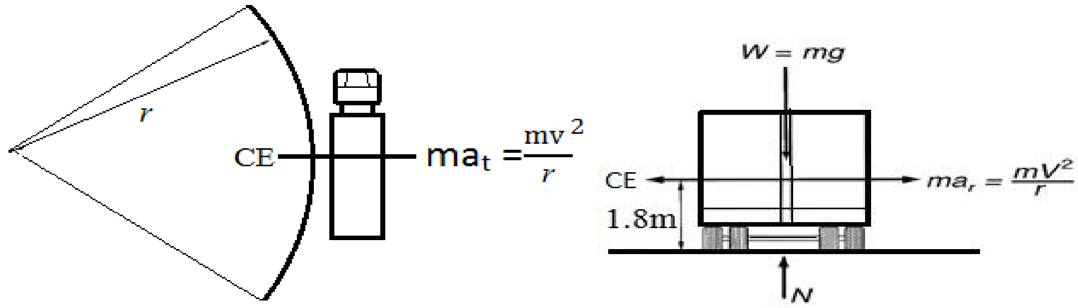


Figure 6.7.4 Centrifugal Force for Highway Bridge

Lane load is neglected in computing the centrifugal force, as the spacing of vehicles at high speed is assumed to be large, resulting in a low density of vehicles following and/or preceding the design truck. Centrifugal forces shall be applied horizontally at a distance 1800 mm above the roadway surface, and transformed as a couple to the girder.

6.7.5 Longitudinal Forces Due to Braking and Traction

Braking Force: *BR*

Based on energy principles, and assuming uniform deceleration, the braking force determined as a fraction of vehicle weight is:

$$b = \frac{v^2}{2ga}$$

Where a is the length of uniform deceleration and b is the fraction. Calculations using a braking length of 122 m and a speed of 90 km/hr. (25 m/sec.) yield b = 0.26 for a horizontal force that will act for a period of about 10 seconds. The factor b applies to all lanes in one direction because all vehicles may have reacted within this time frame.

The braking force shall be taken as the greater of:

- 25 percent of the axle weights of the design truck or design tandem or,
- percent of the design truck plus lane load or 5 percent of the design tandem plus lane load

These forces shall be assumed to act horizontally at a distance of 1800 mm above the roadway surface in either longitudinal direction to cause extreme force effects.

6.7.6 Vehicular Collision Force

Abutments and piers located within a distance of 15m to the edge of the roadway shall be investigated for collision in accordance with the AASHTO LRFD (see AASHTO 3.6.5).

6.7.7 Earthquake Effects

The Owner shall classify a bridge's importance category for seismic design. These classifications shall be based on the following:

- A bridge may be classified as "critical" which shall be designed based on a 2500 year return period event.
- All national highway bridges are classified as "essential" unless a direct road detour is near the bridge. An "essential" bridge shall be designed based on a 475 year return period event.
- All other bridges shall be designed based on a 50 year return period event.

6.7.8 Temperature Effects

For force effects due to temperature change, the temperature range for bridges designed in Lao PDR, unless otherwised directed by the Client, shall be as follows:

- Steel or Aluminum –5 °C to 50 °C
- Concrete 0 °C to 40 °C
- Wood 0 °C to 35 °C

6.7.9 Construction Loading

Construction loading shall be in accordance with the structure system of bridge. This loading shall include, but not be limited to, the erection and handling of girders and the effects of deck casting.

6.7.10 Wind Forces on Bridges

Wind loading offers a complicated set of loading conditions which must be idealized in order to provide a workable design. Although the problem of modeling wind forces is a dynamic one, with winds acting over a given time interval, these forces can be approximated as a static load being uniformly distributed over the exposed regions of a bridge.

The loading on a bridge due to wind forces is specified by AASHTO based on an assumed wind velocity of 160 km/h. With regard to the superstructure, wind forces are applied in a transverse and longitudinal direction at the center of gravity of the exposed region of the superstructure. AASHTO LRFD offers a set of wind loading values for truss and girder bridges based on the angle of attack (skew angle) of wind forces. Conventional slab on stringer bridges, however, with span lengths less than or equal to 38.1 m can utilize the following basic loading.

(1) **Wind Pressure on Structures: WS**

- Transverse loading

Table 6.7.3 Transverse Wind Pressure on Structures

SUPER STRUCTURE COMPONENT	WIND WARD LOAD (MPa)	LEEWARD LOAD (MPa)
Trusses, columns, and arches	0.0024	0.0012
Beams	0.0024	NA
Large flat surfaces	0.0019	NA

- Longitudinal loading = 0.57 kN/m^2

The total wind loading shall not be taken less than 4.4 N/mm in the plane of a windward chord and 2.2 N/mm in the plane of a leeward chord on truss and arch components, and not less than 4.4 N/mm on beam or girder spans.

(2) **Wind Pressure on Vehicles: WL**

When vehicles are present, the design wind pressure shall be applied to both structure and vehicles. Wind pressure on vehicles shall be represented by an interruptible, moving force of 1.46 N/mm acting normal to, and 1800 mm above, the roadway and shall be transmitted to the structure. When wind on vehicles is not taken as normal to the structure, the components of normal and parallel force applied to the live load may be taken as specified in Table 6.7.4 with the skew angle taken as referenced normal to the surface.

Table 6.7.4 Wind Pressure on Vehicles with the Skew Angle

Skew Angle (Degrees)	Normal Component (N/mm)	Parallel Component (N/mm)
0	1.46	0.00
15	1.28	0.18
30	1.20	0.35
45	0.96	0.47
60	0.50	0.55

- Longitudinal loading=0.58 kN/m^2

The transverse and longitudinal loads are to be placed simultaneously for both the structure and live load.

(3) **Vertical Wind Pressure (effect of overturning)**

To account for the effect of overturning, AASHTO specifies a vertical upward wind force of $9.6*10^{-4}$ MPa times the width of the deck, including parapets and sidewalks, shall be considered to be a longitudinal line load. This force shall be applied only for limit states that do not involve wind on live load, and only when the direction of wind is taken to be perpendicular to the longitudinal axis of the bridge. This lineal force shall be applied at the windward quarter-point of the deck width in conjunction with the horizontal wind loads. This load may govern where overturning of the bridge is investigated.

6.7.11 Distribution of Live Load

The following parameters determine how loads are distributed in a bridge superstructure

- Type of floor
- Spacing between stringers
- Spacing of secondary members
- Stiffness of primary members
- Stiffness of secondary members
- Type of bracing employed
- Size and position of loads

In order to simplify the computation of load distribution, AASHTO LRFD chose to utilize a distribution factor based on some of the above referenced criteria; type of floor, stringer spacing and stiffness, deck thickness and bridge span length. To account for the effects of load distribution, a load distribution factor (DF) is computed and applied to live load bending moments. Distribution will also vary depending on whether longitudinal or transverse members are being analyzed. AASHTO LRFD offers tabulated and well organized distribution factors based on the above criteria.

6.7.12 Multiple Presences

The multiple presence factors have been included in the approximate equations for distribution factors. the extreme live load force effect shall be determined by considering each possible combination of number of loaded lanes multiplied by a corresponding multiple presence factor to account for the probability of simultaneous lane occupation by the full HL- 93 design live load.

The factors specified in Table 6.7.5 shall not be applied in conjunction with approximate load distribution factors, except where the lever rule is used or where special requirements for exterior beams in beam-slab bridges.

Table 6.7.5 Multiple Presence Factors

Number of Design Lane	Multiple Presence Factor m
1	1.20
2	1.00
3	0.85
More than 3	0.65

6.8 FATIGUE LOADS AND SERVICIABILITY REQUIREMENTS

6.8.1 Fatigue

(1) Magnitude and Configuration

The strengths of various components of the bridge are sensitive to repeated stressing or fatigue. When the load is cyclic, the stress level that ultimately fractures the material can be significantly below the nominal yield strength. The fatigue strength is typically related to the range of live-load stress and the number of stress cycles under service load conditions.

The fatigue load shall be one design truck or axles with a constant spacing of 9000 mm between the 145000N axles and a load factor of 0.75 for finite load-induced fatigue life (Fatigue II) and 1.5 infinite load-induced fatigue life (Fatigue I). The dynamic load allowance shall be applied to the fatigue load. Since the fatigue and fracture limit state is defined in terms of accumulated stress-range cycles, specification of load alone is not adequate. Load should be specified along with the frequency of load occurrence. The frequency of the fatigue load shall be taken as the single-lane average daily truck traffic ($ADTT_{SL}$). This frequency shall be applied to all components of the bridge, even to those located under lanes that carry a lesser number of trucks.

In the absence of better information, the single-lane average daily truck traffic shall be taken as:

$$ADTT_{SL} = p \times ADTT$$

Where:

ADTT = the number of trucks per day in one direction averaged over the design life

$ADTT_{SL}$ = the number of trucks per day in a single-lane averaged over the design life

p = taken as specified in Table 6.8.1.

Table 6.8.1 Fraction of Truck Traffic in a Single Lane

Number of Lanes Available to Trucks	p
1	1.00
2	0.85
3	0.80

Note that the number of stress–range cycles is not used in the structural analysis directly. The fatigue truck is applied in the same manner as the other vehicles and the range of extreme stress (actions) are used. The number of stress–range cycles is used to establish the available resistance.

6.8.2 Pedestrian Loads

The AASHTO [A3.6.1.6] pedestrian load is 3.6×10^{-3} MPa, which is applied to sidewalks that are integral with a roadway bridge. If the load is applied to a bridge restricted to pedestrian and/or bicycle traffic, then a 4.1×10^{-3} MPa live load is used.

6.8.3 Deflection

Service load deformations may cause deterioration of wearing surfaces and local cracking in concrete slabs and in metal bridges that could impair serviceability and durability, even if self-limiting and not a potential source of collapse. Bridges should be designed to avoid undesirable structural or psychological effects due to their deformations. AASHTO LRFD provides two alternative criteria for controlling the deflections.

(1) Limiting computed deflection

Vehicular load, general	span length/800
Vehicular and/or pedestrian loads	span length/1000
Vehicular load on cantilever arms	span length/300
Vehicular and/or pedestrian loads on cantilever arms	span length/1000

(2) Limiting span–to–depth ratios for superstructures with constant depth

AASHTO recommends typical minimum depth for a given span length. Deflections of bridges can be estimated in two steps as instantaneous deflection and long time deflection. The live load portion of Load Combination Service I of Table 6.9.1 should be used, including the dynamic load allowance, IM.

6.9 LOAD COMBINATIONS

6.9.1 Load Factors and Load Combinations

The load factors for various load combinations and permanent loads are given in Table 6.9.1 and Table 6.9.2, respectively. Explanations of the different limit states are given in the sections as follows. For all limit states, both global and local, the basic design expression must be satisfied in the AASHTO (2004b) LRFD Bridge pecifications:

$$\eta i\ \gamma i\ Qi \le \varphi\ Rn = R_r$$

where Qi is the force effect, Rn is the nominal resistance, γi is the statistically based load factor applied to the force effects, φ is the statistically based resistance factor applied to nominal resistance, and ηi is a load modification factor. For all nonstrength limit states, $\varphi = 1.0$.

(1) **Service Limit State**

The service limit state refers to restrictions on stresses, deflections, and crack widths of bridge components that occur under regular service conditions AASHTO [A1.3.2.2]. For the service limit state, the resistance factors $\varphi = 1.0$, and nearly all of the load factors γi are equal to 1.0. There are four different service limit state load combinations given in Table 6.9.1 to address different design situations AASHTO [A3.4.1].

(2) **Fatigue and Fracture Limit State**

The fatigue and fracture limit state refers to a set of restrictions on stress range caused by a design truck. The restrictions depend on the number of stress-range excursions expected to occur during the design life of the bridge AASHTO [A1.3.2.3]. They are intended to limit crack growth under repetitive loads and to prevent fracture due to cumulative stress effects in steel elements, components, and connections. For the fatigue and fracture limit state, $\varphi = 1.0$.

(3) **Strength Limit State**

The strength limit state refers to providing sufficient strength or resistance to satisfy the inequality of the equation shown in 6.9.1 for the statistically significant load combinations that a bridge is expected to experience in its design life AASHTO [A1.3.2.4]. Strength limit states include the evaluation of resistance to bending, shear, torsion, and axial load. The statistically determined resistance factor φ will usually be less than 1.0 and will have different values for different materials and strength limit states.

(4) **Extreme Event Limit State**

The extreme event limit state refers to the structural survival of a bridge during a major earthquake or flood or when collided by a vessel, vehicle, or ice floe AASHTO [A1.3.2.5]. The probability of these events occurring simultaneously is extremely low; therefore, they are specified to be applied separately. The recurrence interval of extreme events may be significantly greater than the design life of the bridge AASHTO [C1.3.2.5]. Under these extreme conditions, the structure is expected to undergo considerable inelastic deformation by which locked-in force effects due to TU, TG, CR, SH, and SE are expected.

Table 6.9.1 The Load Factors for Various Load Combinations

Load Combination Limit State	*DC* *DD* *DW* *EH* *EV* *ES* *EL* *PS* *CR* *SH*	*LL* *IM* *CE* *BR* *PL* *LS*	*WA*	*WS*	*WL*	*FR*	*TU*	*TG*	*SE*	Use One of These at a Time				
										EQ	*BL*	*IC*	*CT*	*CV*
Strength I (unless noted)	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength III	γ_p	—	1.00	1.40	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength IV	γ_p	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—	—
Strength V	γ_p	1.35	1.00	0.40	1.0	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Extreme Event I	γ_p	γEQ	1.00	—	—	1.00	—	—	—	1.00	—	—	—	—
Extreme Event II	γ_p	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00	1.00
Service I	1.00	1.00	1.00	0.30	1.0	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—	—	—	—	—	—
Service III	1.00	0.80	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service IV	1.00	—	1.00	0.70	—	1.00	1.00/1.20	—	1.0	—	—	—	—	—
Fatigue I— *LL, IM & CE* only	—	1.50	—	—	—	—	—	—	—	—	—	—	—	—
Fatigue I II— *LL, IM & CE* only	—	0.75	—	—	—	—	—	—	—	—	—	—	—	—

Table 6.9.2 Load Factors for Permanent Loads, *γp*

Type of Load, Foundation Type, and Method Used to Calculate Downdrag		Load Factor	
		Maximum	Minimum
DC: Component and Attachments *DC:* Strength IV only		1.25 1.50	0.90 0.90
DD: Downdrag	Piles, α Tomlinson Method Piles, λ Method Drilled shafts, O'Neill and Reese (1999) Method	1.4 1.05 1.25	0.25 0.30 0.35
DW: Wearing Surfaces and Utilities		1.50	0.65
EH: Horizontal Earth Pressure • Active • At-Rest • *AEP* for anchored walls		 1.50 1.35 1.35	 0.90 0.90 N/A
EL: Locked-in Construction Stresses		1.00	1.00
EV: Vertical Earth Pressure • Overall Stability • Retaining Walls and Abutments • Rigid Buried Structure • Rigid Frames • Flexible Buried Structures o Metal Box Culverts and Structural Plate Culverts with Deep Corrugations o Thermoplastic culverts o All others		 1.00 1.35 1.30 1.35 1.5 1.3 1.95	 N/A 1.00 0.90 0.90 0.9 0.9 0.9
ES: Earth Surcharge		1.50	0.75

6.10 BRIDGE DESIGN DOCUMENTATION

The bridge design documents shall include the following sections give a brief description about each submission.

6.10.1 Design Report

A design report is a preliminary engineering study of proposed alignments for a project. The report will be subject to cheduled review. The Bridge Designer's tasks are to provide the necessary bridge information, cost estimates, and sketches for the report to be developed. This requires the Bridge Designer to look at existing conditions (geometry, major utilities, right-of-way, existing and/or adjacent structures, etc.), historical data, hydraulic opening, and proposed alignments to assist in the development of the report. The Bridge Designer should develop a cost and a plan and profile drawing for each alternate. These drawings are simple line drawings with minimal details (stationing, grades, vertical and horizontal curve data, etc.). The cost estimates shall be based on historic data for similar structures on a cost per square foot basis.

(1) Preliminary Study /Conceptural Design Stage

The Bridge Designer should have meetings with the Client to discuss on the feasible structural systems and span arrangements that should be included in the report. The purpose of this meeting will be to eliminate or add additional alternates for further consideration. This will save considerable time in the stage of bridge design. The Client will make this final decision on what alternates should be studied and designed. For the meeting, the Bridge Designer should provide the following:

- Preliminary line and grade.
- Draft site plan for each recommended alternate showing both plan and profile views. Abutment location should be fairly accurate at this time. Piers should be located for each alternate being studied.
- Discussions on why alternates were chosen and others were not.
- Location of utilities, environmental concerns, roads, railroad tracks, etc.
- Include any obstacles that may influence recommendations.
- Superstructure types being considered.
- At this time, no preliminary cost estimates, or girder analysis should be completed.

(2) Outline /Basic Design Stage

The following contnts should be included in the report.

- Alignment, grades, typical sections, and superelevations used shall be documented.
- Consider all viable construction materials. Equal treatment between alternates is essential in ensuring competition and optimum cost-effectiveness.
- Uniformity of design criteria, material requirements, and appropriate unit costs shall be considered and documented.
- Hydraulic study (if crossing a waterway) should be included in justifying the proposed span arrangement, scour features, and the grade.
- Discuss constructability, any special staged construction, clearance criteria (if crossing a road, railroad, or navigable waterway), freeboard (if crossing a waterway), and maintenance of traffic requirements.
- A description of the proposed superstructure depth and preliminary superstructure type

utilized in the study, for each alternative span arrangement.

- All proposed computer software to be used during the phase of study and final design phases of the bridge project.
- Deck drainage, superstructure joint, and bearing device requirements.
- Special environmental, aesthetic, and utility considerations.
- A description of the assumed foundation type used for cost estimates and geotechnical data.
- A preliminary total structure cost estimate for each span arrangement studied.
- Note proposed right-of-way limits, construction easements, and future maintenance operations.
- A detailed discussion documenting the Designer's recommended bridge layouts, and the reasons for their selection. In most cases, the Bridge Designer is encouraged to recommend advancement of at least one concrete and one steel superstructure alternate. However, more than two alternates may be advanced.
- Unit prices shall be submitted for approval for all pay items that may be used during the plan development process.

The decisions on what alternates are advanced is based on several factors:

- Cost of each alternate (cost differences of 10% or less from the final engineer's estimate be desired)
- Future maintenance costs
- Aesthetics
- Environmental concerns
- Constructability
- Redundancy
- Additional construction costs inherent of complex structures

All of these factors shall be taken into consideration, with present cost being the primary concern, to determine the recommended alternates. The ultimate decision is made by the Client.

(3) Detialed Dsign Stage

The Final Detailed Design Report shall be submitted to the Client for approval prior to submission of the tender documents including detiled drawangs, specification and estimate (priced BoQ) for comments and approval. At this stage, the plans and design shall be 100% complete. They should be ready to go to contract if no comments are given.

- Plans (Drawings A3 size)
- Detailed cost estimate
- All applicable special provisions
- Contract completion time chart
- Reference to standard bridge and roadway drawings
- Final Hydraulic Report
- Strucutral Anyalyis including table of loads and factors to be adopted.

6.10.2 Establishing Contract Duration

The Designer is responsible for the development of a contract duration time bar chart. This document is to be used as a starting point in determining contract duration, and should be augmented with outside sources of information, past experience with work of a similar nature, and good engineering judgment.

6.10.3 Engineer's Cost Estimate

The Engineer's Cost Estimate shall be an accurate reflection of the anticipated costs of the various items of work that are contained in the construction project. The Client provides annually references unit bid prices for the relevant bridge construction projects. It is advisable to consult past projects of a similar nature and scope near the project that is being estimated to arrive at realistic cost data.

APPENDIX-A

BIBLIOGRAPHY

1. Section 1

Consultants working in Laos, which have been consulted and participated in the preparation and formulations of Technical Standards Documents and Manuals, were;

- SweRoad, -Sweco, -SMEC, -Cowi Consult.
- Kampsax, -Maunsel SKP, -CES, -Lao Survey, and John Holland.

Sources of information, institutions contacted, literature and technical papers referenced and used, acknowledged herewith, have been as follows;

- Ministry of Communication Transport, Post and Construction (MCTPC) Vientiane, Laos,
- Department of Highways (DOH) of Bangkok, Thailand.
- Highway Authority of Malaysia.
- United Nations, UNDP Vientiane and ESCAP Bangkok, Thailand,
- AASHTO, ASTM, British Standards (BS) and BS Codes of Practices,
- National Transportation Study of Laos of 1991,
- Transport and Road Research Laboratory, TRRL of UK, reference several of TRRL Road Notes, e.g. RN 3,6,29 and 31 in particular and several other publications,
- National Association of Australian State Road Authorities,
- Swedish National Road Authority,
- National Institute for Transport and Road Research and
- Council for Scientific and Industrial Research of RSA,Transportation and Research Boar, of US AID, plus
- Relevant working papers/documentation from eastern and southern Africa, plus
- Recommendations and advice received from many others working on short term and permanently in Laos.

APPENDIX-B

UNIT AND ABBREVIATIONS

1. Units of Measurement

The standard units or measurement to be used are essentially based on the International System (SI) units.

Multiples and sub-multiples of the SI units are formed either by the use of indices or prefixes. The definitions of applicable prefixes are shown in table below.

Table. Definitions of Prefixes

Prefix	Symbol	Factor (Symbol x Factor)
Mega	M	10^6
Kilo	K	10^3
Hector	h	10^2
Deca	da	10^1
Deci	d	10^{-1}
centi	c	10^{-2}
Milli	m	10^{-3}
Micro	μ	10^{-6}

Table. Basic Units, Multiples and Sub-Multiples

Quantity	Unit	Symbol	Multiples
Length	meter	m	km, m
Mass	kilogram	kg	Mg, g, mg
Time	Second	s	day, hour (h), minute (min.)
Area	square meter	m^2	km^2, hectare, mm^2, (1h=10,000m^2)
Volume (solids)	cubic meter	m^3	cm^3, mm^3
Volume (liquid)	liter	l	ml
Density	kilogram per cubic meter	kg/m^3	kg/m^3, mg/m^3, l, kg/l, g/ml
Force	newton	N	MN,kN, lN=lkgm/s^2, l, kgf=9,81N
Pressure and stress	newton per square meter	n/m^2	kN/m^2, N/mm^2
Velocity	meter per second	m/s	km/h, 1 km/h=l mp/3.6
Angle	degree or grad	º or g	Minute ('), second ("), (360 degree circle), (400 degree circle),
Temperature	degree Celsius	ºC	

2. Definitions, Abbreviations and Glossary of terms.

AADT (Average Annual Daily Traffic) - The total annual traffic in both directions on a road link divided by 365 (the number of days in the year).

ADT(Average Daily Traffic) - the total traffic volume during a given time period in whole days greater than one day and less than one year divided by the number of days in that time period.

AASHTO - Abbreviation for American Association of State Highways andTransportation Officials.

Acceleration Lane- A speed change lane to enable a vehicle entering a roadway to increase its speed to merge with through traffic.
Access Control- The regulated limitation of access that is achieved through the regulation of public access rights to and from properties abutting the road facilities.

Access Road - The lowest level of road in the network hierarchy with the function of linking traffic to and from rural areas, either direct or adjacent urban centers, or to the Collector road network; a feeder road or a tertiary route.

Accuracy - The degree of agreement between a measured value and a true value.

ACV - Aggregate Crushing Value

ADL - Average Least Dimension

Adverse cross fall - Cross fall on a horizontal curve that tilts away from the center of the curve.

Adverse grade - On a long descending grade, a short section of ascending road and vice versa.

Aesthetics - In highway engineering, aesthetic judgments have to do,primarily with the road as a whole and the roadsides, including screening out unpleasant views.

Approach - All lanes by which vehicles may lawfully proceed toward an intersection.

Arterial road - A main route primarily for the movement of through traffic, connecting national orinternational centers; a primary route.

ASTM - Abbreviation for American Society for Testing and Materials.

Auxiliary lane - The portion of the roadway adjoining the travelled way for weaving, truck climbing, speed change, or for other purposes supplementary to through traffic movement.

Axle load - The total load transmitted by all wheels on a single axle extending across thefull width of the vehicle.

Back slope - In cuts, the slope from the bottom of the ditch to the top of the cut.

BS - British Standard

BST - Bitumen surfaced treatment prefixed by either S (for single) or D (for double).

Bridge - A structure normally exceeding 6 meters clear span measured along the centerline of the roadway, which carries traffic over a watercourse or opening.

Camber - The convexity given to the curved cross-section of a carriageway or a shoulder.

CBR - California Bearing Ratio

Centre line - The axis along the middle of the road.

CR - Crushing Ratio

Curvilinear alignment- A flowing alignment in which the majority of its length is composed of a series of curves

Design class- The classification (grouping) of roads for geometric design purposes according to traffic and road function.

Design speed - A selected highest safe speed (normally the85th percentile vehicle speed) for the purpose of design in correlation with the geometric features of a specific road.

Design load - The load that must be supported by the structure.

Design period-The number of years of intended service life of a structure before the first major rehabilitation, a time of 10 to 20 years from the start of construction, is normally used.

ESA - Equivalent Standard Axle

ESAL- Abbreviation for Equivalent Single Axle Load, normally referring to an 8- ton or 80 kN standard single axle load.

Eighty-fifth percentile speed - The speed at or below which 85 % of the vehicles are being operated.

Environment - The totality of man's surroundings, -social,-physical,-natural, and manmade

Environmental Design - The location and design of a road that includes consideration of the impact this has on the community or region based on aesthetic, ecological, cultural, sociological, economic, historical, conservation and other factors.

Feeder road - A classified (versatile) road which services all other road categories mainly providing access to land, e.g. privately owned properties, industrial or commercial developments or recreational areas, but also services as "feeder - access" to and from local roads, villages and towns and to/from and between other major roads.

FI - Flakiness Index

Functional Classification - The grouping of individual roads in a road network system according to their purpose or function and the type of traffic they will serve e.g. in terms of being classified as "Arterial", "Collector" or "Access" or alternatively "National", "Provincial", "District", "Access/Local".

Geometric Design- Guidelines for limiting values of road alignment and cross-section design including the visible elements of the road, such as alignment, grades, sight distances, widths, slopes, etc.,

Gradient- The rise or fall on any length of road in the alignment profile and with respect to the horizontal distance.

HF - Hubbard Field

Horizontal alignment - The horizontal geometries of the roadway

Horizontal curve or curvature - A curve or succession of curves, normally circular, in plan.

ISO - International Standard Organization

K- value - The ratio of the minimum of the length of vertical crest curve in meters to the algebraic difference in percentage of gradients adjoining the curve...

Kerb - A border, flush or up-standing, of stone, concrete or other material laid or formed at the edge of a carriageway, shoulder or footway.

LAA - Los Angeles Abrasion

Lane - A portion of the travelled way (carriageway) providing for a single lane of moving vehicles in one direction. Los Angeles Abrasion

Level (terrain) - Flat or gently rolling terrain with largely unrestricted horizontal and vertical alignment. See "Terrain" for definitions.

LL - Liquid Limit

MC - Moisture Content

MDD - Maximum Dry Density

Median - The portion of a divided road separating the carriage way for traffic in opposite directions.

Median lane - A speed-change lane within the median to accommodate left-turning vehicles

Mountainous (terrain) - Terrain that is rugged and very hilly with substantial restrictions in both horizontal and vertical alignment. See "Terrain" for definitions.

Network (hierarchy) - The classification of roads according to Arterial, Collector and

Access or National, Provincial, District and Access roads.

OMC - Optimum Moisture Content

Operating speed - The highest overall speed that a driver can travel on a given road, under favorable circumstances, without exceeding the safe speed as determined by the design geometries.

Optimum - The best quantity, number or condition.

Passenger car unit (pcu) - A unit for converting the equivalence in terms of effect on capacity of different vehicle types in relations to one normal passenger car.

Pavement - The part of the road designed to withstand the weight or loading by traffic.

Pavement Design- The arrangement of materials in depth (or in thickness) to best accommodate the anticipated loading

Pavement structure - The combination of wearing course, base course and sub-base placed on a sub-grade to support the traffic load and to distribute it to the roadbed.

Percentile - The percentage of the total below which the given number of values fail.

PL - Plastic Limit

PI - Plasticity Index

PM - Plasticity Modulus (Product of PI and % passing 0.425 mm sieve)

Profile - A longitudinal section of a highway, drainage course, etc.

Profile grade - The trace of a vertical plane intersecting the top surface of the proposed wearing surface, usually along the longitudinal centerline of the roadbed. Profile grade means either elevation or gradient of such trace according to the context.

Rate of pavement rotation - The ratio of the change of cross fall to the time taken to travel along the length of a transition curve when travelling at the design speed.

Rest area- A roadside area with parking facilities separated away from the roadside,providing motorists with opportunities to stop and rest for short periods.

Residual value - The value of a road which remains at the end of its economic evaluation period; normally taken as the difference in cost between rebuilding the road at the end of its life using the structure remaining from the initial project, and the building cost if the first project were not to take place.

Resurfacing - The placing of one or more new wearing courses(e.g. bitumen) on an existing surface.

Reverse curve - A curve consisting of two arcs of the same or different radii curving in opposite directions and having a common tangent or transition curve at their point of junction.

Right-of-way - The physical extent of the right of access that is granted in association with a road.

Roadbed - Any layered area, in cut or in fill, having the sub grade as the top layer, upon which the road pavement, consisting of sub base, base course, shoulders and wearing course is placed.

Roadside - A portion of the right-of-way outside the roadway.

Roadway - The portion of a road, including shoulders, for vehicular use.

Rolling terrain - Terrain with low hills introducing moderate levels of rise and fall with some restrictions on vertical alignment. See "Terrain" for definitions.

Sag curve - A depression formed in the vertical curve by the junction of two gradients.

SG - Specific Gravity

Shoulder - That part of the verge adjacent to the carriageway, and substantially at the same road level, designed for the accommodation of stopped vehicles for emergency use and for lateral support of the upper pavement.

Sight distance - The length of roadway ahead at which an object becomes visible to the driver

Single axle load- The total load transmitted by all wheels through the axle extended across the full width of the vehicle.

Slope - The face of an embankment or cut section; any ground whose surface makes an angle with the plane of the horizon.

Speed environment - The speed below which 85 percent of vehicles are driving on the longer straights and large radius curves of a section of road where speed is not constrained by traffic or geometric elements.

SS - Standard Specification for Road Construction

SSS - Sodium Sulphate Soundness

Stabilization - Modification of soils or aggregates by incorporating a material that will increase load-bearing capacity, firmness and resistance to weathering or displacement.

Stage construction- The construction of a road instages as traffic develops.

Structural pavement section - The designed layers of specified materials, normally consisting of the wearing course, base course and sub base placed over the subgrade.

Subbase - The layer or layers of specified or selected material of designed thickness placed on a subgrade to support the base course.

Subgrade - The top layer of embankments or in cut (excavated areas) controlled to a specified depth (thickness), on which the pavement (including shoulders) is constructed or the top of the roadbed on which the pavement structure is constructed.

Substructure - For bridges, all of that part of the structure constructed below the deck bearings.

Super elevation - The inward tilt or the transverse inclination given to the cross-section of a carriage way through the length of a horizontal curve to partially offset the centrifugal force of a vehicle passing through the curve.

Super elevation run-off - The length of road over which super elevation is reduced from its maximum value to zero.

Superstructure - For bridges, the entire structure except for the sub structure.

Surface treatment - Application(s) of bituminous material and aggregate.

Sustained grade - A continuous road grade of appreciable length and consistent or nearly consistent gradient.

Taper - A transition length between a passing place, auxiliary lane or climbing lane and the standard carriage way.

Terrain - The classification of "flat" or "level", "rolling" and "mountainous' terrain is defined by both subjective description and by the average ground slope. The average ground slope is measured as the number of 5 meter contour lines crossed per kilometer on a straight line linking the two ends of the road section. (The slope can be interpolated using other contour intervals on a proportional basis).

<u>Terrain Classification;</u>

Flat or Level; (0 -10 five meter ground contours per kilometer). Level or gently rolling terrain with largely unrestricted horizontal and vertical alignment.

Rolling; (11 - 25 five meter ground contours per kilometer). Rolling terrain with low hills introducing moderate levels of rise and fall with some restrictions on the vertical alignment.

Mountainous; (Greater than 25 five meter ground contours per kilometer). Rugged, hilly and mountainous terrain with substantial restrictions in both horizontal and vertical alignment.

Traffic analysis period- A common analysis period (usually20 years) used in road design.

Traffic markings - A traffic control device consisting of lines, patterns, words, symbols or colors on the pavement or adjacent to the roadway.

Traffic sign - A traffic control device mounted on a support above the level of the roadway that conveys a specific message by means of words or symbols.

Transition - A section of variable width required when changing from one width of travelled way to a greater or lesser width road,

Transition curve - A curve in which the radius changes continuously along its length, used for the purpose of connecting a straight with a circular curve, or two circular curves of different radii.

Transverse - At right angle to the longitudinal direction.

Travelled way - Synonymous with Carriage way. See Carriage way.

Traverse - In surveying, a series of interconnected straight lines. The lengths of the lines and the angles of deviation between them are measured as the traverse develops.

TS - Tensile Strength

Typical cross section - A transverse section of a proposed road showing the lateral dimensions and functional and structural elements of the road.

Vertical alignment - The direction and course of the centerline in profile.

Verge - That part of the road outside the carriageway and generally at substantially the same level. It may contain footpaths, cycle tracks or ditches.

Vertical curve/curvature - A curve/succession of curves, normally parabolic, on the longitudinal profile of a road to provide for change of gradient

Wearing course (Surface course) - The top layer of the pavement.

Weathering - The decomposition of natural material

Weaving- The crossing of traffic streams moving in the same general direction accomplished by merging and diverging.

Weaving sections - Road segments where the pattern of traffic entering and leaving at contiguous (same) points of access resulting in vehicle paths crossing each other.

UC - Uniformity Coefficient

UCS - Unconfined Compressive Strength

UH - Vibrating Harmer

APPENDIX-C

PROJECT PROCEDURE AND DESIGN ACTIVITY

As mentioned in preface, this manual is utilized for Preliminary Design for Feasibility Study (F/S) and Detailed Design (D/D). Required activitis and dwarings of Preliminary design for Feasibility Study (F/S) and Detailed Design (D/D) are detailed in Figure A.2 and A.3.

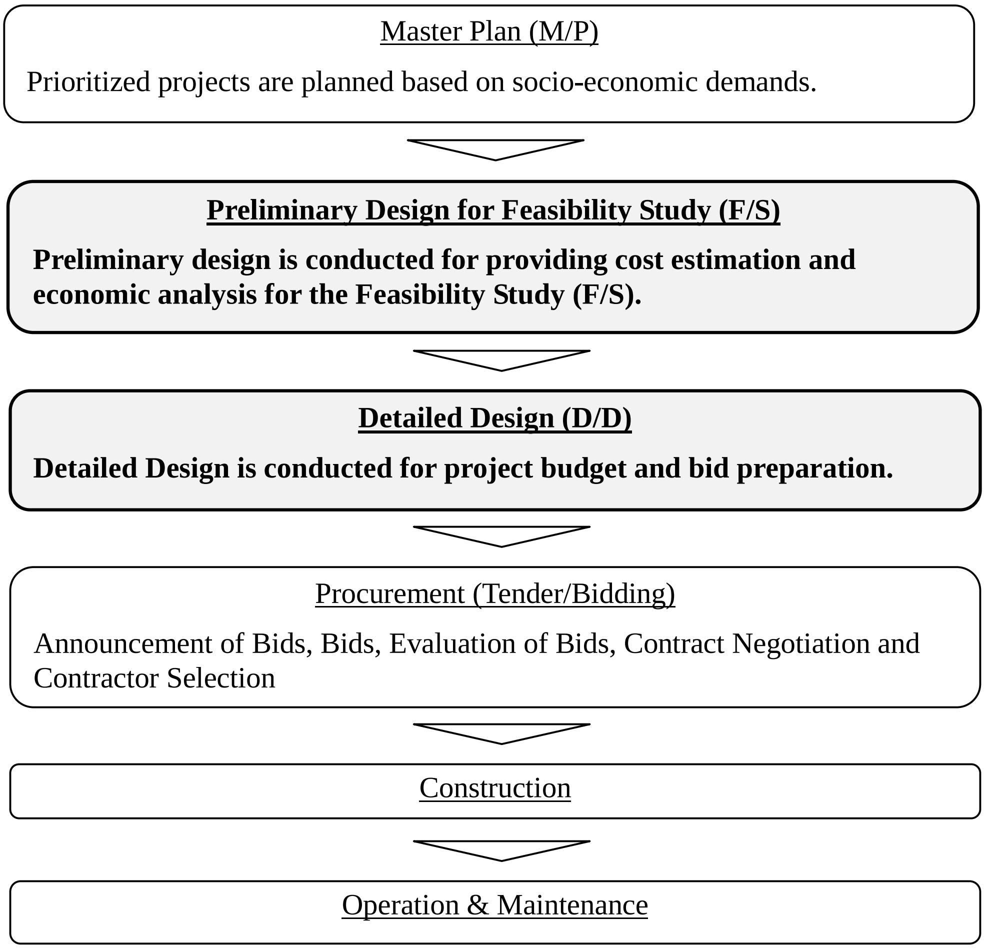


Figure A.1 Project Procedure

Survey

Activity	Remarks
Topographic survey	
- Aerial Photo 1/5,000-1/1,000 for route comparison	For route selection
- Ground Survey 1/1,000 for plan and profile	For preliminary design
Geotechnical survey for representative location	
- CBR test and Laboratory test for subgrade/pavement material	For pavement design
- Boring	For Box Culvert / Bridge
-Standard Penetration Test (SPT)	
- Laboratory test for Bore hole	
Traffic count survey	For Traffic forecast and pavement design
Axle Load survey	For pavement design
Hydrological survey	For calculation of discharge volume and H.W.L

Preliminary Design

Activity

Design	Remarks
Road Alignment Planning	To study selection of route
Preliminary Design	To make drawings and quantity

Output

Drawings	Recommended scale
Project Location Map	various
Route comparison	1/1,000 - 1/ 5,000
Plan and Profile	H: 1/1,000 - 2,000, V: 1/100
Typical Cross Section	1/200 - 1/250
Following Preliminary Drawings	
- Structure Bridge Box Culvert Pipe Culvert Side Ditch and etc.	various
- Road Side Facility Gurdrail Gurad Post and etc.	various
-Road Marking and Traffic Sign	various
- Lighting	various

Quantity/Cost Estimation and Economic Analysis

Other Activity	Remarks
Traffic demand forecast	For determining number of lane and pavement design
Construction Plan	To make a construction method
Social and Environmental Impact	To plan to mitigate negative impact
Project Implementation Plan	To plan a project schedule

Feasible

or

Not Feabile

Figure A.2 Required Activitis and Output of Preliminary Design for Feasibility Study (F/S)

Survey

Activity	Remarks
Topographic survey	
- Ground Survey 1/1,000	For detailed design
- Ground Survey 1/500 - 200	For detailed design of maily structure
Geotechnical survey for detailed location	
- CBR test and Laboratory test for subgrade/pavement material	For pavement design
- Boring	For Box Culvert / Bridge
- Standard Penetration Test (SPT)	
- Laboratory test for Bore hole	

Note: Surveying titems and the details are determined based on result of the Preliminary Design

Detailed Design (D/D)

Design

Activity	Remarks
Review of Preliminary Design	
Detailed Design	To make drawings and quantity

Output

Drawings	Recommended scale
Project Location Map	various
Alignment	1/1,000 - 1/5,000
Plan and Profile	H: 1/1,000 - 1/2,000, V: 1/100
Typical Cross Section	1/200 - 1/250
Cross Section	1/200 - 1/250, 20-25m interval
Following Detailed Drawings	
- Intersection of Road	1/250 - 1/500
- Drainage System	1/1,000 - 1/2,000
- Structure Bridge Box Culvert Pipe Culvert Side Ditch and etc.	various
- Road Side Facility Gurdrail Gurad Post and etc.	various
- Road Marking and Traffic Sign	various
- Lighting System and Structure	various

Other Activity	Remarks
Construction Plan/Schedule	To make a construction method/schedule
Construction Cost Estimation	To develop target cost of the project
Procurement Documents (Typical) - Invitation for Bid - Instructions to Bidders - Bid Data Sheet - Employers Requirements - Condition of Contract (General/Particular) - Drawings - Technical Specification (General/Particular) - Bill of Quantity	

Procurement

Figure A.3 Required Activitis and Output of Detailed Design (D/D) for Procurement

APPENDIX-D

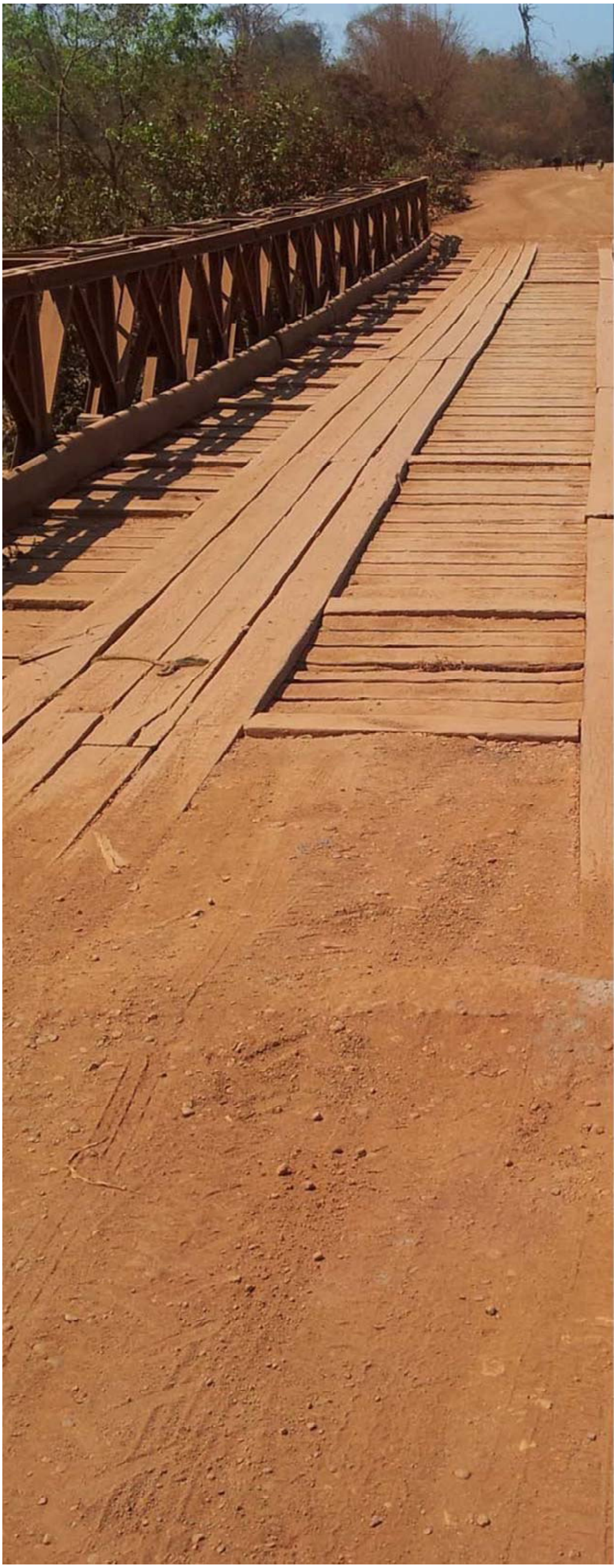
RISK ASSESSMENT PROCEDURE AND GUIDELINE

TRANSPORT SECTOR

RISK ASSESSMENT
& Procedure Guideline

TRANSPORT SECTOR

Technical Assisstance by Asian Disaster Preparedness Center



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Acronyms

ADB	Asian Development Bank
ADPC	Asian Disaster Preparedness Center
DEM	Digital Elevation Model
DHUP	Department of Housing and Urban Planning
DMG	Department of Mines and Geology
DMH	Department of Meteorology and Hydrology
DOA	Department Of Agriculture
DoG	Department of Geology
DoI	Department of Irrigation
DoP	Department of Planning
DoR	Department of Roads
DRR	Disaster Risk Reduction
EVRA	Exposure, Vulnerability and Risk Assessment
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GRID	Global Resource Information Database
ISDR	International Strategy for Disaster Reduction
JTWC	Joint Typhoon Warning Center
Lao PDR	Lao People's Democratic Republic
LDS	Lao Department of Statistics
LNMC	Lao National Mekong Committee
MAF	Ministry of Agriculture and Forestry
MMI	Modified Mercalli Intensity
MPI	Ministry of Planning and Investment
MPWT	Ministry of Public works and Transport
NAFRI	National Agricultural and Forestry Research Institute
NCDC	National Climatic Data Center
NDMO	National Disaster Management Office
NGD	National Geography Department
NGO	Non-Governmental Organization
NOAA	National Oceanic Atmospheric Administration
NRA	National Regulation Authority
NSC	National Statistic Center
OCHA	Office for the Coordination of Humanitarian Affairs
PGA	Peak Ground Acceleration

PTI	Public Work and Transport Institute
TMD	Thai Meteorological Department
TWG	Technical Working Group
UNDP	United Nations Development Programme
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USACE	United States Army Corps Engineering
USGS	United States Geological Survey

Procedures and Guidelines for Risk Assessment of Transport Sector

1 Introduction

1.1 Background

The Ministry of Planning and Investment (MPI) is executing a project entitled "Mainstreaming Disaster and Climate Risk Management into Investment Decision (MDCID)" with support from the World Bank who is acting as administrator of grant funds provided by Japan under the Japan Policy and Human Resources Development Technical Assistance Program to Support the Government of Lao PDR in its efforts to strengthen the institutional authority and implementation capacity of the Government of Lao PDR at national and sub-national levels to mainstream disaster risk management and climate change adaptation into public infrastructure investments, thereby potentially decreasing the vulnerability of the population and national economy to climate change and natural hazards.

The project will be coordinated by the Ministry of Planning and Investment. The implementing partners will be the Ministry of Agriculture and Forestry (MAF), and Ministry of Public works and Transport (MPWT). ADPC has been engaged by the Ministry of Planning and Investment (MPI), Lao PDR to provide professional consulting services for the implementation of the project.

This document is prepared as a part of Activity 2.2: 'Develop procedures and guidelines for hazard and risk assessment' of Task 2. Existing documents related to procedures for risk assessment in the line departments, i.e. Department of Roads (DoR) and Department of Housing and Urban Planning (DHUP), Ministry of Public Work and Transport (MPWT) and Department of Irrigation (DOI), Ministry of Agriculture and Forestry (MAF) are analyzed.

As a part of Task 2: a Multi-hazard Risk Assessment was carried out in key sectors such as transport (road and bridge), irrigation (Irrigation head works and Irrigated area), rural housing and urban land use for Flood, Earthquake, Landslides and Typhoon hazards.

Based on the existing documents and risk assessment, guidelines for hazard assessment of flood, earthquake, landslides and typhoon hazards was developed. Additionally, a risk assessment of transport (road and bridge), irrigation (irrigation head works and irrigated area), rural housing and urban land use sectors for these hazards was produced.

These guidelines are arranged separately for,

- Transport sector
- Irrigation sector
- Rural housing and urban land use

1.2 Objectives

1. To instruct the user/reader how to implement risk assessment for transportation sector, irrigation sector, rural housing and urban land use due to natural hazards including flood, landslide, earthquake, and typhoon.
2. To describe data requirements perform risk assessment for different natural hazards.

1.3 Target Readers

All the officials who are involved in hazard assessment for flood, earthquake, landslides and typhoon hazards. Additionally, officials who are involved in risk assessment of the transport (road and bridge) sector in DoR, the rural housing and urban land use sector in DHUP of MPWT, and the irrigation (irrigation head works and irrigated area) sector in DoI of MAF can use this document for data collection for hazard and risk assessment.

1.4 Structure of Guidelines

This document is for the irrigation sector of MAF. It consists of 3 chapters. Chapter 1 introduces the project and this document. Chapter 2 consists of guidelines for risk assessment of the irrigation sector. Chapter 3 is conclusions and remarks.

2 Procedure and Guidelines for Risk Assessment of Transportation Sector

Introduction

In Lao PDR, existing categories of roads are based on what types of settlements, zones, and districts are connected to the specific road. The existing categories of roads in Lao PDR are:

- National roads – connecting the national capital to the provincial and special zone capitals and to international borders and other major roads of strategic significance for national defense and security
- Provincial roads –linking provinces to the national capital and to other provinces and provincial capitals to districts centers and other important locations within the province
- District roads – connecting districts and district centers to villages and other important locations within the district
- Rural roads – connecting villages to other villages and to production and service centers serving the village
- Special roads –

Road in Lao PDR is shown in Table 2.1 (PTI, 2011).

Table 2.1: Total length of road categories in Lao PDR

Categories of Road	Road Length (km)	Percentage
National	7,225.4	17.6
Provincial	8,097.7	19.7
District	5,270.0	12.8
Urban	2,045.2	5.0
Rural	17,424.5	42.5
Special Roads	980.1	2.4
Total Length (km)	41,042.9	100.0

The road sector contributes greatly to economic growth in Lao PDR. The national road network notably aid in this growth as it connects Lao PDR to neighboring countries like Thailand, Vietnam and China. Rural roads (highest length among the road categories) connect isolated areas, improve welfare, and reduce poverty by providing access to markets and livelihood opportunities in various parts of country.

The road sector is affected by natural hazards, especially flood, landslide and typhoons. The northern part of Lao PDR (mountainous terrain) exists in a high intensity earthquake probability zone. Though severe damage earthquake has not been reported to the road sector so far, it is necessary to understand the risk factors for risk assessment and reduction in future. Therefore, guidelines have been made to collect data and build a disaster risk database suitable for conducting risk assessments. These guidelines consists of data requirement for hazard assessment, updating of the existing GIS database and risk assessment and also risk factors to be considered in planning and design of irrigation infrastructure in future.

What is Risk Assessment?

The International Strategy for Disaster Reduction (ISDR)'s definition of "risk" is adopted which defines risk as "the probability of damage". Risk assessment is the final step leading to inputs for realistic disaster risk management (DRM) planning. Risk assessment quantifies the interaction among the hazard, vulnerability, and exposure factors. The risk factor can be simply represented in the following equation:

$$\boldsymbol{Risk} = (\boldsymbol{Hazard} \times \boldsymbol{Exposure} \times \boldsymbol{Vulnerability})$$

Components of risk assessment are described in Figure 2.1. The risk assessment estimates the level of risk involved with specific sectors.. The risk assessment identified the high-risk areas in the study regions by mapping the geospatial distribution of risks to different sectors. The risk is quantified based on the hazard assessment, exposure assessment outcomes, and vulnerability assessment.

The risk usually refers to damage or loss that the at-risk elements are expected to suffer from the hazard. It is important to distinguish between the damage and loss. However, in this guideline damage refers to physical damage to the elements at-risk, while loss is the monetary consequences of the hazard.

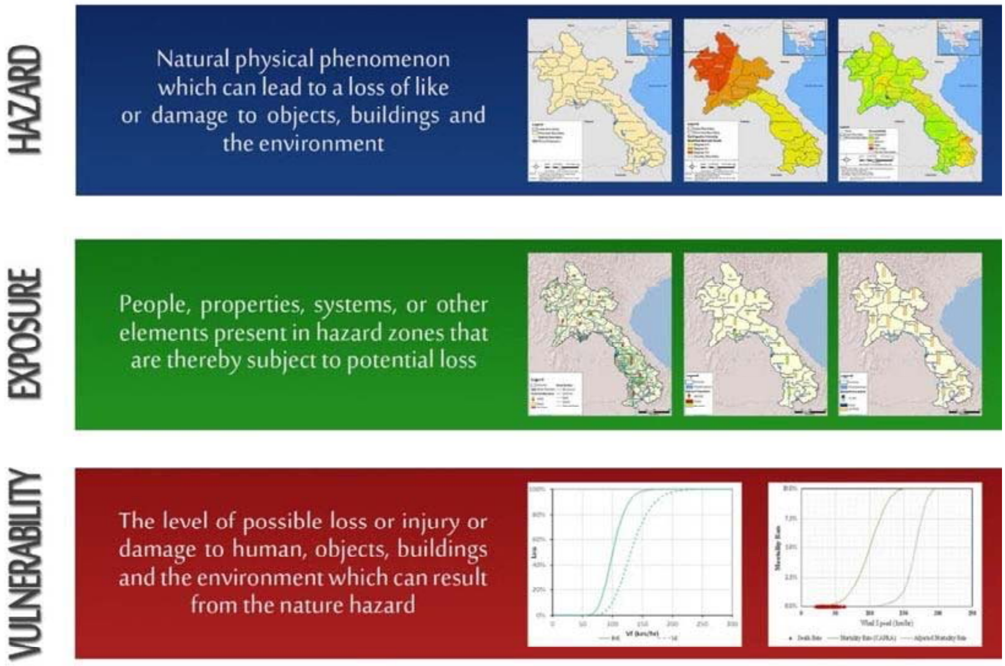


Figure 2.1: Three ingredients of risk assessment

These aspects are discussed in detail for transport, irrigation, rural housing and urban land use sectors separately in three separate documents. In this document, Procedures and Guidelines for Risk Assessment of Transport sector (Road and Bridges) are given.

Estimate of risk due to natural hazard requires experts in each field. The list of experts is described in Table 2.2.

Table 2.2: List of experts in each field that requires for risk assessment

	Hazard	Vulnerability
Flood	Hydrologist, Meteorologist	Structural engineers
Landslide	Geologist, Meteorologist	Structural engineers
Earthquake	Geologists, Seismologists	Structural engineers
Typhoon	Meteorologist	Structural engineers

2.1 Hazard

In the project "Mainstreaming Disaster and Climate Risk Management into Investment Decision" (MDCID), four hazards (flood, earthquake, landslides and typhoon) are considered. In this section, procedure for hazard assessment is discussed.

2.1.1 Flood

In general, a flood hazard assessment is carried out for determining the flood level, which gives a fixed probability of occurrence or return period and can be conducted in various ways depending on the data availability.

The below mentioned steps may be followed for flood hazard assessment.

- The origin and causes of flood are to be observed. These phenomena may vary from region to region.
- Based on such observations in a region, main causative factors for flood are to be assessed.
- Data required for relevant causative factor is to be collected from concerned departments, i.e., Department of Metrology and Hydrology (DMH).
- Most suitable method of hazard assessment is to be selected based on resources available for analysis.

Nature of Flood:

Flood hazards tend to be specific in occurrence both temporally and spatially. They can occur due to intense or prolonged rainfall and a sudden release of water from storage reservoirs or breach of embankments, dams and other flood protection structures. There are a number of factors that contribute to the risk of flooding and determine the level of damage it causes.

Riverine floods can be caused by natural and/or human activities, such as:

- Heavy rainfall (precipitation)
- Erosion and landslides
- Deforestation
- Structural failure (eg. dams, embankments)
- Excessive water releases or breach of water retention structures in upper catchment areas etc.

Factors contributing to flooding:

Meteorological Factors	Hydrological Factors	Human Factors
• Rainfall • Small-scale storms • Snowfall and snowmelt • Cyclones	• Soil moisture level • Level of ground water prior to the storm • Surface infiltration rate affected by vegetation, soil texture, density, structure, soil moisture, etc. • Presence of impervious cover • Hydraulics of overland sub-surface and open channel flow • Channel cross-sectional shape and roughness • Presence or absence of over bank flow • Channel network • Duration of run-off production relative to run-off travel time	• Land-use activities (deforestation, and urbanization) increase the volume and rate of run-off • Occupation of the flood plain • Structural flood control measures • Greenhouse gas emissions which may cause long-term climate change affecting the frequency and magnitude of precipitation events

(Source: WMO, 1999)

The origin of flooding is based on meteorological and hydrological parameters and river basin conditions. The information can be used to determine relationships between meteorological and hydrological parameters and create flood models, along with frequency and general magnitude of floods.

Table 2.2 shows the diagram of data requirement for flood hazard assessment and Table 2.3 describes the source of the data for flood hazard assessment

Figure 2.2: Data requirements for flood hazard assessment

Table 2.3: Source of the data for flood hazard assessment

Data	Possible Source
Hydrology data • Extreme discharge data. • Daily rainfall data. • Rainfall station and discharge station.	• Department of Meteorology and Hydrology (DMH), Lao PDR
Land use/ land cover	• National Geographic Department (NGD), Lao PDR
Elevation	• Aster resolution 30 Meters, http://asterweb.jpl.nasa.gov/gdem.asp
River network and catchments	• Google Earth • National Geographic Department (NGD), Lao PDR

The origin of flooding is based on meteorological and hydrological parameters and river basin conditions. The information can be used to determine relationships between meteorological and hydrological parameters and create flood models, along with frequency and general magnitude of floods.

Information and Data Collection

The information to be collected for the flood hazard assessment will be both quantitative (numeric in nature) or qualitative (cannot be described numerically), information may have to be arranged and assigned a value in order to apply it.

Examples of Quantitative Data: Flood extent in urban area / Hydrological and Meteorological data / Digital Elevation Model (DEM)

Examples of Qualitative Data: Severity of flood

How do you get the above data?

- Records from municipality, water authority, environment agency / ministry.
- Media reports
- Existing documentation for construction and other projects.
- Information or assessment data obtained through PRA techniques.
- Hydrological information from monitoring stations, stream flow and rainfall maps.
- Interviewing the public and experts.
- Site investigations, geophysical tests, vegetation.
- Photos and satellite images of post-flood impact.
- Collecting the data during the events

Basic Principles in Flood Hazard Assessment

Data: Obtaining accurate, consistent and continuous data for a long time period is difficult.. In such circumstances, where the accurate and continuous data is not available, alternative data sources to deal with this situation is provided below:

There are limitations and difficulties when estimation of infrequent floods has to done using the data obtained through short observation periods. For example it is difficult to gain knowledge on the 100-year flood, as there will be little data because of its rare occurrence. In this case, supplementary information from the following two methods can be useful:

1. Regionalisation: This approach is based on the assumption that within a homogenous region floods which frequently curve at various sites are similar to hydrological and meteorological characteristics of individual sites. In essence, data from several sites are pooled together to produce a larger sample than is available as a comprehensive region. Although the advantage may be offset by correlation between sites, however, this is a more robust study than using flood frequency analysis at a single site.

2. Paleo-flood and historical data: Paleo-flood data is derived from the geological / geomorphologic and botanical evidence of past floods. Historical data refers to information on floods that occurred before the existence of systematic stream-gauging measurements. It may be in the form of a specific stage, date of occurrence or knowledge that the flood has exceeded a certain level during a certain time.

Alternative data sources and methods

Assessment based on observations of extent of past flooding: Ground observations, aerial photographs or satellite imagery, as well as geomorphologic or soil studies, all carried out after flooding, can be used to determine the area flooded and delineate the floodplain.

Rainfall run-off models use mathematics to predict the discharge of the river as a function of the rainfall. They tend to be used for return intervals greater than 100 years or for sites where there are less than 25 years of streamflow records. Hypothetical storms can be used to model the run-off. One of these storms could be the Probable Maximum Precipitation (PMP), the largest amount of rainfall that could occur in the given watershed. The PMP is used to model the Probable Maximum Flood (PMF). Precipitation records over time can be used to determine normal and average daily precipitation for that location during particular times of the year. A normal rainfall pattern can be assigned to it and all rainfall can be classified as being greater or less than the average rainfall.

Watershed with limited topography data

It is difficult to do any hazard assessment in areas without topographic data. It might be possible to carry out community-based flood and risk assessments, but they are only suitable for small areas. These small area maps can be integrated to prepare a bigger area map. It can be made more accurate with the support of GPS measurements. It can also be augmented with spot heights through ground measurements to define topography. At present, there are many remote sensing (RS) and GIS methods available for developing digital elevation models and with adequate resources this problem can be overcome easily. Otherwise simple inundation maps can be prepared using assessments based on observations of extent of past flooding as explained above.

Watersheds with no data

If sufficient regional discharge data is available regional flood frequency curves or regional regression equations can be used for un-gauged watersheds. Regional regression equations relate to peak flow at a specific return period to physiographic characteristics such as area extent, slope, altitude, etc. (WMO, 1999).

Secondary hazards to flood hazard

Where flooding occurs, there may be occurrence of other hazards. These may include secondary hazards, which are triggered by the primary hazard (flooding). Landslides, riverbank erosion, building collapse, transport accidents, leak of toxic substances, epidemiological concerns and the failure of flood control structures are all associated with floods.

The aforementioned information and data are required to do flood hazard assessment. The assessment should be done by hydrologists, while data (i.e. rainfall and typhoon) should be provided by meteorologists.

2.1.2 Landslide

Figure 2.3 shows the diagram of data requirement for landslide hazard assessment and Table 2.4 describes the source of the data for landslide hazard assessment

Figure 2.3: Data requirements for landslide hazard assessment

Table 2.4: Source of the data for landslide hazard assessment

Data	Source
Elevation	• Aster resolution 30 m, http://asterweb.jpl.nasa.gov/gdem.asp
Land use/ land cover	• National Geographic Department (NGD), Lao PDR
Geological map of Lao PDR	• Department of Mines and Geology (DMG), Lao PDR
Precipitation data	• Department of Meteorology and Hydrology (DMH), Lao PDR

The country of Lao PDR is prone to landslides. However, the landslide inventory in Lao PDR is still under development and does not cover the whole country. An existing landslide hazard inventory plays an important role in determining the indicators for landslide. The factors which are affecting landslides are,

- Topography - slopes and hilly areas.
- Characteristics of soil type (parameters such as cohesion, consolidation, etc.).
- Soil strength.
- Saturation.

- Vegetative cover.
- Loading on soil (buildings, roads, additional water from rainfall).
- Sub-surface formations (geology, fracture density, etc.).

Among the above factors, the major triggering factor for landslides is heavy precipitation, especially in the northern provinces of Lao PDR whereas the topography is dominated by mountainous terrain. Lao PDR has a tropical monsoon climate. The climate is hot and tropical, with the rainy season between May and October, when temperatures are at their highest. Other principal factors that influence landslide are slope gradient, rock condition (lithology), and land use.

Data availability is especially relevant in developing countries, where data is scarce or not in the appropriate format. Furthermore, the level of analysis is relevant as it determines the quantity of data, in terms of area coverage and detail. National level assessment involves small-scale input data, which is generalized and which determines the analysis method that can be used (Abella and van Westen, 2007). Therefore the model is constrained by data availability and level of analysis. Considering the limited available data, a semi-quantitative approach has been used to come up with a national landslide hazard assessment. A Landslide hazard zone is developed using a set of maps comprising of criteria selected from slope angle, land use, lithology and rainfall maps. These four maps have been overlaid using a weighing method. The final landslide hazard index was done by summing up the weight of the determined factors.

The aforementioned information and data are required to do landslide hazard assessment. The assessment should be done by geologists, while data (i.e. rainfall and typhoon) should be provided by meteorologists.

2.1.3 Earthquake

Figure 2.4 shows the diagram of data requirement for earthquake hazard assessment and Table 2.5 describes the source of the data for earthquake hazard assessment

Figure 2.4: Data requirements for earthquake hazard assessment

Table 2.5: Source of the data for earthquake hazard assessment

Data	Source
Earthquake catalog for Lao PDR area	• U.S. Geological Survey (USGS), http://earthquake.usgs.gov/earthquakes/eqarchives/epic/
Soil Profile • Average shear velocity down to 30 m (Vs30)	• U.S. Geological Survey (USGS), http:// http://earthquake.usgs.gov/hazards/apps/vs30/predefined.php

A large number of earthquakes have been reported in the past along the Thailand-Laos-Myanmar border region. However, impact of earthquakes on Lao PDR so far has been light. Recent earthquakes did not have their magnitude large enough or their origins too far away from populated areas to cause trouble to buildings and infrastructure. They were however felt by people in various Northern provinces. Nevertheless, an analysis of the possible maximum magnitude earthquakes indicates that the northern part of Pak Beng-Luang Prabang areas are capable of generating an earthquake annually with magnitude of 4.0 - 5.0 and that an earthquake of magnitude 7.0 is possible within 50 years (Pailoplee et. al, 2013). This kind of earthquake can cause serious consequences if proper preventive measures are not in place.

The earthquake phenomena primarily can induce ground ruptures and ground shaking, along with secondary effects such as liquefaction, landslides and ground settlement. Ground rupture is the movement along one side of a fault relative to the other side, and ground shaking is caused by the passage of seismic waves. Liquefaction is a process by which water-saturated sediment temporarily loses strength and acts as a fluid, like when you wiggle your toes in the wet sand near the water at the beach. This effect can be caused by earthquake shaking. Though these phenomena are not so destructive so far, but can be deadly and pose a real and serious threat to the life of people, property damage, economic growth and development of the country. A proper understanding of the distribution and detailed level of seismic hazard throughout the country is therefore necessary. It is suggested that probabilistic seismic hazard assessment for Lao PDR is necessary.

In lieu of dedicated probabilistic hazard maps, the earthquake hazard map for Lao PDR can be extracted from global earthquake maps developed as a part of the Global Seismic Hazard Assessment Program (GSHAP), which is available on its website (http://www.seismo.ethz.ch/static/GSHAP/). This map uses the Peak Ground Acceleration (PGA) values as a proxy for the earthquake intensity. They are further reclassified into 4 earthquake hazard categories through MMI scale: Negligible, low, moderate and high. The MMI scale is one of the simple indicators for understanding the severity of earthquake hazards.

Earthquake Hazard Category	MMI Scale	PGA Value (g)
High	VIII	0.32 – 0.59
Moderate	VII	0.168 – 0.31
Low	VI	0.090– 0.167
Negligible	I - V	0.0014 – 0.089

In most hazardous earthquake zone (high), local level micro seismic zonation map is required. A micro seismic zonation consists of three components:

- A seismic hazard analysis is based on knowledge of fault pattern and structural geology, that results in a specification of probable locations and depths of hypocenters and earthquake intensity

- Detailed characterization of the subsurface (soil profiles, groundwater levels, and geotechnical parameters such as shear-wave velocity, plasticity index, and unit weight)
- Modeling the propagation of the seismic waves through the subsurface will provide spatial variability of expected ground motion or PGA.

The aforementioned information and data are required to do seismic hazard assessment. The assessment should be done by geologists and/or seismologists.

2.2 Exposure

Development of a GIS database is required for exposure assessment. The development of a GIS database for transportation sectors is very important because this data represents the location of the roads and bridges. In case of any disastrous event, roads and bridges are very important for transporting for the relief and rescue operations. In case of risk assessment of such lifelines is available, before an event occurs, preparedness plans can determine which road or bridge will be damaged from a natural hazard. In view of this, it is important that this database is developed for Lao PDR. Since the transportation sector database already exists, an explanation of how to update the database is explained in the following sections.

2.2.1 Existing Transport Sector Database

Transportation sector data consisting of roads and bridges is considered for the risk assessment. The road network data, as a GIS database consists of a road network shape file (polyline) and attribute data. Attribute data consists of road types by category, pavement type, road condition and road no, shown in Figure 2.5. Details of these attributes are given in Table 2.6.

Table 2.6: Details of the road attribute data

Categories of Roads	Pavement Type	Road Condition	Road No.
1 – National	1 – Paved (Concrete)	1 = excellent	1 – 1A
2 – Provincial	2 - Paved (Asphalt)	2 = good	2 – 13 N
3 – District	3 –Gravel	3 = fair	3 – 13 S
4 – Urban	4 - Earth	4 = bad	4 – 2 W
5 – Rural	5 - Planned Road	6 = failed	
6 – Special Roads			

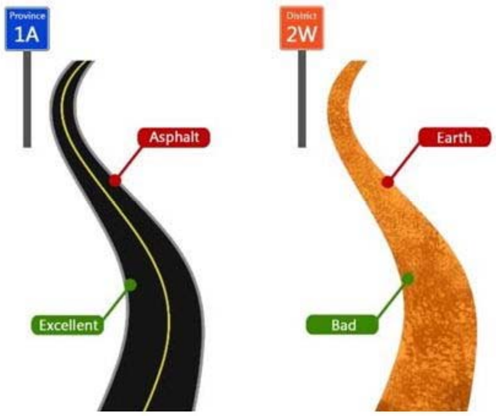
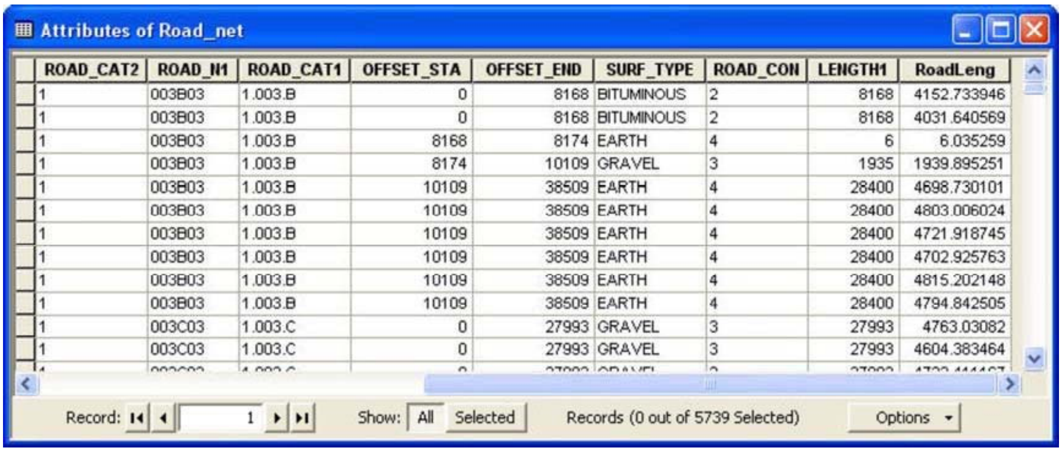


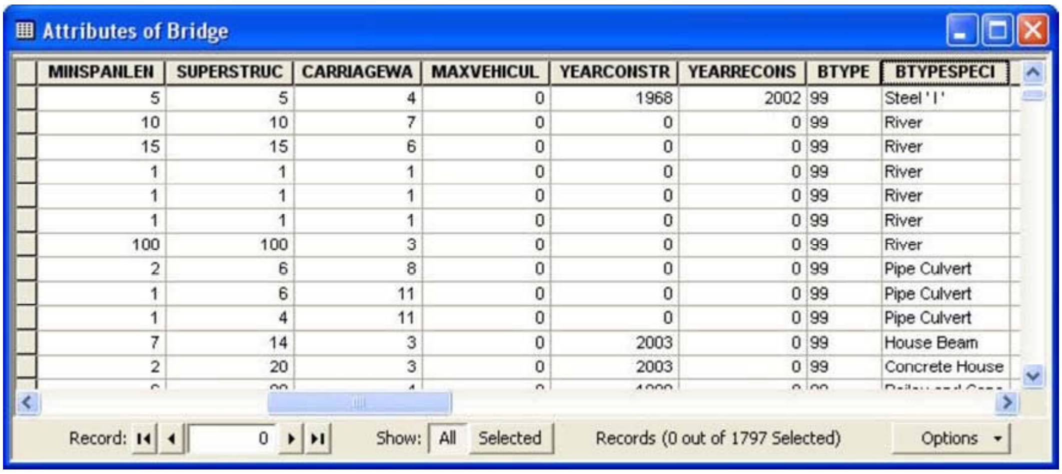
Figure 2.5: Example of attribute data of road

In Lao PDR, the road sector data are available at Department of Roads (DoR). Example of GIS database from Lao PDR shows in Figure 2.6. and Figure 2.7



ROAD_CAT2	ROAD_N1	ROAD_CAT1	OFFSET_STA	OFFSET_END	SURF_TYPE	ROAD_CON	LENGTH1	RoadLeng
1	003B03	1.003.B	0	8168	BITUMINOUS	2	8168	4152.733946
1	003B03	1.003.B	0	8168	BITUMINOUS	2	8168	4031.640569
1	003B03	1.003.B	8168	8174	EARTH	4	6	6.035259
1	003B03	1.003.B	8174	10109	GRAVEL	3	1935	1939.895251
1	003B03	1.003.B	10109	38509	EARTH	4	28400	4698.730101
1	003B03	1.003.B	10109	38509	EARTH	4	28400	4803.006024
1	003B03	1.003.B	10109	38509	EARTH	4	28400	4721.918745
1	003B03	1.003.B	10109	38509	EARTH	4	28400	4702.925763
1	003B03	1.003.B	10109	38509	EARTH	4	28400	4815.202148
1	003B03	1.003.B	10109	38509	EARTH	4	28400	4794.842505
1	003C03	1.003.C	0	27993	GRAVEL	3	27993	4763.03082
1	003C03	1.003.C	0	27993	GRAVEL	3	27993	4604.383464

Figure 2.6: Example of GIS database for roads in Lao PDR



MINSPANLEN	SUPERSTRUC	CARRIAGEWA	MAXVEHICUL	YEARCONSTR	YEARRECONS	BTYPE	BTYPESPECI
5	5	4	0	1968	2002	99	Steel ' I '
10	10	7	0	0	0	99	River
15	15	6	0	0	0	99	River
1	1	1	0	0	0	99	River
1	1	1	0	0	0	99	River
1	1	1	0	0	0	99	River
100	100	3	0	0	0	99	River
2	6	8	0	0	0	99	Pipe Culvert
1	6	11	0	0	0	99	Pipe Culvert
1	4	11	0	0	0	99	Pipe Culvert
7	14	3	0	2003	0	99	House Beam
2	20	3	0	2003	0	99	Concrete House

Figure 2.7: Example of GIS database for bridges in Lao PDR

2.2.2 Updating of Existing Transport Sector Database

Road

Updating the GIS road network database has two components:

1. Updating attribute data of existing GIS database of roads (change in road category, change in pavement type, change in road condition and change in road number etc.), this should be continued on regular basis.

   Example:

   - If Provincial road is converted to National road, change road category code from 2 to 1.
   - If a road number is changed, change it accordingly.
   - If pavement (surface) type is changed from earth to gravel (change the code from 4 to 3), gravel to bituminous (3 to 2), gravel to concrete (3 to 1) .....
   - If road condition is changed fair to excellent (change code from 3 to 1)...

2. Additional attribute data which can be added to the road network database is:
    - Width of the road
    - Type and extent of damage of road sections due to natural events (if any)
    - Repairs carried out for type of damage
    - Details of road closure due to damage and its impact
    - Volume and type of traffic on important road sections
    - Surface type laid (month-year)
    - Last change of surface type (bituminous to concrete etc.)
    - Last change of road category (district road to provincial road etc.)
    - Information on availability of alternate routes for important road sections
    - What is alternate route?

3. Adding new road network data in a GIS database and updating relevant attributes.

This can be carried out using the approved road alignment plans and relevant data of road network mentioned above.

<u>Bridge</u>

Bridges are an important component of the transport sector in Lao PDR. Similar to road data, updating bridge data also has two components.

1. Updating attribute data of existing GIS database of bridges. The important attribute data available for bridges is:
    - Type of bridge
    - Bridge material
    - No. of spans
    - Length of the spans (maximum and minimum)
    - Year of construction

    In addition of this it is suggested to add the below mentioned additional attribute data, which will help in risk assessment

    - Designed flood level of the bridge site
    - Highest flood level observed at the bridge site
    - Catchment area of the river
    - Type and extent of damage of bridge due to natural events, if any
    - Repairs carried out for type of damage
    - Details of bridge closure due to damage and its impact
    - Volume and type of traffic
    - Information on availability of alternate routes
    - What is the alternate route?

2. Adding of new bridge data in GIS database and updating relevant attributes.

This can be carried out using the approved bridge location plans and relevant data of bridge mentioned above.

2.2.3 New Transport Sector Database

Instead of a risk assessment, a new transportation system utilized a safeguard assessment, which is beyond the scope of this guideline. The principles of a safeguard assessment for a new transportation system are described in Environmental and Social Operations Manual (ESOM) (DOR, 2009). It is noted that data requirement of a new transportation system should be based on the existing database attributes which are described in Section 2.2.1.

2.3 Vulnerability

Vulnerability is represented by a damage function, which indicates the percentage of damage expected in a house/building based on structural type (road surface/bridge type) and hazard intensity. The development of damage or vulnerability functions requires experts with knowledge of damage patterns and causative factors of the damage, which generally comes from years of experience and practice of engineering principles. This guideline does not intend to guide its readers to develop new damage functions. Rather it intends at providing broad information on the methodology for developing the damage functions and, more importantly, the required data and its format. This would allow the readers to understand the process and can collect the data that will be useful for improving the vulnerability calculation.

One methodology to construct a damage function is development from historical damage data and corresponding hazard intensity which may be collected from reports and/or field survey. The field survey form may include, for example:

- Road/bridge ID
- Location (GPS coordination)
- Road/bridge description (2 lanes, 4 lanes, etc.)
- Road surface type and length
- Bridge structural type and span length
- Road and bridge value/construction cost
- Damage and loss from each hazard and corresponding the hazard intensity

The example of the road and bridge damage show in Figure 2.8.

Figure 2.8: Road and bridge damage

Once the historical damage data and corresponding hazard intensity has been gathered, they will be plotted and determine their relationship by regression analysis. It must be noted that the damage function developed from this method has to have a lower bound 0% of loss and the upper bound less than or equal 100% of loss. Then, the developed damage function has to be validated and improved when there are more damage data. In the case where there is no vulnerability function available like in the case of Lao PDR, a risk matrix based on historical data or expert judgment can be used.

2.3.1 Flood

Road

Vulnerability of roads to flood events is represented by fragility or damage curve, which indicates percentage of damage expected to road based on type of road surface and flood velocity. It should be developed for local conditions, based on the past damage history. In the case of no vulnerability function available, a risk matrix based on historical data or expert judgment can be used. In addition, if flood velocity is not available, flood depth is used instead based on the velocity profile in Figure 2.9. The example of risk matrix shows in Table 2.7.

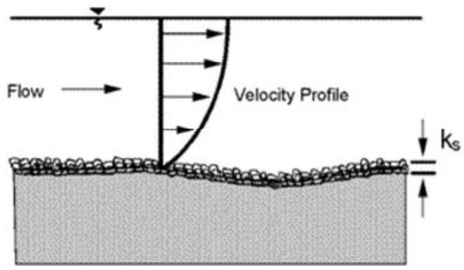


Figure 2.9: Typical boundary-layer velocity profile

Table 2.7: Risk matrix of road surface type due to flood

Flood Level (m)	Road Surface Type			
	Concrete	Asphalt Concrete (Bituminous)	Gravel	Earth
No Flood	None	None	None	None
< 0.3	Low	Low	Moderate	High
0.3 - 1.0	Low	Moderate	High	Very High
1.0 - 2.0	Moderate	High	High	Very High
> 2.0	Moderate	High	Very High	Very High

Possible damages can be recorded as indicated below.

Damage Code	Damage Category	Percentage of Damage
ND	No Damage	0
D 1	Low	1-15
D 2	Moderate	15–35
D 3	High	36-60
D 4	Very High	>=61

Addition data is required for development of road vulnerability/damage functions due to most frequent flood. It is proposed that this data may be collected locally, by concerned DoR staff. It is observed that most of the damage to the roads is due to improper drainage conditions. The following additional data is to be collected, which can be supplemented to the attribute data in GIS database.

- History of damage of road due to flood
- Last damage of road reported due to Flood
- Depth and duration of flood at damaged road
- Extent of damage reported
- Number of hours of road closure

Bridge

Vulnerability of bridge to flood is represented by a fragility or damage curve, which indicates percentage of damage expected to bridge based on type of bridge and flood velocity. The vulnerability function should be developed for local conditions, based on the past damage history. In case of no vulnerability function available, a risk matrix based on historical data or expert judgment can be used. In addition, if flood velocity is not be available, flood depth is used instead based on the velocity profile in Figure 2.9. The example of risk matrix shows in Table 2.8.

Table 2.8: Risk matrix of bridge for flood hazard

Flood Level (m)	Bridge Material				
	Concrete	Concrete-Steel	Steel	Timber	Others
No Flood	None	None	None	None	None
< 0.3	Low	Low	Low	Moderate	Moderate
0.3 - 1.0	Low	Low	Low	High	High
1.0 - 2.0	Moderate	Moderate	Moderate	Very High	Very High
> 2.0	High	High	High	Very High	Very High

Addition data is required for bridges, which are subjected to damage due to the most frequent flood. This data should be collected locally by trained DoR staff. It is observed that most of the damage to the bridge is due to improper assessment of hydrologic / drainage conditions. The following additional data is to be collected for each cross drainage structure on the road, which can be supplemented to the attribute data in GIS database.

- History of damage due to flood
- Existing drainage infrastructure
- Last damage of bridge reported due to flood
- Depth and duration of flood at damaged bridge
- Extent of damage reported
- Number of hours of bridge closure

2.3.2 Landslide

Road

Vulnerability of roads to landslide is represented by the fragility or damage curve, which indicates percentage of damage expected to road based on type of road surface, landslide type and intensity. The vulnerability function should be developed for local conditions, based on the past damage history. In case of no vulnerability function available, a risk matrix based on historical data or expert judgment can be used. Additionally, when landslide type and intensity are not be available, landslide susceptibility can be used instead. The example of risk matrix shows in Table 2.9.

Table 2.9: Possible damages to different road surface types to landslide

Landslide Susceptibility	Road Surface				
	Concrete	Asphalt Concrete (Bituminous)	Earth	Gravel	Planned
Negligible	None	None	None	None	None
Low	Low	Low	Low	Low	None
Medium	Moderate	Moderate	Moderate	Moderate	None
High	High	High	Very High	Very High	None
Very High	Very High	Very High	Very High	Very High	None

Bridge

The vulnerability of bridges to landslides is represented by fragility or damage curve, which indicates percentage of damage expected to bridge based on type of bridge, landslide type and intensity. Vulnerability function should be developed for local conditions, based on the past damage history. In case of no vulnerability function available, a risk matrix based on historical data or expert judgment can be used. Additionally, when landslide type and intensity are not be available, landslide susceptibility can be used instead. The example of risk matrix shows in Table 2.10.

Table 2.10: Possible damages to different bridges based on material due to landslide

Landslide Susceptibility	Bridge Material				
	Concrete	Concrete-Steel	Steel	Timber	Others
Negligible	None	None	None	None	None
Low	Low	Low	Low	Moderate	Moderate
Medium	Low	Low	Low	High	High
High	Moderate	Moderate	Moderate	Very High	Very High
Very High	High	High	High	Very High	Very High

2.3.3 Earthquake

Road

The vulnerability of roads to earthquakes is represented by fragility or damage curve, which indicates percentage of damage expected to road based on type of road surface and seismic intensity. The example of damage functions for road due to earthquake show in Figure 2.10. Vulnerability function should be developed for local conditions, based on the past damage history.

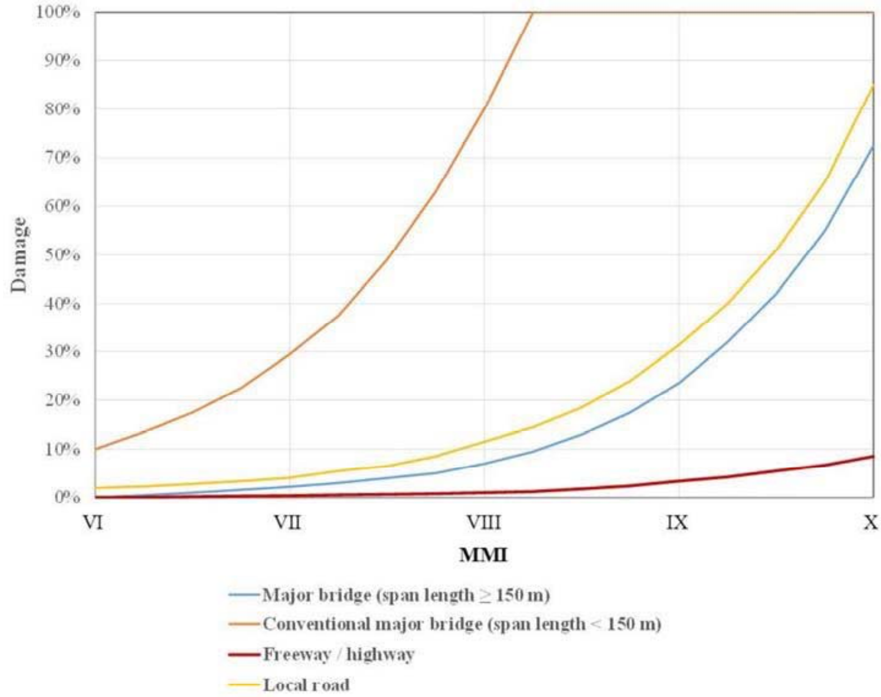


Figure 2.10: Modified damage functions for road and bridge due to earthquake (FEMA 224, 1991)

Bridge

The vulnerability of bridges to earthquake is represented by the fragility or damage curve, which indicates percentage of damage expected to bridge based on bridge type and seismic intensity. The example of damage functions for road due to earthquake show in Figure 2.10. Vulnerability function should be developed for local conditions, based on the past damage history.

2.4 Risk Assessment

Integrating hazard map, elements at risk, and vulnerability/damage functions (risk matrixes), as shown in Figure 2.11, the exposure can be transformed into risk. Risk assessment procedure for each hazard (flood, earthquake, landslide, and typhoon) is described in the following sections.

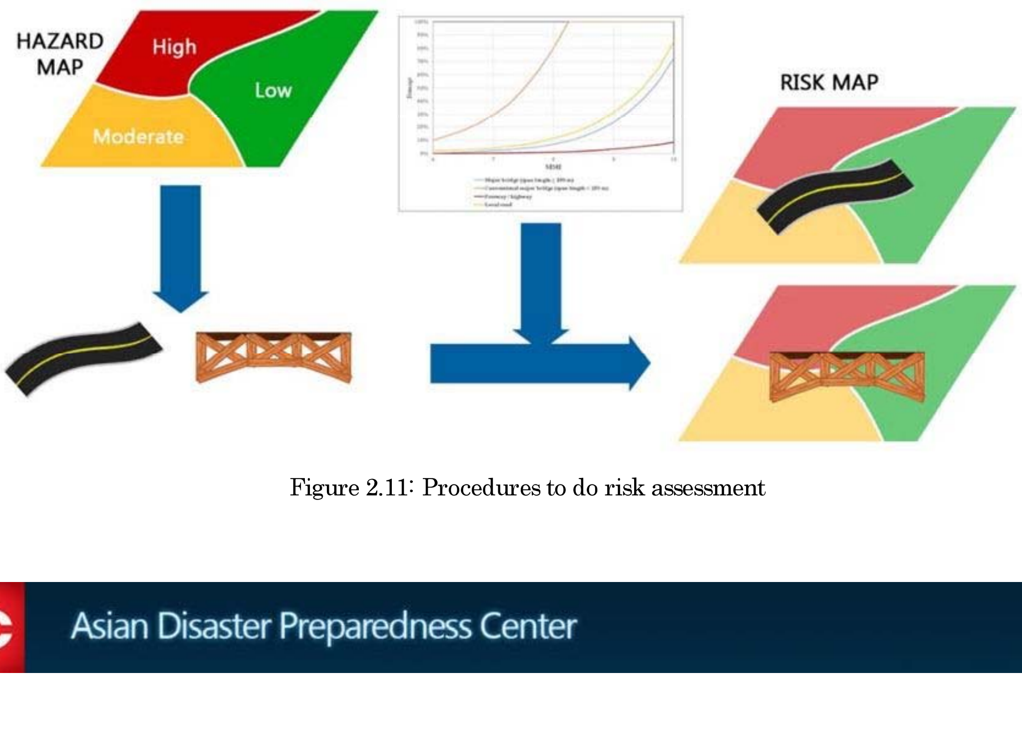


Figure 2.11: Procedures to do risk assessment

Two methodologies to assess risk based on the availability of vulnerability/damage functions are quantitative and qualitative analyses. In case of vulnerability function available, a quantitative risk assessment is done. While there is no vulnerability function available, a qualitative risk assessment is done.

2.4.1 Flood

Road

The risk of the transport sector (road) explained in this guideline is qualitatively assessed, due to lack of quantitative data on damage functions due to flood.

Suppose that a road with 15 km of concrete and 10 km of asphalt concrete exposed to flood depth of 0.7 meter, as shown in Figure 2.12. Based on the road surface and the risk matrix (cf. Table 2.7), risk to the road is low for concrete surface and moderate for asphalt concrete surface. Given that unit risk score 0, 1, 2, 3, 4, and 5 for none, low, moderate, high, very high levels, respectively, the risk score is computed by multiplying road length with its unit risk score for each level. The risk score of the concrete and asphalt concrete surface roads is equal to 15 and 20, respectively. Then, total risk score for this road is 35.

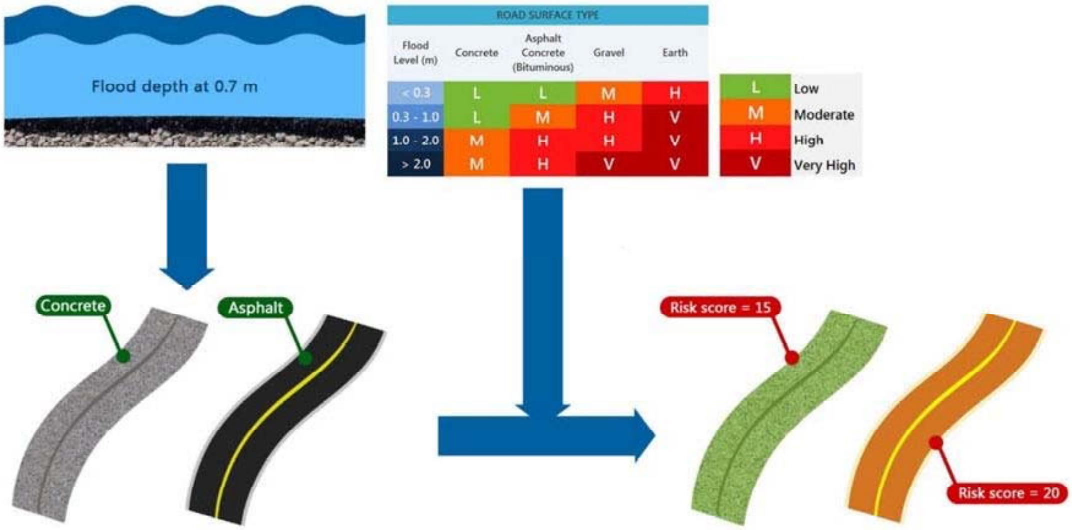


Figure 2.12: Example of flood risk assessment of road

Bridge

The risk of transport sector (bridge) that is illustrated in this guideline is qualitative risk assessment, due to lack of quantitative data on damage due to flood.

Suppose that a wooden bridge exposed to flood depth of 0.6 meter, as shown in Figure 2.13. Based on the bridge type and the risk matrix (cf. Table 2.8), risk to the bridge is high level. Given that unit risk score 0, 1, 2, 3, 4, and 5 for none, low, moderate, high, very high levels, respectively, the risk score of this bridge is equal to 4.

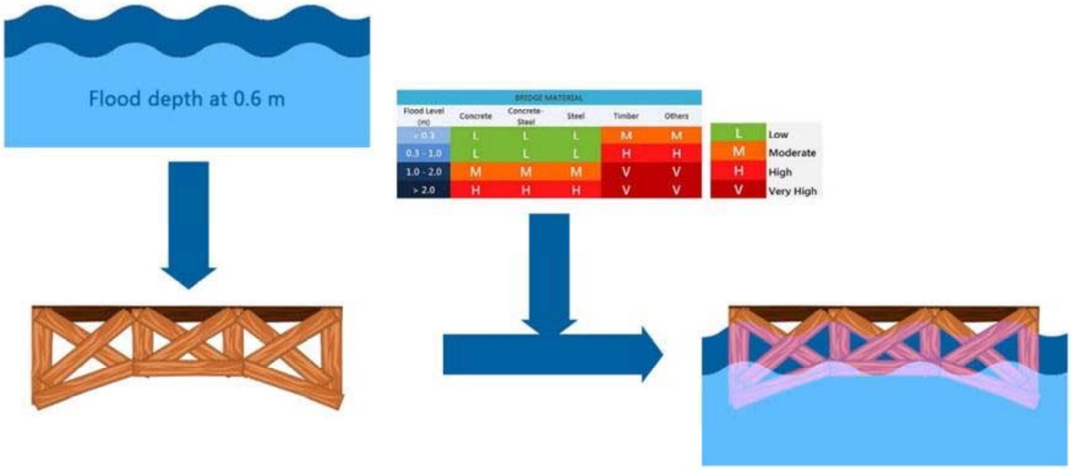


Figure 2.13: Example of flood risk assessment of bridge

2.4.2 Landslide

Unlike the other hazards, a susceptibility map is used for landside risk assessment instead a hazard map. Integrating landslide susceptibility map, elements at risk, and vulnerability/damage functions (risk matrixes), the exposure can be transformed into risk.

Road

The risk of the transport sector (road) explained in this guideline is qualitatively assessed, due to lack of quantitative data on damage functions due to landslide.

Suppose that a road with 15 km of concrete and 10 km of earth surface exposed to high level of landslide susceptibility, as shown in Figure 2.14. Based on the road surface and the risk matrix (cf.Table 2.9), risk to the road is high level for concrete surface and very high level for earth surface. Given that unit risk score 0, 1, 2, 3, 4, and 5 for none, low, moderate, high, very high levels, respectively, the risk score is computed by multiplying road length with its unit risk score for each level. The risk score of the concrete and earth surface roads is equal to 60 and 50, respectively. Then, the total risk score for this road is 110.

An alternative methodology is a road slope risk assessment exposed to landsides developed by Japan Road Association (1988). This approach requires the data given in Table 2.11.

Based on the data from the field in Table 2.11, 'Assigned Weight' column is filled using the reference weight provided in 'Weight' column. The assessment of stability is determined by using only Table 2.12(a), assess the stability of the road section if there is no retaining wall to the road. In case a retaining wall exists, both Table 2.12(a) and (b) are also used to assess the stability of the road section.

This methodology can be replicated throughout Lao PDR to assess road slope risk, which will help the concern authorities to plan the landslide prevention and mitigation measures in the road development sectors.

Figure 2.14: Example of landslide risk assessment of road

Table 2.11: Road slope risk assessment calculations

Location No.:	Road Section:	Location:	
Road:	Chainage:	Side way:	
Item	Category	Weight	Assigned Weight
(1) Height of slope, H (m)	50 m ≤ H 30 m ≤ H < 50 m 10 m ≤ H < 30 m H < 10m	10 8 7 3	
(2) Angle of slope, α	1:0.6 ≤ α 1:1.0 ≤α < 1:0.6 α < 1:1.0	7 4 1	
(3) Overhang	Formed in no walled Slope Formed in walled Slope Not formed	7 4 1	
(4) Geology	Many unstable stones Many stones on the surface of slope Very weathered rock Gravelly soil Weathered rock Cracked rock Sand Clay Intact rock	10 7 6 5 4 4 4 1 0	
(5) Thickness of weathered soil layer	More than 0.5 m Less than 0.5 m	3 0	
(6) Water flow	Flow No flow	2 0	
(7) Frequency of rock fall	More than once per year Less than once per year None	5 3 0	
		Total Weights	

Table 2.11: Road slope risk assessment calculations (cont')

Item	Category	**Weight**	Assigned Weight
(8) Deformation of slope	Deformed Not deformed	I III	
(9) Deformation of retaining wall	Deformed Not deformed	I III	
(10) Rock fall which induce traffic problem	Occurred Not occurred	I III	
(11) Cut or fill on slope	Many cut or fill Few cut or fill Nothing	I II III	
		Total Weights	
(12) Stability of retaining walls	Unstable Stable Very stable	I II III	
		Total	

Table 2.12: Assessment of stability

(a) Without retaining wall (stage 1)

Summation of weights from (1) to (7) / Weighting based on (8) to (11)	Less than 13 (A)	14 to 23 (B)	More than 24 (C)
Class I ≥ 1			
One class II, other class III			
All class III			

(A): Slope failure likely; (B): Slope failure probable; (C): Slope failure not likely

(b) With retaining wall (stage 2)

Stage 1 / Rank in (12)	(A)	(B)	(C)
I			
II			
III			

(A): Slope failure likely; (B): Slope failure probable; (C): Slope failure not likely

Source: Japan Road Association, 1988

Bridge

The risk of the transportation sector (bridge) that is illustrated in this guideline is qualitative risk assessment, due to lack of quantitative data on damage due to landslide.

Suppose that a concrete bridge exposed to high level of landslide susceptibility, as shown in Figure 2.15. Based on the bridge type and the risk matrix (cf. Table 2.10), risk to the bridge is moderate level. Given that unit risk score 0, 1, 2, 3, 4, and 5 for none, low, moderate, high, very high levels, respectively, the risk score of this bridge is equal to 2.

Landslide Susceptibility	Bridge Material: Concrete	Concrete-Steel	Steel	Timber	Others
Negligible	N	N	N	N	N
Low	L	L	L	M	M
Medium	L	L	L	H	H
High	M	M	M	V	V
Very High	H	H	H	V	V

N	None
L	Low
M	Moderate
H	High
V	Very High

Figure 2.15: Example of landslide risk assessment of bridge

2.4.3 Earthquake

<u>Road</u>

The risk of transportation sector (road) to earthquake in this guideline is only quantitatively assessed because damage functions based on road category (highway and local road) to earthquake are available. Then, roads which different surface types have to be grouped into highway or local road prior estimation of risk.

Suppose that 15 km of concrete and 10 km of earth surface roads are in MMI VIII zone, as shown in Figure 2.16. The concrete and earth surface roads are grouped into highway and local road, respectively. Based on the road category and the modified damage functions (cf. Figure 2.10), damage to the road is 2% for highway and 12% for local road. The expected damage for highway is 0.3 km (15 km * 2%) and for local road is 1.2 km (10 km * 12%). The total damage length is 1.5 km (6%). Let the damage levels of 0%, 0-10%, 10%-25%, 25%-50%, and 50%-100% are none, low, moderate, high, very high risk. Then, the total risk of these roads is low.

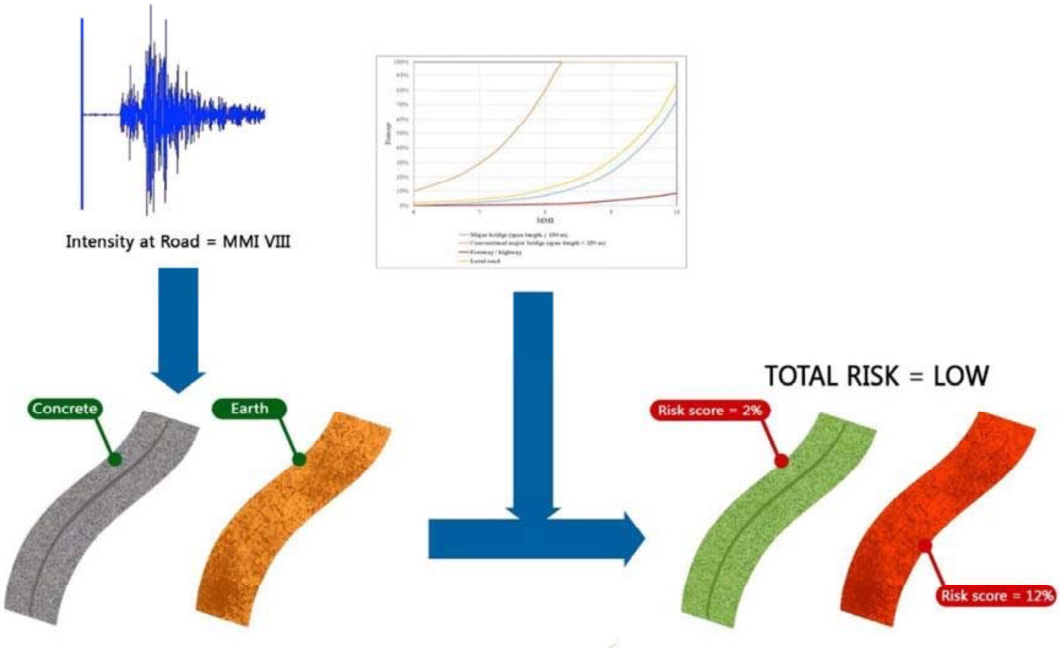


Figure 2.16: Example of earthquake risk assessment of road

Bridge

The risk of transportation sector (bridge) to earthquakes in this guideline is only quantitatively assessed because damage functions based on bridge category (major and minor bridges) to earthquake are available.

Suppose that a bridge with span length 50 meters is in MMI VII zone, as shown in Figure 2.17. Based on the bridge category and the modified damage functions (cf. Figure 2.10), damage to the bridge is 30%. Let the damage levels of 0%, 0-10%, 10%-25%, 25%-50%, and 50%-100% are none, low, moderate, high, very high risk. Then, the risk of this bridge is high.

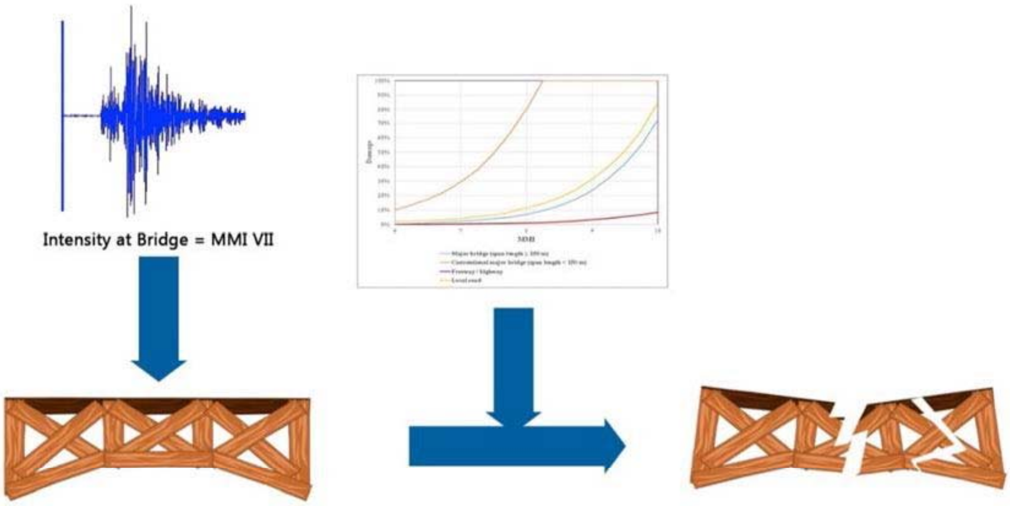


Figure 2.17: Example of earthquake risk assessment of bridge

3 Concluding Remarks

Since gaining independence in 1975, the Government of Lao PDR has emphasized the importance of infrastructure development, particularly the road sector, as the key in the country's development. In the absence of a railway system and access to the sea, Lao PDR depends primarily on road transport and, to less extent, on river and air transport. The development and maintenance of an efficient transport system is of paramount importance for regional integration and socio-economic development of the country. The road network carries 90% of passenger traffic (passenger-km) and 61% of freight traffic (ton-km).

Lao PDR has experienced several natural disasters such as flood, landslides and typhoons, all of which can affect the road sector significantly. Even though there is no major damage reported to road network due to earthquakes, the area is prone to high intensity earthquakes, and therefore it is necessary to understand the possible risk due to earthquakes.

In this document, an attempt has been made to provide guidelines for risk assessment due to flood, earthquake, landslides, and typhoons, along with data requirements for hazard assessment in future.

3.1 Road and Bridges

The Public Work and Transport Institute (PTI) of the Ministry of Public Works and Transport maintains an updated database of the road network in the country in tabular form. However, a GIS database also exists within the Environmental and Technical Division (ETD), which has been used in this project. However, it is not updated as tabular data. In view of this, the necessity of updating of GIS database of road network and also bridges, with additional attribute data is given in this document.

Along with updating of GIS database, there is a necessity of collecting additional data for flood, landslide, earthquake, and typhoon hazards for the assessment in future. Vulnerability of road to these hazards is assessed based on literature for earthquake and qualitatively for flood and landslide hazards. It is necessary to collect data for a vulnerability assessment, which is explained in this document, which will be useful in risk assessment in future.

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APPENDIX-E

LOW VOLUME RURAL ROAD

ENVIRONMENTALLY OPTIMISED DESIGN MANUAL

MINISTRY OF PUBLIC WORKS AND TRANSPORT

Low Volume Rural Road Environmentally Optimised Design Manual

April 2009

Typical low volume rural road in Lao PDR

CONTENTS

Glossary

Access	The ability to travel, for which adequate vehicles and infrastructure are required.
Armoured gravel	Specified natural gravel laid to camber and compacted overlain by a protective armouring (usually 75mm thick) of crushed stone aggregate laid to camber and compacted
Base	A pavement layer of medium to high strength material and on which the surface is constructed.
Bituminous seal	A thin surface comprising bitumen and either single sized chips (giving DBST) or graded aggregate (giving an Otta seal).
Budget	The funding available for the construction or maintenance of a road.
Capping	A low strength soil which can be placed onto a subgrade in order to reduce the required thicknesses of the pavement layers above and to provide a working platform for the construction
Chainage	The measurement of distance along the road, normally starting from 0+000.
Cross section	A section of road and terrain taken right angles to the longitudinal alignment.
Design life	The expected life of the road for which the road is designed. Roads designed using this manual will have a design life of between 8 to 12 years.
Environment	Either the green environment, comprising vegetation and water sources, or a more general term referring to the various technical, social and institutional features of where and how the road will be constructed.
Flat terrain	Terrain with minimal gradient and minimal restriction on horizontal and vertical alignment.
Gaz 66	A medium truck, common in Lao PDR, for which the LVRR Standards are suitable.
Geometric cross section	The transverse shape of a road, including the carriageway and shoulders.
Geometry	The nature of the alignment of the road in terms of curves, crests, dips and gradients.
Gravel	A natural well graded material with plasticity and a good particle structure and which is suitable as a base layer and a

	wearing course.
Infrastructure	Constructed works, such as roads and bridges, in order to provide access and allow road users to travel.
Isuzu	A medium truck, common in Lao PDR, for which the LVRR Standards are suitable.
Kolao	A small truck, common in Lao PDR, for which the LVRR Standards are suitable.
LVRR Standards	A set of design requirements which are suitable for low volume rural roads in Lao PDR.
Mountainous terrain	Terrain with steep hills and substantial restrictions on horizontal and vertical alignment.
Pavement	One or more layers of imported material which are compacted onto a subgrade in order to allow vehicles to travel more easily.
Prioritisation	Selection of the sections to be improved using priority criteria.
Priority criteria	Criteria which are given to a length of road on the basis of its current passability and safety in order to select the most important sections when funding is limited.
Rolling terrain	Terrain with low hills and some restrictions on horizontal and vertical alignment.
Screening	A decision, made using initial information, to go ahead with or cease work in order to prevent wasted effort on an unrealistic project.
Sub-base	A pavement layer of low to medium strength material which is constructed on a capping layer or subgrade and on which the roadbase is constructed.
Subgrade	The surface of natural material on which an improved pavement will be constructed.
Subgrade design strength	The strength of the subgrade which is used when designing the layers of the improved pavement.
Surface	The top layer of a pavement, a thin bituminous seal, concrete or gravel wearing course.
Travel	Movement from place to place, typically using vehicles and on constructed paths and road.
Uniform section	A length of road which is similar in several aspects and which may be improved in its entirety with a single design.

Abbreviations

AADT	Average Annual Daily Traffic
BoQ	Bill of Quantities
CBR	California Bearing Ratio
DBST	Double Bituminous Surface Treatment
DCP	Dynamic Cone Penetrometer
DPWT	Department of Public Works and Transport
EOD	Environmentally Optimised Design
GPS	Global Positioning System
LRD	Local Roads Division
LRDM	Lao Road Design Manual
LVRR	Low Volume Rural Road
MPa	Mega Pascals
MPWT	Ministry of Public Works and Transport
OPWT	Office of Public Works and Transport
ORN	Overseas Road Note
PI	Plasticity Index
VMC	Village Management Committee

1 Introduction

1.1 Rural travel and infrastructure

Travel is necessary for economic, government, employment, agricultural, commercial, health, schooling and social purposes and is vital for development and poverty reduction.

There are four aspects of rural travel, all of which need to be addressed if development is to be sustainable and equitable: durable infrastructure, efficient and affordable transport services, vehicles which are appropriate for the conditions and travel reduction measures such as the relocation of services close to communities.

This manual is concerned with the improvement of rural infrastructure with a focus on improved pavements and surfaces. It provides a range of low cost designs which are adequate for typical traffic on rural roads.

1.2 The Environmentally Optimised Design (EOD) approach

This manual is based on the EOD approach. With this approach, the road is designed to suit a variety of task and environmental factors such as rainfall, available materials, construction capacity, gradient, flood risk and so on.

Some of these factors vary from road to road and even from site to site along a road. Therefore a road design may vary along the length of a road with, for example, a sealed surface up a hill or gravel along a level section. This variable nature is referred to as 'variable longitudinal design'.

Whereas the priority of those using national highways is to travel fast and comfortably, the priority of those using low volume rural roads is on safe and reliable travel, being confident that one will arrive at one's destination safely and without the route being blocked. When funds are limited, therefore, they should be used to improve sites which do not currently provide safe and reliable access, for example a badly damaged or flooded section. Sites which do provide this level of access can be left without improvement, for example a length of track which is not eroding, slippery or damaged, allowing the funds to be used to improve access on other roads. Sites which are improved in such a way are referred to as 'spot improvements'.

The EOD approach combines variable longitudinal design with, when funds are limited, spot improvements.

This manual is based on the guidance in Low Volume Rural Road Standards and Specifications Part I-III, which were produced under the SEACAP 3.01 project in the South East Asia Community Access Programme (SEACAP).

This manual has been written by a team of road researchers and engineers from LTEC, OtB and TRL.

1.3 Structure and use of the manual

Chapter 2 describes the steps in the design of improvements to a road or track which has deteriorated and is now in poor condition.

Chapter 3 briefly describes the steps in the design of new road, where they differ from those in Chapter 2.

The Appendices give design tables and technical guidance to support the steps in Chapters 2 and 3 and exercises and examples in several important topics.

It is impossible to produce guidance for every example of path, track and road and the condition in which they may be found. Therefore the steps may need to be amended to suit the specific circumstances of each case.

The design process will normally include a first site visit for a rapid survey, a second visit for the main survey and a possible third visit to collect additional data. The design process may take two to six months.

2 Improvement of an existing road

Figure 1 is a flowchart showing the design steps to improve a road or track in poor condition.

2.1 Screening	Screen out unrealistic projects where funding is too low, traffic is too heavy or maintenance capacity is inadequate.
2.2 Site visit and rapid survey	Collect general information and form an initial opinion of the problems and likely improvements along the road.
2.3 Assessments	Assess the traffic, terrain, rainfall, available materials and the construction and maintenance capacity that will affect the design.
2.4 Initial design work	Use the results of the assessments to design the geometric cross section and geometry of the road.
2.5 Main survey	Collect more design information, identify required improvements and determine the relative importance of each improvement.
2.6 Data collection	Collect data relating to the strength of the surface on which improved pavements may be constructed and the quality of materials that will be used in these pavements.
2.7 Selection of improvements	Use the collected survey information and other data to select the most appropriate improvements for each section of the road.
2.8 Pavement and surface design	Select the pavement and surface type and use subgrade strength and traffic to determine the layer thicknesses and strengths of the required pavement.
2.9 Estimation of costs	Calculate the cost of the improvements over their design life – their whole life asset costs –and, if necessary, compare them with alternatives.
2.10 Prioritisation	Select the sections of the road that will be improved if funds are restricted.
2.11 Contract documents	Prepare technical documents relating to the road and the improvements that are required in the contract.

Figure 1 Design steps

2.1 Screening

The design process can be time consuming and expensive. Time and money can be saved by identifying and screening out projects which should not be undertaken or where this manual is inapplicable.

Fund screening

It is essential that adequate funds are available for construction and future maintenance of any improvements.

Typical minimum construction and maintenance costs should be obtained from LRD, taking into account the location of the road and the likely nature of the improvements. If the available construction funds are less than these typical minimum construction costs, it is very unlikely that the current level of access will be noticeably improved. If the available maintenance funds are less than the typical minimum maintenance costs, it is very likely that the improvements will deteriorate within 3-5 years and all benefits will be lost. In either case, more funding should be sought or another project should be chosen.

Traffic screening

If it is obvious from a brief visit or discussion with communities or DPWT or OPWT staff that any of the following are likely, this manual should not be used and the Lao Road Design Manual (LRDM) should be used instead.

- Trucks with axle loads more than 4.5 tonnes will use the road
- More than 150 motorised 4 wheel vehicles will be the road every day
- Vehicles from logging, mining or other development activities will use the road

Maintenance screening

All improvements must be maintained if they are to provide access for more than 3-5 years. If the required technical capacity (skills and equipment) is not available locally to the road, it is unlikely that maintenance will be carried out. Either another project should be chosen or the user of this manual should carefully check that only those pavements and surfaces for which capacity is available are chosen.

2.2 Site visit and rapid survey

Unless the designer is very familiar with the road, it is strongly recommended that a visit is made to the road before the main survey is carried out. The entire road should be seen during the visit, either walking or driving. This visit allows the designer to form an initial opinion of the nature of the problems and the likely improvements. The designer should be accompanied by someone who has walked or driven along the road in wet and dry seasons.

It is recommended that the Rapid Survey Form is used to collect general information during this site visit. This Form is given and explained below. A tape measure is required for the rapid survey and a hand level or inclinometer should be taken if available.

For the rapid survey, if it is possible, chainage posts should be fixed every 50 metres along the road using a long tape measure or other means, either before or during the survey. These posts should remain for the duration of the design and construction work. If these chainage posts are not possible at this stage, the odometer of a vehicle can be used and reference points, such as villages and junctions, should be recorded so that the rapid survey can be matched to the more accurate chainage posts after they have been fixed.

The Rapid Survey Form is given below and should be expanded on a photocopier to give a form of usable size. It can also be obtained from LRD. Complete one row every 100 metres with the observed condition at that exact point.

- Road name, Start point, Province, District, Surveyor, Date – complete as normal.
- Chainage – complete with 0+000, 0+100, 0+200, etc.
- Cross section – complete with 1-6 depending on whether the road is flat, embanked, across sidelong ground, etc.
- Driveable width (m) – complete with the width which motorised vehicles can use.
- Surface – complete with E, G, S, B or C according to the surface material.
- Gradient – complete with 1-5 according to the estimated gradient. Include + for uphill and – for downhill.
- Village – tick if the point is close to houses or is a site of increased pedestrian activity.
- Flooding frequency. – complete with 1-3 according to the frequency with which the road surface is covered with water during the wet season.

- Water course – tick if a water course crosses the road in the preceding 100 metres.
- Condition – complete with 1-3 according to the passability of the road.
- Remarks – record any additional information relating to nearby material sources or landmarks such as junctions or village names.

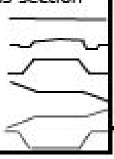
LVRR Rapid Survey Form

Road name............. Province............. Surveyor...................

Start point............ District................ Date.......................

Chainage	Cross section	Driveable width (m)	Surface	Gradient (+/-)	Village (√)	Flooding freq.	Water course (√)	Condition	Remarks - material sources, landmarks

Cross section
1
2
3
4
5
6



Surface
E Earth
G Gravel
S Stones
B Bitumen
C Concrete

Gradient
1 0-1 %
2 2-5 %
3 6-10 %
4 >10 %
5 crest/sag

Flooding frequency
1 Never
2 < 1 / year
3 ≥ 1 / year

Condition
1 Passable all year
2 Passable dry only
3 Impassable all year

2.3 Assessments

After the site visit and rapid survey, a series of assessments should be carried out. These assessments are required for the later design work.

2.3.1 Traffic assessment

Design life

All roads are designed to last for a defined design life. If the design life is very short, repeated construction costs will be very high; if the design life is very long, traffic may grow to the extent that the road is no longer adequate. Roads designed using this manual will have a design life of between 8 and 12 years.

Objective of traffic counting

In order to design a road, it is necessary to estimate the traffic that will be using the road at the end of the design life. To do this, it is necessary to count the current levels of traffic and then estimate how it will increase when the improvements are completed and then how it will grow over the following years.

The expected traffic has already been screened in order to prevent unnecessary design work on roads that are likely to carry traffic that is beyond the capacity of the designs in this manual.

Traffic categories

In this manual all vehicles are grouped into one of the five categories shown in Table 1.

Table 1 Traffic categories

Traffic Category	Description	Vehicles	Remarks	
1	Non-motorised vehicles and pedestrians	Pedestrian Bicycle Animal	LVRR Standards should ensure that these road users are not in danger from motorised vehicles	
2	2&3-wheeled motorised vehicles	Motorcycle Tuk-tuk Jambo Farm tractor	LVRR Standards are specifically suited to roads carrying vehicles in Categories 2 and 3	
3	Light 4-wheeled motorised vehicles: Width ≤ 1.8 metres & Axle load ≤ 2.5 tonnes	Car Pick-up 4WD Minibus Kolao	LVRR Standards are specifically suited to roads carrying vehicles in Categories 2 and 3	
4	Medium 4-wheeled motorised vehicles: Width = 1.8-2.3 metres & Axle load = 2.5-4.5 tonnes	Isuzu Gaz 66 Medium bus	LVRR Standards suit roads carrying small numbers of vehicles in Category 4	
5	Heavy 4+-wheeled motorised vehicles: Width > 2.3 metres or Axle load > 4.5 tonnes	Large truck Large bus	Large vehicles in Category 5 are beyond the scope of LVRR Standards	

Traffic counts

The traffic should be counted at defined locations so that variations along the road are recorded. The sites defined in Table 2 are the recommended minimum. If the counts at different locations are significantly different, the road may be divided into separate lengths, each with a different count.

Table 2 Traffic count locations

Description of road	Traffic count locations
Shorter than 10 km and does not pass through any villages	One location mid way along the road
Longer than 10 km	Two non-village * locations, one near each end For other locations, interpolate between these figures
Has a major junction	One non-village * location on either side of the junction
Passes through one or more villages	One village location and one non-village * location
Passes through villages of different size and level of activity	In the largest village and in the smallest village For other villages, interpolate between these figures

* Non-village locations should be beyond the limits of normal village activity so that the count is not affected by short distance village journeys. 'Village' can refer to any site of increased pedestrian activity.

At each location traffic should be counted in both directions from 06:00 to 18:00 using the LVRR Traffic Counting Form below, which should be expanded on a photocopier to give a form of usable size. This Traffic Counting Form can also be obtained from LRD.

Ideally the traffic should be counted on 7 consecutive days but if this is not possible, 3 consecutive days are acceptable. Unusual days, such as local festivals, should be avoided. If the road is impassable during the wet season, the count should take place in the dry season. A traffic counting team should have two or more people so that they can work in shifts and count all vehicles. The counts should be added up for each vehicle type and then the totals for each of the five categories calculated. The totals for each category should then be averaged over the total counting days.

LVRR Traffic Counting Form

Road name.................. Province............................ Surveyor..........................

Survey point................. District.............................. Date..............................

Traffic Category	Vehicles	06:00 - 09:00	09:00 - 12:00	12:00 - 15:00	15:00 - 18:00	**Total two-way count**		
1	**Pedestrian**							
	Bicycle							
	Animal							**Category 1**
2	**Motorcycle**							
	3-wheeler							
	Farm tractor							**Category 2**
3	**Car**							
	Pick-up							
	4WD							
	Minibus							
	Kolao							**Category 3**
4	**Isuzu**							
	Gaz 66							
	Medium bus							**Category 4**
5	**Large truck**							
	Large bus							**Category 5**

Traffic increase and growth

This manual is normally used for improving roads in poor condition, in which case the traffic levels are likely to increase immediately after the improvements are completed and the level of access improved. This increase depends upon the current level of access and the current level of economic activity in the region. The increase can be estimated by surveying road users' origins and destinations and identifying how many road users are likely to use the improved road, comparing the road with one nearby with similar populations and economic activity or by asking for guidance from LRD.

After a road has been rehabilitated or opened traffic volume is likely to grow and vehicle usage change over future years as social and economic activity increases. This growth is estimated by applying a constant growth factor for the remaining years of the design life.

Traffic analysis

Traffic counts should be analysed as follows using the LVRR Traffic Analysis Form below, which should be expanded on a photocopier to give a form of usable size. This Traffic Analysis Form can also be obtained from LRD.

1. Transfer the total daily counts on the LVRR Traffic Counting Form into the five grey cells on the Analysis Form.
2. Multiply these counts by a Daily factor to include traffic which may have passed by the count site during the night. The Daily factors can be found on the Analysis Form.
3. Multiply these values by a Seasonal factor (obtained from MPWT) to convert the count into a daily average over the year.
4. Estimate the likely traffic increase after completion of the improvements for each category and add this to the daily average.
5. Use the table on the Analysis Form, the annual economic growth rate and the design life to derive the Traffic growth factor over the design life. Multiply the daily average after completion of the improvement by this Traffic growth factor to derive the daily traffic at the end of the design life (Average Annual Daily Traffic – AADT) in each category.

LVRR Traffic Analysis Form

Road name................. Province.......................... Surveyor........................ Count duration: from...............to...............

Traffic count location................ District.............................. Date.............................. Design Life (yr).........................

Traffic Category	1	2	3	4	5	
Vehicles	Pedestrian Bicycle Animal	Motorcycle Tuk-tuk Jambo Farm tractor	Car Pick-up 4WD Minibus Kolao	Isuzu Gaz 66 Med bus	Large truck Large bus	
Total two-way count = A						from LVRR Traffic Counting Form
Daily factor = B						
A x B = C						
Seasonal factor = D						
C x D = AADT						
Add 2 way traffic increase on completion = E						
AADT + E = F						
Annual growth rate (%) = G						
Traffic growth factor = H						
F x H = Final year AADT						

Traffic growth factors over the Design Life

Annual growth rate (%)	1	2	3	4	5	6	7	8	9	10
DL = 10 yr	1.10	1.22	1.34	1.48	1.63	1.79	1.97	2.16	2.37	2.59
DL = 12 yr	1.13	1.27	1.43	1.60	1.80	2.01	2.25	2.52	2.81	3.14
DL = 15 yr	1.16	1.35	1.56	1.80	2.08	2.40	2.76	3.17	3.64	4.18
DL = 20 yr	1.22	1.49	1.81	2.19	2.65	3.21	3.87	4.66	5.60	6.73

Count duration	6.00 - 18.00	0.00 - 24.00
Daily factor	1.2	1

Month in which count was made	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasonal factor	x	x	x	x	x	x	x	x	x	x	x	x

Traffic analysis is required for three decisions: the applicability of the LVRR standards, the design of the geometric cross section of the road and the allocation of Traffic Group for pavement design

LVRR standards

If there are any vehicles in Traffic Category 5, LVRR standards do not apply and the LRDM should be used

If the sum of the final year AADTs of Traffic Categories 3 and 4 is 150 or more, LVRR standards do not apply and the LRDM should be used

Traffic Group

If the final year AADT of Traffic Category 4 is less than 10, the traffic is in Traffic Group A

If the final year AADT of Traffic Category 4 is 10 or more, the traffic is in Traffic Group B

Design of the cross section

If there are any vehicles in Traffic Category 4, the carriageway is 3.5 metres wide and each shoulder is 1 metre wide

If there are no vehicles in Traffic Category 4 and the final year AADT of Category 1 is 150 or more, the carriageway is 2.5 metres wide and each shoulder is 1.5 metres wide

If there are no vehicles in Traffic Category 4 and the final year AADT of Category 1 is less than 150, the carriageway is 2.5 metres wide and each shoulder is 1 metre wide

Traffic decisions

The final year daily traffic figures are used in three decisions in the design process. Two are described here; a third is described in a later section.

Firstly, use the final year AADTs of traffic categories 3, 4 and 5 and Table 3 to determine if the LVRR Standards are applicable. If the LVRR Standards are not applicable, the LRDM should be used instead. If the road has been divided into separate lengths, each with a different count, and the manual is not applicable for one or more lengths, the LRDM should be used for the entire road. This Table is a more accurate check of the traffic screening carried out earlier.

Table 3 Applicability of the LVRR standards

Category 5 vehicles in any year	**Sum of the final year AADTs of Categories 3 and 4**	
	< 150	**≥ 150**
None	LVRR standards are applicable **Continue using this manual**	LVRR standards are not applicable The LRDM should be used
Some	LVRR standards are not applicable The LRDM should be used	LVRR standards are not applicable The LRDM should be used

Secondly, use the figure for traffic category 4 and Table 4 to allocate the traffic into a Traffic Group for use during pavement design.

Table 4 Traffic Groups

Final year AADT of Category 4	**Traffic Group**
< 10	A
≥ 10	B

An example of traffic analysis and decisions is given in Appendix 10.1.

Traffic restriction

In order for this manual to be applicable and to benefit from its low cost designs, it is possible to use posts, barriers or gates to prevent large or heavy vehicles using a road. If so, it must be done with the agreement of the DPWT and local communities.

Goalpost barrier

Concrete side posts

2.3.2 Terrain assessment

Terrain refers to the nature of the land that the road passes through. It does not refer to each specific curve and hill. If the terrain changes along the length of the road, for example a hill road descending to a valley floor, the terrain for each part can be assessed separately.

Use Table 5 to determine if the terrain is flat, rolling or mountainous. The number of 5 metre contours crossed can be estimated in the following ways.

- Use a GPS instrument to measure the height of each rise and fall. However, it is important to check the accuracy of altitude measurements with the GPS before using this method.
- Use a map with 25 or 50 metre contours and interpolate between contour lines
- Carry out a longitudinal level survey along the road

If these methods are not possible, the descriptions in Table 5 or the experience of the surveyor can be used instead.

Table 5 Terrain classes

Number of 5 metre contours crossed per km	Description	Terrain	
0-10	Terrain with minimal gradient and minimal restriction on horizontal and vertical alignment	Flat	
11-25	Terrain with low hills and some restrictions on horizontal and vertical alignment	Rolling	
>25	Terrain with steep hills and substantial restrictions on horizontal and vertical alignment	Mount-ainous	

2.3.3 Rainfall assessment

The climate of a region affects the design of a road, from the materials that can be used to the need to seal a gravel surface on a hill. Although there are many aspects of climate – total rainfall, duration of wet season, rainfall intensity, etc – in this manual climate is represented by the total annual rainfall.

The total annual rainfall in the area of the road should be established from DPWT or OPWT records and the area should be classed using Table 6. The rainfall class will be used during the design process.

Table 6 Rainfall classes

Total annual rainfall (mm/year)	Rainfall class
1000-1500	Moderate
1500-2000	High
> 2000	Very high

2.3.4 Materials assessment

An assessment of available materials will give important indications as to the feasibility and costs of pavement types and associated earthworks and drainage. Table 7 lists common material groupings encountered in Lao PDR with potential uses. Note that the economic use of materials in Groups I and VI may depend upon whether or not processing equipment is available (extraction, crushing and screening).

Table 7 Common material groupings in Lao PDR

Material Group	Description	Possible uses
I Hard rock	Strong to very strong igneous (granite, basalt), sedimentary (crystalline limestone) and metamorphic (schist) rock types. Will require processing.	Filter and drainage aggregate Concrete aggregate Pavement sub-base and base material Surfacing aggregate
II Weak rock	Weak to very weak mainly sedimentary rocks such as shale, mudstone and non-crystalline limestone. Also includes weathered Type I rock types	Common fill and capping Pavement sub-base material Unsealed surfacing wearing course
III Hill gravels	Hill gravels (colluvium) derived from a combination of hard rock weathering and down-slope accumulation.	Common fill and capping Shoulders Pavement sub-base Pavement base material (high quality only) Unsealed surfacing wearing course
IV Laterite gravel	Soil-like materials with a clay-silt-sand-gravel nature with small nodules or concretions. Occasional forms more continuous hardened layers	Common fill and capping Shoulders Pavement sub-base Pavement base material (high quality only) Unsealed surfacing wearing course.
V Residual soil (laterite soil)	Formed by the in situ weathering of Group I and II materials, no significant granular material.	Common fill Capping
VI Alluvial materials	Sand, gravel and cobble derived mainly from Group I materials. Will require some processing (screening/crushing)	Filter and drainage aggregate Concrete aggregate Pavement sub-base and base material Surfacing aggregate

2.3.5 Construction and maintenance capacity assessment

There are three aspects to the capacity to construct and maintain an improvement: technical ability, resources and maintenance management. In most cases this assessment focuses on pavement type options such as gravel, bituminous seal or concrete.

If the capacity does not exist for a particular pavement type, a different type should be selected and designed. If the capacity does not exist for any pavement type, the project may not be feasible.

Technical ability

Construction and maintenance work must meet the LVRR specifications. The experience and technical knowledge of the contractors should be assessed. Some of the pavement types in the LVRR standards are technically more difficult than others. Only those who are able to meet the specifications should be allowed to tender for the work. Technical training may be required for contractors and other parties before a programme of improvements can begin.

Resources

It is important that contractors have the correct resources for the required work and that they are able to complete the work within the required period, this often being a single dry season. These resources include unskilled and skilled labourers, gang leaders, supervisors, technicians, engineers, management, materials, tools, equipment and plant. Only those with sufficient resources should be allowed to tender for the work. Appropriate resources are also required for maintenance work whether it is carried out by contractors or VMCs.

Maintenance management

In addition to meeting the LVRR specifications, it is essential that maintenance is reliable and is carried out when required. A common reason for the deterioration of low volume roads is the failure to carry out maintenance when it is required, particularly for gravel roads but also for all other pavement types. Maintenance management includes adequate funding, availability of contractors or VMCs and a system which sets up a regular cycle of routine maintenance, identifies the need for additional maintenance when required and ensures that all work is carried out.

Cutting grass

Clearing drains

Different pavement types require different skills, materials, resources and activity types. The required maintenance activities of different pavement types and the importance of the maintenance are summarised in Table 8, adapted from Table A1.1 in Low Volume Rural Road Standards and Specifications Part III.

Table 8 Summary of LVRR maintenance requirements

Pavement type	Routine maintenance requirement	Periodic maintenance requirement	Importance of maintenance
Gravel	Basic maintenance * plus pothole repairs and camber reshaping	Regravelling to replace material lost due to traffic and weather	Very high
Sealed granular	Basic maintenance * plus pothole repairs	Reseal of the surface after 8-12 years	Moderate
Unreinforced concrete	Basic maintenance * only	Crack sealing and joint repairs	Low

* Basic maintenance includes all off-surface items such as shoulder repairs, vegetation control, cleaning the drainage system and erosion repairs, which will be of similar quantity for all surfaces on low volume rural roads

These three aspects should be assessed for each possible pavement type through discussion with communities and OPWT staff. The conclusion of the assessment should be whether or not a particular pavement type can be constructed well and maintained well.

2.4 Initial design work

The geometric cross section and the geometry of the road should be designed using the results of the above assessments. Geometric cross section refers to the width and camber of the carriageway and shoulders and the height of the road above ground or flood water. Geometry refers to the horizontal and vertical curvature, super-elevation, sight distance and gradient.

2.4.1 Width of carriageway and shoulders

The width of the carriageway and shoulders should allow the expected numbers and types of vehicles and other road users to travel in safety. Use Table 9 to determine the required widths.

Table 9 Width of carriageway and shoulders

Final Year AADT of Category 4 Traffic	Final year AADT of Category 1 Traffic	
	< 150	≥ 150
None	Carriageway width = 2.5 m Shoulder width = 1 m	Carriageway width = 2.5 m Shoulder width = 1.5 m
Some	Carriageway width = 3.5 m Shoulder width = 1 m	Carriageway width = 3.5 m Shoulder width = 1 m

2.4.2 Camber of carriageway and shoulders

The camber of the carriageway and shoulders should shed rain water falling on the road into the side ditches. Use Table 10 to determine the required cambers.

Table 10 Camber of carriageway and shoulder

	Surface type [1]		
	Gravel	Bituminous	Concrete
Camber of carriageway [2]	6% [3]	4%	1-2%
Camber of shoulders	6%	6%	6%

1 This design decision will be completed when the surface type has been determined
2 All lower pavement layers should have the same camber as the carriageway
3 The camber of a gravel surface should be maintained at no less than 4%

2.4.3 Height of the subgrade above ground or flood water

The height of the top of the subgrade above ground or flood water should prevent the water excessively weakening the pavement layers of the road. Use Table 11 to determine the minimum allowable subgrade height.

Table 11 Minimum height of the subgrade above ground or flood water

Highest water level in the last 5 years [1]	Minimum height of the top of the subgrade
Surrounding land floods	0.65 m above the highest flood level
Surrounding land does not flood but ground water is above the base of the side ditches	0.65 m above the water level in the side ditch
Ground water is below the base of the side ditches but within 0.5 m of ground level	0.65 m above the base of the side ditch
Ground water is always more than 0.5 m below ground level	0.45 m above the base of the side ditch

1 The water level will be recorded during the main survey

Flooding covering a rural road

2.4.4 Radius of horizontal curvature

The radius of horizontal curvature of the road should allow vehicles travelling at typical speeds for the terrain to travel safely around curves without sliding off the road. Use Table 12 to determine the minimum allowable radius of horizontal curvature.

Table 12 Minimum radius of horizontal curvature

		Terrain		
		Flat	**Rolling**	**Mountainous**
Surface type [1]	**Gravel**	$H_{min} = 110$	$H_{min} = 70$	$H_{min} = 40$
	Bituminous or concrete	$H_{min} = 95$	$H_{min} = 60$	$H_{min} = 35$

H_{min} is the minimum horizontal radius of a curve (m)
1 This design decision will be completed when the surface type has been determined

An exception can be made to the limits in Table 12 if all of the following apply. All exemptions must be agreed with the DPWT.

- Compliance would require expensive earthworks or land purchase.
- The radius is made as high as practical.
- Visual obstructions inside the curve are removed.
- Warning signs are placed before the curve in both directions.

Horizontal curve

2.4.5 Super-elevation

The LVRR design speeds of 30 and 40 km/h are below those for which super elevation is generally recommended. However, the removal of crossfall on the outer half of the carriageway on horizontal curves below 500 metre radius is recommended.

If super-elevation is to be applied for 40-50 km/h roads then it should follow recommended practice with a maximum of normal crossfall (4-6%) and be applied over the distances recommended in the LRDM.

2.4.6 Radius of vertical curvature

The radius of vertical curvature of the road should allow vehicles travelling at typical speeds for the terrain to travel safely over crests and sags without losing traction or control and with adequate sight distance. Use Table 13 to determine the minimum allowable radius of vertical curvature.

Table 13 Minimum radius of vertical curvature

		Terrain		
		Flat	**Rolling**	**Mountainous**
Surface type [1]	**Gravel**	VC_{min} = 1500 VS_{min} = 400	VC_{min} = 900 VS_{min} = 250	VC_{min} = 400 VS_{min} = 150
	Bituminous or concrete	VC_{min} = 1000 VS_{min} = 400	VC_{min} = 500 VS_{min} = 250	VC_{min} = 300 VS_{min} = 150

VC_{min} is the minimum vertical radius of a crest (m)
VS_{min} is the minimum vertical radius of a sag (m)
Values of VC_{min} and VS_{min} have been rounded from those given in the LVRR Standards
1 This design decision will be completed when the surface type has been determined

An exception can be made to the limits in Table 13 if all of the following apply. All exemptions must be agreed with the DPWT.

- Compliance would require expensive earthworks.
- Crests are removed as much as possible.
- Warning signs are placed before the crest or sag in both directions.

Vertical crest

2.4.7 Combined curves

The above sections have given limits for horizontal and vertical curvature. However, it is also important to consider how curves should be combined. Within practical limits, horizontal and vertical curves should be kept separate by lengths of straight road with constant gradient. When this is not possible, warning signs should be used wherever one curve follows closely after another.

2.4.8 Sight distance

The sight distance along the road should allow two vehicles approaching one another at typical speeds for the terrain to stop before hitting each other. Use Table 14 to determine the minimum allowable sight distance.

Table 14 Minimum sight distance

		Terrain		
		Flat	**Rolling**	**Mountainous**
Surface type [1]	**Gravel**	SD_{min} = 130	SD_{min} = 100	SD_{min} = 60
	Bituminous or concrete	SD_{min} = 100	SD_{min} = 70	SD_{min} = 50

SD_{min} is the minimum sight distance along the road (m)
1 This design decision will be completed when the surface type has been determined

An exception can be made to the limits in Table 14 if all of the following apply. All exemptions must be agreed with the DPWT.

- Compliance would require expensive earthworks or land purchase.
- The sight distance is made as high as possible.
- Warning signs are placed before the restriction in both directions.

2.4.9 Gradient

The gradient of the hills along the road should allow vehicles travelling at typical speeds for the terrain to travel safely up and down hills without losing traction or control. Use Table 15 to determine the maximum allowable gradient.

Table 15 Maximum gradient

			Terrain		
		Annual rainfall (mm/year)	**Flat**	**Rolling**	**Mountainous**
Surface type [1]	**Gravel**	1000-1500	G_{max} = 6%	G_{max} = 6%	G_{max} = 6%
		1500-2000	G_{max} = 4%	G_{max} = 4%	G_{max} = 4%
		>2000	G_{max} = 1%	G_{max} = 1%	G_{max} = 1%
	Bituminous or concrete		G_{max} = 6%	G_{max} = 8%	G_{max} = 10%

G_{max} is the maximum gradient of a hill
1 This design decision will be completed when the surface type has been determined

An exception can be made to the limits for bituminous and concrete surfaces in Table 15 by allowing gradients up to 15% if all of the following apply. All exemptions must be agreed with the DPWT.

- Compliance would require expensive earthworks or land purchase.
- The length of slope is less than 300 metres.
- Warning signs are placed before the hill in both directions.

Steep hill

2.5 Main survey

The site visit and rapid survey are used to form an initial opinion of the problems and likely improvements along the road and to collect general information. However, it is also necessary for a survey team to walk the entire site and carry out a more detailed survey, possibly also taking samples and carrying out tests. The objectives of this main survey are to collect most of the required information, identify the required improvements and determine the relative importance of each in case not all can be constructed with available funds. The Main Survey Form below should be expanded on a photocopier and used for the survey. It can also be obtained from LRD.

It is important to note that the main survey is not a maintenance survey.

2.5.1 Survey steps

The steps in the main survey are as follows:

1. Assemble the team and equipment
2. Establish chainages
3. Record initial information
4. Identify uniform sections
5. Collect survey information
6. Select priority criteria
7. Collect supporting information

LVRR Main Survey Form

Road name.............................. Province.............................. Surveyor..............................

Start point.............................. District.............................. Date..............................

Chainage	Change of uniform section	Cross section	Driveable width (m)	Shoulder width - total (m)	Surface	Gradient (+/-)	Plan view	Village (√)	Flooding freq	Height in flood (+/-)	Water course (√)	Missing structure (√)	Surface in poor condition	Drainage in poor condition	Dusty when dry	Slippery when wet	Unstable slope (A/B)	Safety concerns	Environmental concerns	Cross section below standard	Geometry below standard	Surface below standard	Pavement below standard	Priority criteria	Supporting information - materials, samples, test pits, material sources, landmarks, villages, tight curves, safety concerns, environmental concerns, water courses, flooding frequency, realignments

Uniform section criteria	Cross section	Surface	Flooding frequency	Priority criteria	
Road appearance	1	E Earth	1 Never	1 Unsafe - high risk	8 Unstable slope
Gradient	2	G Gravel	2 < 1 / year	2 Impassable at any time	9 Environmental concerns
Village	3	S Stones	3 ≥ 1 / year	3 Impassable in wet only	10 Very slow travel
Risk of flooding	4	B Bitumen		4 Condition likely to deteriorate	11 Geom cross sect below standard
Overall condition	5	C Concrete		5 Health risk	12 Geometry below standard
Water crossing	6			6 Drainage in poor condition	13 Surface below standard
				7 Unsafe - medium risk	14 Pavement below standard

2.5.2 Team and equipment

The survey team should include an engineer or technician from DPWT or OPWT and at least one road user or member of the local community who has experience of the road and its condition throughout the year and for the last five years.

Table 16 shows what equipment is necessary for the survey and what equipment can be taken if available.

Table 16 Survey equipment

Essential	30-50 metre tape measure LVRR Main Survey Form Clipboard Spade, sample bags and cards
Recommended	Hand level or inclinometer GPS instrument Camera Compass DCP instrument Umbrella

2.5.3 Chainages

If chainages posts were not fixed during the site visit and rapid survey, they should be fixed before the main survey. They should be fixed every 50 metres along the road using a long tape measure or other means. These posts will remain for the duration of the design and construction work.

2.5.4 Reference information

At the start of the road, complete the reference information at the top of the Main Survey Form.

2.5.5 Uniform sections

The survey process is based upon identifying the start and end points of sections which are reasonably uniform in the factors listed in Table 17 and on the Main Survey Form. Uniform sections can be of variable length, from 100 metres or less in mountainous terrain to several hundred metres in flat terrain. For each uniform section, measurements and assessments will be made. In most cases, a single improvement will be designed for each uniform section, although if further variation is found, for example in subgrade strength, uniform sections can be divided further and an improvement designed for each sub-section.

Very short uniform sections can be difficult and uneconomic for a contractor to construct. To prevent this, the guidance below should be followed.

- Minor variation in the factors should be allowed, as indicated in Table 17.
- A uniform section with a less arduous sub-section within it, for example a steep hill with a short flat sub-section half way up or a section in poor condition with a short sub-section in better condition half way along, should be considered as a single section with the improvement designed for the more arduous conditions of the longer section.
- Except in unusual situations, uniform sections should not be less than 50 metres.

Table 17 Factors of a uniform section

Factor	Description
Road appearance	This factor includes aspects such as driveable width, camber, presence of side ditches, cross section (1-6 as described in 2.2 above) and surface material, all of which affect the type of problems that are likely to occur and the work required to improve the road. Some variation within these aspects should be allowed in order to prevent uniform sections being too short.
Gradient	Gradient affects the likelihood of erosion and the severity of any slipperiness, as well as the suitability of different surfaces. The following categories, as used in 2.2, should be used: 0-1%; 2-5%; 6-10%; >10%. If measurement is not possible, gradient should be estimated as flat, gentle or steep.
Village	The increased presence of pedestrians alongside the road increases the need for safety measures and surfaces which prevent dust.
Risk of flooding	Risk of flooding affects the required improvements and their importance. The following ranges, as used in 2.2, should be used: never; < 1 per year; ≥ 1 per year.
Overall condition	Overall condition affects the passability of the road and the importance of the improvements. The following ranges, as used in 2.2, should be used: passable all year; passable dry season only; impassable all year.
Water crossing	A defined water course should be considered as a separate section of road. This should not include a crossing across a wide flood plain without a defined water course.

Low volume road passing through a village

2.5.6 Survey information

Before the survey begins, it is useful to review the Rapid Survey Form and recall the nature and variability of the road and the problems along it.

For the main survey, complete one row of the Main Survey Form every 50 metres along the road using the guidance on the Form and in Table 18. In addition and on a separate row, record the chainage at which one uniform section changes to another. In this way, the regularity of information collection is maintained but the start and end points of each uniform section are also identified.

Table 18 Main Survey Form items

Item	Description
Chainage	Record the chainages as 0+000, 0+050, 0+100, etc.
Change of uniform section	Record the chainage where one uniform section changes to another.
Cross section	Complete with complete with 1-6 depending on whether the road is flat, formed, embanked, across sidelong ground or in a cutting.
Driveable width	Record the width of the road which motorised vehicles can use.
Shoulder width	Record the total width of both shoulders, if present.
Surface	Complete with E, G, S, B or C according to the current surface material.
Gradient	Record the gradient. It is recommended that a hand level or inclinometer is used. Use "+" for uphill and "-" for downhill going up-chainage. Gradient can be measured after the main survey and added to the Form later if necessary.
Plan view	Draw a small sketch of the road to indicate if there are any tight curves nearby.
Village	Tick if the point is close to houses or is a site of increased pedestrian activity.
Flooding frequency	Complete with 1-3 according to the frequency with which the road surface is covered with water during the wet season.
Height in flood	Record the height of the subgrade above the ground or flood water (+) or the height of water above the subgrade (-) when in flood. If the ground water is deeper than 0.5 metres, it is not necessary to measure it – record with '0.5+'.
Water course	Tick if the uniform section is a defined water course but not if it crosses a wide flood plain without a defined water course.
Missing structure	Tick if the water course is missing a structure or if a structure is in very poor condition.
Surface in poor condition	Tick if the road surface is in poor condition and passability is reduced.
Drainage in poor condition	Tick if the drains are in poor condition and drainage capacity or performance is reduced.

Dusty when dry	Tick if the surface is dusty when dry.
Slippery when wet	Tick if the surface is slippery when wet and affects vehicle traction.
Unstable slope	Tick if the slopes above or below the road are unstable and at risk of slipping. Alternatively record with an A for slopes above the road or B for slopes below the road.
Safety concerns	Tick if there are any safety concerns along the road, as given in Table 19.
Environmental concerns	Tick if construction or future usage may cause environmental concerns along the road such as erosion of bare soil, disruption of a water course or contamination of a water supply.
Geometric cross section below standard *	Tick if the width or camber of the carriageway or shoulders or the heights of the subgrade above ground or flood water do not meet those determined in 2.4 above.
Geometry below standard *	Tick if the curvature, sight distance or gradient of the road do not meet those determined in 2.4 above.
Surface below standard	Tick if the surface is dusty, slippery or gravel on a steep hill
Pavement below standard *	Tick if the pavement thickness and strength is not adequate for expected traffic, as described in 2.6.2.
Priority criteria	Complete with the priority criteria for the section, as described in 2.5.7.
Supporting information	Complete with necessary supporting information, as described in 2.5.8.

* It may not be possible to make these three assessments until after the main survey has been completed and other tests have been made

Table 19 Safety concerns

Typical safety concerns
• Unstable slope above a village
• Unprotected steep or high drop alongside the road
• Slippery surface, particularly a hill
• Motorised traffic near a village, school or place of work
• Narrow road with risk of sliding off
• Dust with risk to health
• Poor visibility around curve
• Tight curve with risk of leaving the road
• Poor visibility over a crest
• Area next to the road used as a bus stop with risk of accidents
• Area next to the road used by market traders with risk of accidents
• Dangerous sites without warning signs

2.5.7 Priority criteria

An important objective of the main survey is to determine the relative importance of each improvement in case not all can be constructed with available funds. This is done by assigning each uniform section a priority criteria from Table 20 based on the impact of the condition on the safety and reliability of the access along the road. If only some improvements can be constructed, those sections with the most severe criteria will be improved first. If more than one criteria applies to a section, that which is highest in Table 20 should be used on the Form.

Table 20 Priority criteria

Priority criteria	Description
1 Unsafe – high risk	Safety concerns put road users or others at high risk of injury or death.
2 Impassable at any time	Road users are unable to pass along the road at any time of the year.
3 Impassable in wet season only	Road users are unable to pass along the road in the wet season, although closures up to 24 hours after rainfall are accepted.
4 Condition likely to deteriorate	Vehicles or rainfall are likely to cause significant deterioration of the road in the next year.
5 Health risk	The health of road users and others is at risk, typically due to dust from a gravel road.
6 Drainage in poor condition	Drainage capacity or performance is reduced and retained water is likely to damage the road.
7 Unsafe – medium risk	Safety concerns put road users or others at medium risk of injury.
8 Unstable slope	The slopes above or below the road are unstable and at risk of slipping.
9 Environmental concerns	Construction or future usage may cause environmental concerns along the road such as erosion of bare soil, disruption of a water course or contamination of a water supply.
10 Very slow travel	Vehicles travel very slowly along the road due to its poor condition.
11 Geometric cross section below standard *	The width and camber of the carriageway and shoulders do not meet those determined in 2.4 above.
12 Geometry below standard *	The curvature, sight distance or gradient of the road do not meet those determined in 2.4 above.
13 Surface below standard	The surface is dusty, slippery or gravel on a steep hill.
14 Pavement below standard *	The pavement does not meet the requirements specified in 2.6.2 below.

* It may not be possible to select these priority criteria until after the main survey has been completed and other tests and comparisons with standards have been made.

2.5.8 Supporting information

Although most of the required information will be recorded on the preceding columns of the Main Survey Form, there will be some information to support the analysis and design that cannot be collected with simple ticks and measurements. This information should be written in the final column. Table 21 lists what is likely to be required but is not exclusive and any other information that might be relevant should also be recorded.

Table 21 Supporting information

Supporting information	Description
Materials	Record the current road surface material and, if observed, the material below the surface.
Samples	Record the chainage and details of any material samples taken or planned.
Test pits	Record the chainage of any test pits dug or planned.
Material sources	Record the location and material type of any sources close to the road.
Landmarks	Record the chainage of any landmarks for help with referencing and reinstatement if required.
Villages	Record the start chainage and names of villages or other sites of increased pedestrian activity.
Tight curves	Record the chainage and an estimated radius of any tight horizontal and vertical curves, as shown in Figure 2.
Safety concerns	Record the chainage and type of any safety concerns.
Environmental concerns	Record the chainage and type of any environmental concerns.
Water courses	Record the approximate width and depth of any water courses.
Flooding frequency	Record the frequency of flooding of the section of road.
Realignments	Record any sites where short realignments might simplify the required improvements.

Take a bearing with a compass at the start of the curve and the end of the curve. The difference in the bearings, measured in degrees, is θ. Measure the distance along the road between the two points. This distance is L. The radius of curvature is given by R = (57 x L) / θ.

The same equation can also be used for vertical crests and sags where θ is the angle between the approach slope and the leaving slope.

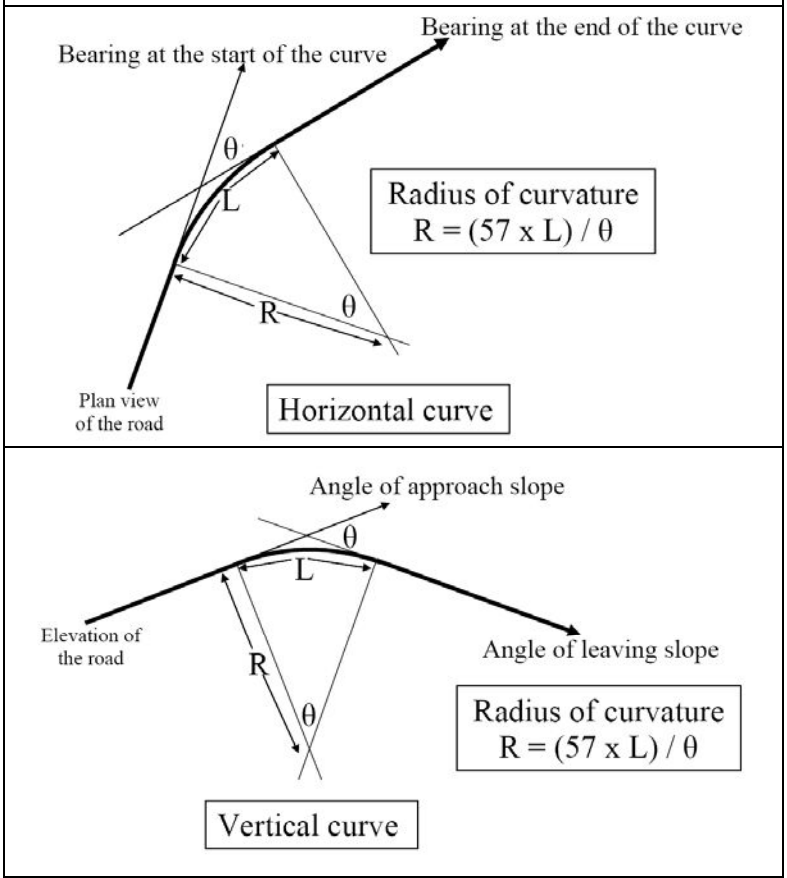


Figure 2 Estimating the radius of horizontal and vertical curvature

2.6 Data collection

During the main survey, information on the nature of the road, the problems along the road and their relative importance is collected. In most cases it is also necessary to collect more specific data relating to the strength of the surface on which improved pavements may be constructed, the strength and thickness of a previously constructed pavement and the quality of materials that will be used in these pavements.

2.6.1 Subgrade strength

The focus of this manual is on the selection and design of improved pavements and surfaces. Two inputs are required for their design: the traffic which is expected to use the road and which was assessed in 2.3.1 and the strength of the surface on which the pavements will be constructed. Although this surface may range from a deteriorated pavement to natural material, it is referred to here in all cases as 'subgrade'.

Extent of the subgrade assessment

It is recommended that the subgrade of the entire road is assessed and that only if budgets for testing and construction are extremely restricted should limited sections of the subgrade be assessed, with emphasis on sections with obvious surface damage.

Some roads are constructed across hillsides, in which case one side is often cut into the slope while the other side is formed by placing and compacting the excavated material. Compacted fill is often much weaker than a cut slope, particularly if compaction was poor. In other cases, road construction can be variable from one side to another. It is therefore recommended that the subgrade is assessed on either side of the road, typically in each wheeltrack.

Measuring subgrade strength

Subgrade strength can be measured in two ways. It is recommended that both are carried out when possible and that the results are compared, as described below.

It should be noted that the surface of a road which has been subjected to light traffic and wetting and drying cycles can appear very strong, although lower layers can be much weaker and unable to support higher levels of traffic. It is therefore important to test the top 500 mm to ensure that a strong surface does not give an incorrect impression.

Laboratory soaked test

This test measures the strength of a sample of soil that is removed from the site, processed to remove particles larger than 20 mm, compacted into a mould and soaked for 4 days. This soaked condition represents the state that the subgrade may be in when saturated and possibly weakened during a wet season.

The soaked test can be carried out in most DPWT laboratories but is slow and expensive and is typically carried out at a spacing of 500 metres along a road. In most cases, the CBR is assessed at 95% of the maximum dry density obtained under AASHTO modified compaction.

Dynamic Cone Penetrometer (DCP) test

The DCP is an instrument comprising a cone on the end of a rod which is driven into the subgrade by successive blows of a falling weight. The rate of penetration can be used to estimate the strength of the subgrade down to a depth of around 800 mm. The test is carried out on the subgrade in its current condition and indicates the strength on the day of the test. Even if the DCP test is carried out at the end of the wet season when the subgrade is at its wettest, it is still subject to daily variation in moisture content and so, unless some allowance is made, the designs may still fail when the subgrade is saturated. Making allowance for this is described below.

DCP tests take 10-20 minutes and can be carried out at a much closer spacing than soaked laboratory tests, typically 50-100 metres. Each test should penetrate to 800 mm or refusal.

Estimating subgrade design strength

It is recommended that laboratory soaked tests and DCP tests are both carried out. The results should then be correlated so that the pattern from the more closely spaced DCP results can be interpolated between the more accurate but less closely spaced soaked results and hence estimate the subgrade design strength. The ways in which the results should be correlated and the subgrade design strength estimated are given in Appendix A1.

2.6.2 Pavement strength and thickness

If the improved pavement is to be constructed on natural material or a deteriorated pavement, the guidance in 2.6.1 should be followed, a subgrade design strength estimated and a new pavement constructed.

However, if the surface is a pavement in fair or good condition, it may be necessary to make a careful assessment of the pavement and the subgrade below. DPWT or OPWT staff should make this assessment, following the general principles in 2.6.1 and the following paragraphs. There are two situations in which this assessment may be useful.

Firstly, it may be possible to use these layers in an improved pavement. For example, the surface may be a gravel pavement and it may be possible to simply thicken the base and add a bituminous seal to provide a sealed gravel pavement.

Secondly, the current pavement may be adequate for increased traffic levels without further improvement.

Layer thicknesses should be estimated by using a DCP and observing the depths at which the penetration rate changes. Test pits at a greater spacing can confirm the thicknesses. Test pits should be at least 500 mm deep.

DCP tests can also estimate the strength of each layer, including the subgrade, but soaked tests of each layer are also recommended so that the results can be correlated, patterns interpolated and soaked strengths estimated at a close spacing. Correlation should follow the guidance in Appendix A1.

It is important to ensure that any changes in the pavement along the road are detected.

The strength and thickness of each pavement layer should be estimated. The pavement should be compared with the designs in Appendix A3 for the required Traffic Group. If the pavement is equivalent to the relevant design, no further improvement is required; if the pavement is not equivalent to the relevant design, DPWT or OPWT staff should determine what additional thicknesses and layers are required for the pavement to be equivalent.

2.6.3 Material quality

The LVRR pavement and surfacing types in this manual are derived from those described in Appendix A of LVRR Standards and Specifications Part II. These specifications also define the required materials characteristics that should be complied with in terms of standard laboratory tests. The requirements for earthworks and drainage materials are similarly defined in the standard documents associated with the LRDM.

The suitability of materials for identified tasks within a road design is assessed by a combination of field and laboratory procedures.

Field assessment

Field assessment of potential materials resources should be undertaken under three headings:

- Location
- Quantity
- Quality

Location should be considered by answering the following important questions:

- How far is the source from the road sections where it is likely to be used?
- Is the source already in use? If not, how much preparation or development is required?
- What is the condition of the access road to the source?
- Are there any environmental impacts associated with using this source?

The potential **quantity** should be estimated by considered the surface extent of the source and its likely thickness. This estimation is best done by considering the surface extent as a simple geometric shape or a combination of shapes. The size of the geometric shapes can be calculated by using a GPS to measure distance from key points. If no GPS is available then estimation by "pacing out" can be undertaken. When estimating volume the following should be taken into account:

- Reduction in volume due to unusable materials (eg overburden)
- A "bulking factor" from in situ volumes to loose excavated volumes.
- A factor for loose excavated to compacted volume in the road

An early and very useful indication of likely materials **quality** can be obtained by field assessment using a number of simple techniques, as follows:

- *Visual assessment*: apart from identifying general material type it is relatively easy to obtain a general idea of grain size and shape. This may be aided by the use of standard charts or cards.
- *Fines content*: can be roughly assessed by the "hand shake" dilatancy test and the jar settlement test.
- *Schmidt Hammer*: can be used to estimate the strength of rock in outcrop or large boulders
- *Hand Sample Index Strength*: for smaller rock samples
- *Field Durability*: to assess the likely erodibility or disintegration potential of soils or weak rocks
- *Aggregate Pliers Test:* may be used to asses the strength of potential aggregate
- *Field Plasticity Test:* can give a very useful indication of likely plasticity

Further detail on field assessment techniques is included in Appendix A2.

Laboratory assessment

It is essential that some laboratory testing is undertaken to identify the characteristics of proposed materials and to assess how they can be best utilised in the road, remembering that an important EOD principle is to design the road to suit available materials rather than find the materials to suit a standard design.

The key materials characteristics and associated laboratory tests are summarised in Table 22 below and further detail is included in Appendix A2.

Table 22 General tests for assessing natural construction materials

	Material characteristic	Description of the material property	Main laboratory tests designed to evaluate the property
1	Particle size distribution	The relative proportions of each size fraction from gravel to clay size	Sieve analysis Hydrometer analysis
2	Plasticity of the fine fraction	The plasticity characteristics of the particles < 0.425 mm – indication of "slipperiness"; swell-shrink and general behaviour under different moisture condition	Liquid Limit Test Plastic Limit Test Linear Shrinkage Test
3	Load bearing capacity of compacted material	The capacity of the compacted materials to support imposed loads under saturated conditions	4-day soaked CBR
4	Volume stability	Volumetric response of the compacted material to swell-shrinkage on soaking-drying.	Swell measurement during 4-day soaked CBR
5	Particle strength and durability (granular materials)	The existing strength of individual particles and the ability of the particles to maintain this strength during the life of the road.	10% Fines Aggregate Crushing Test (10% FACT) and wet/dry ratio Los Angeles Abrasion Test (LAA) Magnesium or Sodium Sulphate Soundness Test
6	Particle shape (granular materials)	The angularity and flakiness of the aggregate particles and their ability to interlock together	Visual description Flakiness Index Test Elongation Index Test

Sampling

The recovery of representative samples, either from potential source or existing road pavement, is a pre-requisite for effective laboratory testing. Recommended sample sizes for common tests on materials used on low volume rural roads are listed in Table 23.

Table 23 Standard material tests and required sample sizes

Test	ASTM	Minimum Sample Required (kg)		
		Clay-silt size maximum	Sand size maximum	Gravel size maximum
Moisture Content	D2216	0.05	0.35	4.0
Liquid Limit (Cone /Casagrande))	D4318	0.50	1.0	2.0
Liquid Limit (one point cone)	D4318	0.10	0.20	0.40
Plastic Limit	D4318	0.05	0.10	0.20
Linear Shrinkage	(BS1377)	0.50	0.80	1.50
Particle Size (Sieve)	C136 -117	0.15	2.50	17.00
Particle Size (Hydrometer)		0.25		
Particle density	D854	0.30	0.60	0.60
Compaction – CBR (Modified)	D1883	80	80	80
Mg/Na Soundness	C88	0.15	0.60	0.85
Point Load Test	(ISRM)	Ten identical samples		
Los Angeles Abrasion (LAA)	C131	5.0-10.0		

It is important to clearly mark all samples with a unique reference number and to ensure their safe transport to the designated laboratory accompanied by a complete inventory list of samples and the required testing.

2.7 Selection of improvements

The survey information relating to the road and its problems and data relating to the strength of the subgrade should be analysed in order to select the most appropriate improvements for each uniform section.

It may be appropriate to subdivide the uniform sections if the survey information and subgrade strength data indicate variation within a uniform section. However, any sub-sections should still comply with the guidance on minimum length in 2.5.5.

The following paragraphs list potential solutions for each issue identified on the Main Survey Form. It is important to identify the fundamental causes of any engineering problems before an improvement is selected. Applying solutions to superficially apparent problems without addressing the underlying cause will lead to failure of the spot improvement. For example, poor road surface condition may be the result of a number factors ranging from poor maintenance to more complex pavement layer, sub-grade or cross-drainage issues. Treating sub-grade failure as a maintenance problem will only lead to a short improvement at best. Some improvements may be required in isolation, others in combination.

These paragraphs describe the appropriate improvements for each condition or defect. The priority criteria assigned to each uniform section will then determine which improvements can be constructed if funds are restricted.

Village

If people live, work or go to school near to the road, the following improvements should be considered:

- An improved pavement with a bituminous or concrete surface if a gravel surface is currently causing health and safety problems – see 2.8.
- Safety measures – see Appendix A8.

Flooding

If the road floods or if flood water rises to within the minimum allowable subgrade heights given above in Section 2.4.3, the following improvements should be considered:

- A road surface which is resistant to flooding if long term closures are acceptable to the local community. Such surfaces are not covered by this manual.
- An embankment to the required level – see Appendix A5 – with an improved pavement and surface – see 2.8.
- A short realignment around the site – see Appendix A7.

Missing structure

If a water course is missing a structure or if a structure is in very poor condition, the following improvement should be considered:

- A water crossing structure – see Appendix A6.

Surface in poor condition

If the road surface is in poor condition and passability is reduced, the following improvements should be considered:

- An improved pavement and surface – see 2.8.
- An embankment if the height of the subgrade above ground or flood water is within the minimum allowable heights – see Appendix A5.

Drainage in poor condition

If the drains are in poor condition and drainage capacity or performance is reduced, retained water is likely to damage the road and the following improvements should be considered:

- Drainage improvements – see Appendix A6.

Dusty when dry

If the surface is dusty when dry and causes health problems to high numbers of people living alongside and using the road, the following improvements should be considered:

- An improved pavement and surface – see 2.8.
- Safety measures since improved surfaces often cause traffic speeds to increase – see Appendix A8.

Slippery when wet

If the surface is slippery when wet, the following improvement should be considered:

- An improved pavement and surface – see 2.8.

Unstable slope

If the slopes above or below the road are unstable and at risk of failure, the following improvements should be considered:

- Slope stabilisation measures – see references in Appendix A9. For these measures, it will be necessary to return to the site to carry out a more detailed survey of the slopes.
- A short realignment around the site – see Appendix A7.

Safety concerns

If there are safety concerns, with supporting information recorded on the Main Survey Form, the following improvements should be considered:

- Safety measures – see Appendix A8. For these measures, it will be necessary to return to the site to carry out a more detailed survey of the concerns.

Environmental concerns

If there are environmental concerns, with supporting information recorded on the Main Survey Form, the following improvements should be considered:

- Environmental mitigation or protection measures, as described in appropriate MPWT guidance. For these measures, it will be necessary to return to the site to carry out a more detailed survey of the concerns.

Geometric cross section below standard

If the width or camber of the carriageway or shoulders or the height of the subgrade above ground or flood water do not meet those determined in 2.4 above, the following improvements should be considered:

- A reconstructed pavement and surface – see 2.8.

Geometry below standard

If the horizontal and vertical curvature, super elevation, sight distance and gradient do not meet those determined in 2.4 above, the following improvements should be considered:

- A reconstructed pavement and surface with improved geometry – see 2.8.
- A bituminous or concrete surface on steep hills – see 2.8.
- A short realignment around the site – see Appendix A7.

Surface below standard

If the surface is inappropriate for the site, for example if it is erodible on a steep hill, dusty through a village or slippery when wet, the following improvements should be considered:

- An improved surface on a reconstructed pavement – see 2.8.

Pavement below standard

If the pavement is inadequate for the traffic that is expected to use it, by comparison with pavement designs in this manual as described in 2.6.2, the following improvements should be considered:

- An improved pavement and surface – see 2.8.

After improvements have been selected for each uniform section, it is useful to produce a summary for discussion with colleagues in DPWT and OPWT offices. This summary should include a general description of the road, the typical problems along it and improvements selected, the materials which will probably be used in the construction and the likely proportion of the road that will be improved.

2.8 Pavement and surface design

The design of an improved pavement and surface has two steps: the selection of the most appropriate pavement and surface type, and the detailed design of that selection.

2.8.1 Selection of pavement and surface type

Available pavement and surface options are shown in Table 24.

Table 24 Pavement and surface types

Unsealed Gravel	Gravel Wearing Course
	Capping as required
Sealed Natural Gravel	Seal
	Base/Sub-base of specified natural gravel
	Capping as required
Sealed Armoured Gravel	Seal
	Stone aggregate armouring
	Base/Sub-base of specified natural gravel
	Capping as required
Sealed Macadam	Seal
	Macadam base and sub-base
	Capping as required
Non Reinforced Concrete	Concrete surface
	Sub-base of specified gravel or macadam

Tables 25 to 27 may be used to select the most appropriate pavement options. These are based on assessments of the key factors: material availability, maintenance and gradient-rainfall that have been made earlier in this design process. Table 28 may use as guidance for the selection of seal option.

Options that are listed as being "NOT recommended" carry with them a significantly high risk of failure within their design life. In addition there is an over-riding recommendation that unsealed option should not be used where there is a specific health or safety risk; for example: within villages, or adjacent to health centres or schools.

If two or more pavement and surface types appear to be appropriate, it is recommended that designs are completed for both and the whole life asset costs for both are compared, as described in 2.9. The cost comparison should be balanced with a consideration of aspects such as construction complexity and maintenance capacity and the most appropriate type should be selected.

Since some factors, such as gradient, flood risk, presence of people, and material availability, can vary from site to site along a road, the most appropriate pavement and surface type may also vary along a road, for example gravel along a flat section and unreinforced concrete up a hill. However, it should also be noted that an excessively varied design will increase the complexity of construction for the contractor and should therefore be carefully considered.

An increase in pavement choice is likely as more surface and pavement types are trialled and proven in Lao road environments.

Table 25 Option selection by Available Material

MATERIALS SCENARIOS

SPECIFICALLY **NOT** RECOMMENDED	Materials available close to road	RECOMMENDED
	Good quality gravel	Unsealed gravel; sealed gravel; armoured gravel
	Moderate quality gravel	Unsealed gravel; armoured gravel
Unsealed gravel, sealed gravel	Poor quality gravel only	Sealed stabilisation options.
	Processed crushed aggregate	Sealed macadam options
	Non-processed hard rock	Cobbles, stone setts, hand packed stone
Unsealed gravel, sealed gravel	Non processed sand and gravel	Sealed mechanically stabilised options
Unsealed options	Sandy soil only	Sealed stabilised (cement) options
Unsealed options	Clayey soil only	Sealed stabilised (lime) options; clay brick

Table 26 Option selection by Maintenance Regime

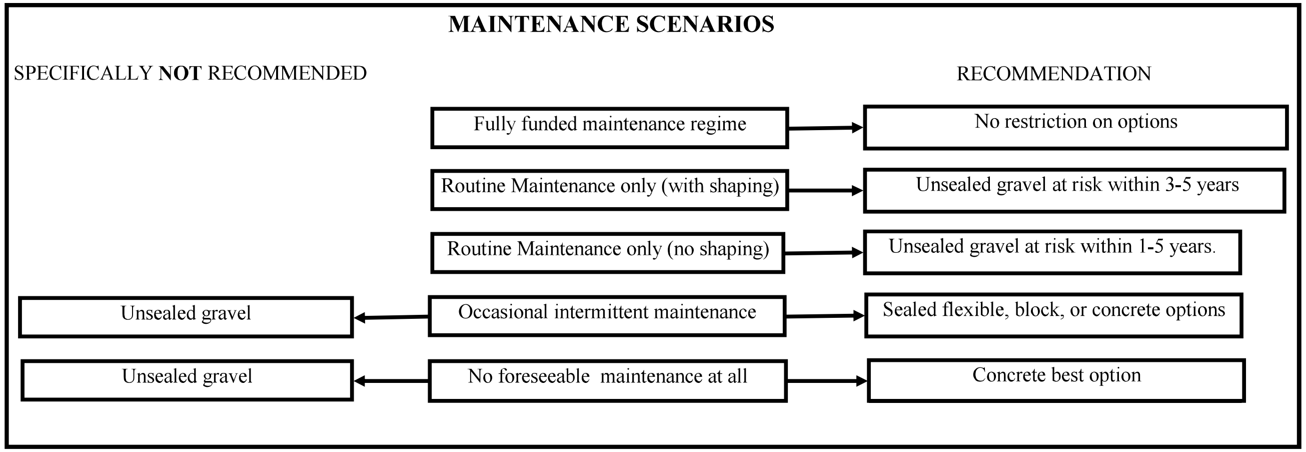


Table 27 Option selection by Gradient-Rainfall

GRADIENT-RAINFALL-FLOOD SCENARIOS

SPECIFICALLY **NOT** RECOMMENDED		RECOMMENDATAION
Unsealed gravel	Gradient > 6% Rainfall >1000mm/year	Sealed flexible, block or concrete
Unsealed gravel	Gradient > 4% Rainfall 1500-2000mm/year	Sealed flexible, block or concrete
Unsealed gravel	Any Gradient Tropical Storms - rainfall >2000mm/yr	Sealed flexible, block or concrete
Unsealed gravel	Occasional flood	Sealed flexible, block or concrete
Unsealed gravel,+ (Seals at risk)	Regular yearly flood	Concrete options

Table 28 Seal Option Selection

SEAL OPTIONS

SPECIFICALLY **NOT** RECOMMENDED	Scenario	RECOMMENDATION
	Good fine aggregate available	DBST
	Some limitation on aggregate, but sand available - low traffic group only	Sand seal on SBST
Sand seal	Flood Risk or Gradient >4%	
	Some limitation on aggregate, but graded sand-gravel available	Double Otta Seal

2.8.2 Design method

Two inputs are required for the design of improved pavements and surfaces: the traffic which is expected to use the road and which was assessed in 2.3.1 and the strength of the subgrade on which the pavements will be constructed and which was measured in 2.6.1 and Appendix A1.

For each of the pavement and surface types, Tables are provided in Appendix A3, as shown in Table 29, which give the required pavement design, in terms of layer thicknesses and strengths, for a defined subgrade strength and Traffic Group. In some cases alternative Tables are provided for the use of a capping layer of low strength material which allows the thickness of the other pavement layers to be reduced. These alternative designs can be compared using whole life asset costs and other considerations and the most appropriate design selected.

Table 29 Pavement and surface appendices

Pavement and surface type	Appendix
Gravel	A3.1
Sealed granular	A3.2
Sealed armoured gravel	A3.3
Unreinforced concrete	A3.4

If the subgrade is very strong or if a pavement has already been constructed, it may be possible to use material that is already in place as one or more layers of the pavement design, reducing the quantity and cost of additional construction. Decisions regarding layer substitution must be made by the DPWT or OPWT and should comply with the following principles.

- Sufficient DCP tests, test pits and laboratory soaked tests should be carried out to ensure that the thickness and strength of any layer is equal to or greater than the layer which is to be substituted.
- The combined structure of additional layers, substituted pavement layers and the resulting subgrade (assessed using the guidance in 2.6.1 and 2.6.2) is adequate for the expected traffic.

- Adjustments to the thickness or strength of any layer in a pavement design are not permitted, unless amended designs are discussed in detail with LRD.

After improvements have been designed for each uniform section, it is useful to summarise them for discussion with colleagues in DPWT and OPWT offices and with any interested outside parties. This summary can be done either as a list of improvements, similar to a Bill of Quantities, or as a map, similar to a strip map of the road.

2.9 Estimation of costs

The costs of the selected and designed improvements should now be estimated. There are two reasons for estimating the costs.

1. It is important to make sure that the improvements can be completed within the available budget
2. It may be necessary to compare the costs of two or more alternative improvements for a section in order to select the cheapest. In most cases this will be between different pavement types, although it may be necessary to compare a short realignment with reconstructing a road up a steep hill or to compare two different water crossing structures.

Some improvements are cheap to construct but expensive to maintain. Selecting these improvements can cause long term financial problems for OPWTs and VMCs. It is therefore recommended that the expected costs over the design life of the road are estimated. These are referred to as whole life asset costs and can then be used to compare costs with available budgets and compare alternative pavement types.

Whole life asset costs have three elements: construction costs, maintenance costs and residual value.

Construction costs

These are the costs of constructing the work and include materials, labour, equipment, transport, fuel, supervision, management, insurance, site camp, land purchase, commercial profit, overheads and tax. Construction costs can be estimated in three ways. Firstly, by using the cost of similar work constructed recently nearby using similar methods and materials. Secondly, by using MPWT figures for the typical costs of various improvements. Thirdly, by multiplying the quantity of each input into the work by the unit costs of that input in a Bill of Quantities (BoQ).

Maintenance costs

These are the costs of maintaining the improvements over the design life. They can be estimated in a similar way to construction costs, by comparison with similar work or by multiplying quantities by unit costs, and using information on the likely frequency and content of required maintenance cycles. Maintenance that happens in future years should be multiplied by a discount factor, referred to as discounting, in order to indicate the effect of that cost on the current budget. Discount factors depend on the annual growth rate and the year in which the work is carried out and can be found in Table 30 below. It should be noted that most pavement types require routine maintenance annually and periodic maintenance every 4-8 years.

Residual value

At the end of the design life, some improvements need to be completely reconstructed but others are still in reasonable condition. The repair of these improvements is normally cheaper than reconstruction. These improvements have residual value which can be estimated by calculating the difference between reconstruction and the required repair work.

The whole life asset cost of an improvement is estimated by adding the discounted maintenance costs to the construction cost and then subtracting the discounted residual value.

Table 30 Discount factors

Design life (years)	Discount rate (%)										
	5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	0.95	0.94	0.93	0.93	0.92	0.91	0.90	0.89	0.88	0.88	0.87
2	0.91	0.89	0.87	0.86	0.84	0.83	0.81	0.80	0.78	0.77	0.76
3	0.86	0.84	0.82	0.79	0.77	0.75	0.73	0.71	0.69	0.67	0.66
4	0.82	0.79	0.76	0.74	0.71	0.68	0.66	0.64	0.61	0.59	0.57
5	0.78	0.75	0.71	0.68	0.65	0.62	0.59	0.57	0.54	0.52	0.50
6	0.75	0.70	0.67	0.63	0.60	0.56	0.53	0.51	0.48	0.46	0.43
7	0.71	0.67	0.62	0.58	0.55	0.51	0.48	0.45	0.43	0.40	0.38
8	0.68	0.63	0.58	0.54	0.50	0.47	0.43	0.40	0.38	0.35	0.33
9	0.64	0.59	0.54	0.50	0.46	0.42	0.39	0.36	0.33	0.31	0.28
10	0.61	0.56	0.51	0.46	0.42	0.39	0.35	0.32	0.29	0.27	0.25
11	0.58	0.53	0.48	0.43	0.39	0.35	0.32	0.29	0.26	0.24	0.21
12	0.56	0.50	0.44	0.40	0.36	0.32	0.29	0.26	0.23	0.21	0.19
13	0.53	0.47	0.41	0.37	0.33	0.29	0.26	0.23	0.20	0.18	0.16
14	0.51	0.44	0.39	0.34	0.30	0.26	0.23	0.20	0.18	0.16	0.14
15	0.48	0.42	0.36	0.32	0.27	0.24	0.21	0.18	0.16	0.14	0.12

The estimated whole life asset costs should allow the costs of two or more alternative improvements for a section to be compared and the improvement with the lowest whole life asset costs to be selected.

An example in Appendix A10.4 shows how whole life asset costs are calculated and how two alternative pavements can be compared.

The comparison of the improvement costs against the available budget is explained below.

2.10 Prioritisation

Improvements have now been selected and designed for each uniform section along the road. The construction and whole life costs of the improvements have been estimated.

However, in most cases the budget available for the improvements is less than the estimated costs. The options are to cancel the project and wait until enough funding is available for the entire road, or to construct some of the improvements to the limit of the budget. Cancelling the project is unrealistic because additional funding is unlikely to become available. It is therefore necessary to select which improvements can be constructed within the construction budget.

Improvements that are important to those who use and rely on the road should be prioritised for construction and those improvements which are less important should be omitted. This process is called prioritisation and is why each uniform section was given a priority criteria. The selected improvements will be referred to as ‘spot improvements’.

In addition to priority criteria, the way in which the road connects at either end affects its priority. On a road which is equally used along its length, all uniform sections of similar priority should be prioritised and improved together. However, for a road such as one from a village into farmland with no onward connection, one end is more used than the other and sections there have greater priority.

Improvements should be prioritised using the following procedure.

Define the connection of the road

Decide if the road connects two significant locations, such as a District centre with a main road, or connects one significant location, such as a kum ban, with, for example, farmland, as shown in Table 31. Prioritisation of the two types of road is described in the paragraphs below.

Table 31 Connection of the road

Description	Connection of the road
Road connects two significant locations	Double entry road
Connection with network at both ends	
Road connects only one significant location	Single entry road
No exit at the far end	

Prioritisation of a double entry road

The objective when prioritising improvements on a double entry road is to improve the entire road equally along its entire length. Improvements are therefore prioritised by firstly constructing all selected improvements on the uniform sections with a priority criteria of 1, then all the improvements on the sections with a priority criteria of 2 and so on until the construction costs are almost equal to the available construction budget.

If it is not possible to address all uniform sections that have, for example, a priority criteria of 7, within the budget, the sections should be improved starting at the end with the higher traffic and moving towards the other end.

The sections which the available budget does not cover will remain unimproved until additional funding can be obtained.

Prioritisation of a single entry road

The emphasis when prioritising improvements on a single entry road is on achieving a balance between the priority criteria and the higher traffic at one end of the road.

The dominant end of the road is defined as the end with the higher traffic, the significant location or the connection with the network. In most cases these will all occur at the same end.

Improvements are therefore prioritised by grouping together all uniform sections with a priority criteria of 1-5. These sections are improved starting at the dominant end and moving towards the other end. If it is possible to address all these uniform sections within the budget, those with a priority criteria 6-10 should be grouped together and improved starting from the dominant end. If these can be addressed within the budget, the remaining sections with a priority criteria 11-14 should be grouped together and improved starting from the dominant end. The sections which the available budget does not cover will remain unimproved until additional funding can be obtained.

Completion of prioritisation

Table 32 lists possible outcomes of the prioritisation process, depending on the available budget.

Table 32 Possible outcomes of the prioritisation process

Available budget	Outcome
High	Entire road improved with a pavement and a bituminous or concrete surface
Medium	Gravel surface with spot improvements of a bituminous or concrete surface on steep hills, through villages and at other dangerous sites
Low	Spot improvements at dangerous sites; the remainder of the road is unimproved

A small amount of funding should be retained to carry out low cost measures, as indicated in Table 33, on the uniform sections which will not be improved. These measures are intended to reduce the rate at which these sections deteriorate. They are all described briefly in Appendix A6.

Table 33 Low cost measures on unimproved sections

Improvement	Description
Drainage humps on unformed tracks	Diagonal humps across a track should be constructed to remove water from the surface and reduce erosion
Mitre drains	Additional mitre drains should be dug wherever possible to reduce the water flow in side ditches
Scour checks	Small dams should be constructed in side ditches to reduce water velocity and erosion

After the improvements have been prioritised, it should be checked that the likely maintenance costs will be within the available annual maintenance budget. If it is not, fewer improvements should be constructed in order to reduce the future maintenance requirement.

The summary list or map of improvements should now be amended to show those which have been prioritised for construction.

2.11 Contract documents

The final part of the design process is to incorporate adequate information on the selected, designed and prioritised improvements into contract documentation so that the work can be tendered.

Table 33 recommends the information that should be included in the contract documentation, which should also comply with standard Lao contract procedures.

Table 34 Design information to be included in the contract

Information that is required in a single package for the contract	• List or strip map of the prioritised improvements • Overall alignment of the road • Landmarks used for referencing chainages • List of villages along the road • List of required safety measures • List of required environmental measures • List of available material sources • Standard paragraphs from the LVRR Specifications • LVRR Specifications for all required pavement types
Information that is required for each uniform section	• Start and end chainages and length • Geometric cross section information, including carriageway and shoulder width, camber and freeboard • Geometry, including gradient, horizontal and vertical curvature and super elevation • Pavement type, layer strengths and thicknesses • Shoulder design • Subgrade preparation • Embankment design • Drainage design • Slope protection works • List of low cost measures on all unimproved sections • Water crossing structure designs

3 Construction of a new road

The design steps for a new road are the same as those for improving a road in poor condition, with the following exceptions.

1. An initial step is to establish the alignment of the road. This manual gives brief guidance on short realignments around difficult sites. Additional guidance should therefore be used when establishing the alignment of a new road. However, determining the alignment of a new road offers the opportunity to avoid areas with many problems, such as wide valley floors or wide flood plains.

2. It is possible that some portions of the agreed alignment will be passable with minimal improvement, for example a length with a flat cross section in gentle terrain which is unlikely to erode, weaken or become slippery.

3. During the rapid survey of the agreed alignment, some items such as width, surface and condition may not be relevant.

4. There will be no traffic to count and it will therefore be necessary to make careful estimates of the traffic that will use the road soon after opening and the rate at which the traffic will grow after that.

5. When identifying uniform sections, road appearance and overall condition will not be relevant.

6. A number of the main survey items, such as width, surface, surface and drainage in poor condition and geometric cross section, geometry, surface and pavement below standard, may not be relevant. It will therefore be more necessary to record conditions such as gradient, flooding and so on which are likely to lead to poor condition when traffic starts to use the road.

7. Safety concerns may be difficult to anticipate on a route which traffic is not yet using.

8. Priority criteria 1-10 are relevant although they may be more difficult to define on a route which traffic is not yet using and which has not yet fallen into poor condition at problem sites.

9. DCP tests are unlikely to be used in their normal role for subgrade assessment but can be used to assess relative strengths and depths. It will therefore be necessary to carry out laboratory soaked tests.

10. Subsequent steps – improvement selection, design, costing and prioritisation – remain similar to those or a road in poor condition.

4 Acknowledgements

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Appendices

A1. Subgrade design strength

A2. Material testing

A3. Pavement design tables
- A3.1 Gravel pavement
- A3.2 Sealed granular pavement
- A3.3 Sealed armoured gravel pavement
- A3.4 Unreinforced concrete pavement

A4. Shoulder design

A5. Earthworks

A6. Drainage and water crossing design

A7. Realignment

A8. Safety measures

A9. Slope stabilisation

A10. Exercises and examples
- A10.1 Traffic analysis exercise
- A10.2 Subgrade design strength and pavement design example
- A10.3 Road and pavement design exercise
- A10.4 Whole life asset cost exercise

A1. Subgrade design strength

The detailed pavement designs in this manual are based upon the traffic that is likely to use the road and the strength of the subgrade on which the pavement will be constructed, which may be either: prepared and compacted in situ material; compacted imported material or layers of an existing pavement.

Subgrade strength may be obtained from one or more of the following sources:

1. Soaked laboratory CBR tests on samples taken of the materials to be used as the subgrade

2. Previous laboratory tests on material similar to that being used for the subgrade

3. In situ DCP-CBR testing on the material forming the subgrade

4. In situ DCP-CBR testing on adjacent roads or sections of road constructed with similar materials

5. Correlation of CBR strength with standard soil index properties

Apart from (5) the options are associated with either laboratory testing or in situ testing; both have their advantages and disadvantages with respect to practical LVRR pavement design.

The laboratory test approach is one which is normally adopted for higher grade road pavement design. The disadvantages the laboratory testing approach for LVRRS are:

1. The difficulty of obtaining reliable CBR results reasonably quickly from remote areas.
2. CBR testing is undertaken only on material <20mm. Material >20mm is removed prior to testing and hence for coarser soils the laboratory value may not be truly representative.
3. Using the laboratory CBR assumes that subgrade will be compacted uniformly to the required standard and hence also relies on site control and/or in situ density testing, (activities which are not necessarily carried out effectively on LVRR projects).

In situ DCP-CBR testing provides an assessment of actual in situ strength at the time and road condition of testing and because of the speed and cheapness of operation can provide a representative number of values within most LVRR investigation budgets. A DCP programme therefore provides a reliable assessment of relative strength along and across alignments at low cost. The principal drawback to its application for design work is that DCP testing provides a snapshot assessment of in situ strength at the existing conditions of moisture and density. An evaluation therefore has to be made as to how this DCP-CBR relates to the strength of the investigated layers under any future conditions of moisture and density.

It is clear from experience with regional LVRR projects that the ideal situation is where a combination of laboratory and in situ testing provide both an adequate coverage of all subgrade variations and good correlations are available between the in situ and laboratory testing. Frequently this will not be the case for LVRR projects and engineering judgement and assessment will have to be used.

This Appendix therefore indicates how the subgrade design strength may be estimated under typical LVRR conditions.

If DCP and laboratory test results are both available for a section whose surface has been well compacted by traffic or weather, the subgrade design strength should be estimated using the steps below. Other situations are covered in the subsequent notes.

1. Take samples of the subgrade or pavement surface along the road at a recommended spacing of 500 metres (or at least two tests per section). In a laboratory determine the soaked CBR strength at 95% of modified AASHTO maximum dry density. If the surface has more than one distinct layer in the top 300 mm, take a separate sample of each layer and determine the soaked strength of each.

2. Carry out in situ DCP tests at a recommended spacing of 100 metres in each wheeltrack and also within 1 metre of every sample site. Plot the penetration data of each DCP test on graph paper and identify the weakest layer within the top 300 mm that is thicker than 50 mm. For this layer, use the following penetration equation to estimate the in situ strength in terms of CBR.

$$\text{Log}_{10}(\text{CBR}) = 2.48 - 1.057\ \text{Log}_{10}(\text{mm/blow})$$

3. If possible, measure the moisture content and density of the subgrade where each DCP test was carried out.

4. Try to establish a correlation between the soaked laboratory CBRs and the DCP-CBRs, taking into account any situ moisture-density condition at each sample site. Note that the ASSHTO testing procedure requires CBR testing at different compaction levels for each sample, thus allowing CBR interpolation for a range of moisture-density conditions.

5. Plot the strengths against chainage along the road or each section of road, indicating separately the in situ strengths from each wheeltrack and the soaked strengths. Try to interpolate the pattern in the in situ strengths into the gaps between the soaked strengths, if possible using the correlation from step 4.

6. Compare the strengths from each wheeltrack. A consistent difference from one side to the other, particularly if the road crosses a steep hillside, might indicate problems with the site or with initial preparation work and should be carefully checked. A low strength on the downhill side across a hillside might be because the road has been formed on top of loose fill which would be at risk of erosion or slipping.

7. Identify and use the design charts in these Appendices which correspond to the pavement types being considered. Note the subgrade strengths which correspond to different rows in the charts.

8. Divide the road into sub-sections if there is a significant change in strength along the road and the strength of one sub-section is in a different row of the design chart to another sub-section. A sub-section should not be less than 100m in length and must include DCP tests on at least 2 chainages.

9. Estimate the design subgrade strength within each section or sub-section. If there are 5 or less soaked strengths (either real or correlated from the in situ strengths), the design subgrade strength is the lowest value; if there are 6-9 strengths, this is the second lowest value, and so on.

10. Overseas Road Note (ORN) 31 is a pavement design document written by TRL for use in tropical and sub-tropical countries. It contains Table A1, which correlates estimated subgrade strength with soil plasticity and water-table position. Although likely to be conservative it is a valid correlation to use in the absence of other data from laboratory or in situ subgrade strength testing.

Table A1 Soil plasticity and subgrade strength

Depth of water table (m)	Subgrade strength (CBR %)				
	Non-plastic sand	Sandy clay (PI = 10)	Sandy clay (PI = 20)	Silty clay (PI = 30)	Heavy clay (PI > 40)
0.5	8-14	8-14	3-4	3-4	2
1	15-29	8-14	5-7	3-4	2
2	15-29	15-29	8-14	5-7	3-4
3	30	15-29	8-14	5-7	3-4

PI – Plasticity Index

Additional Notes

If the road is along a new section of alignment with an as-yet uncompacted surface DCP-CBRs will only relate to this existing condition and should therefore not be used for pavement design purposes. Samples should be taken of the material (either in situ or imported) that is likely to form the subgrade and the laboratory soaked CBR strength determined.

If DCP results are not available additional soaked CBR strengths should be determined. Reduce the spacing between tests if possible. Ideally, at least two tests will be carried out on each uniform section.

If laboratory test results are not available, it may be possible to compare in situ strengths with soaked strengths from nearby roads, but this should be done with very careful consideration of soil types, drainage conditions and terrain.

If neither DCP results nor laboratory test results are available, the lowest strength in the suggested range in the above Table should be used as the subgrade design strength.

A2. Material testing

Tables A2 and A3 provide examples of useful on-site material tests.

Table A2 Simple field tests

Field Test	Description
Fines Content	Relative percentages of silt/clay. • Hand shake dilatancy test – Soil dilation =high silt content • Jar settlement test – allow material to settle in jar of water and measure relative thicknesses of settled fines/sand/gravel
Hand Sample Index Strength	Use of small geological type hammer on hand or core sample • Very weak: easily broken in hand • Weak: broken by leaning on sample with hammer • Moderately weak: broken in hand by hitting with hammer • Moderately strong: broken against solid object with hammer • Strong: difficult to break against solid object with hammer • Very strong: requires many blows of hammer to break sample • Extremely strong: sample can only be chipped with hammer
Aggregate Pliers Test	Take 100-200 pieces of air dry material in the 12 to 20 mm range and attempt to break the pieces between finger and thumb, then try to break remaining pieces with a pair of 180-mm pliers. The percentage unbroken by the pliers is termed the Aggregate Pliers Value and is broadly comparable to a 10% Fines value of over 100 kN.
Field Plasticity	Prepare a ball 20 or 30 mm in diameter. Moisten so that it can be modelled without being sticky. Roll to a 3mm thread adding water if necessary. At 3 mm the material should start to break, then remould into a ball and carry out the following: • Ball is hard to crush – does not crack/crumble = high clay content • Tends to crack/crumble = low clay content • Impossible to make a ball = high sand or silt content, very little clay • The ball has a soft or spongy feel = organic soil

Table A3 Common laboratory tests

Physical Condition Tests	Standard Procedures		Advantages of Test
	BS	ASTM	
Moisture Content	1377: 2:,3.1 812:109	D2216	Simple and widely accepted test.
Water Absorption	812:109	C127 & C128	Simple test with established correlations to aggregate performance
Liquid Limit (WL)	1377:2,:4.3-6	D4318	Well established soil index and classification test
Plastic Limit (Wp)	1377:2,:5.3	D4318	Well established soil index test. Plasticity index (Ip = W_L-Wp) used as a key defining parameter in many specifications.
Linear Shrinkage (Ls)	1377:2,:6.5		Can give an estimate of Ip for soils where W_L and Ws are difficult to obtain. Better repeatability and reproducibility than plasticity test.
Particle Size Distribution	1377:9:2.3-5 812:103,1	D422	Simple and widely accepted test incorporating both sieving and sedimentation. A fundamental soil classification tool.
Sand Equivalent Value		D2419	A rapid site-lab means of determining relative fines content
Aggregate Grading (Sieve) Aggregate Sedimentation	812:103,1 812:103,1	C136 & C117	Simple and widely accepted test for defining aggregate size distribution.
Flakiness Index (If) Elongation Index (Ie)	812:105, 1 812:105, 2	D4791	Standard gauge methods of ascertaining particle shape. Parameters incorporated into coarse aggregate specifications
Soil Particle Density	1377:2, 8.2	D854	Required for use in analysis of other parameters (e.g. psd, compaction)
Compaction	1377:4, 3.3-7	D698 & D1557	Simple test. Basis of control on site compaction of fill and pavement

			materials
CBR	1377:4, 7	D1883	Quick and simple to perform. A convenient and widely established test for defining material suitability for road construction and subsequent quality control.
Vane Shear (Lab)	1377:7, 3	D4648	Very simple and rapid method for obtaining undrained shear strength. Can be used on materials in compaction or CBR moulds.
Sulphate Soundness	BS 812: 121	C88	Assesses aggregate durability as a response to repeated crystallization and rehydration stresses. Incorporated in many specifications
Los Angeles Abrasion (LAA)		C131/535	Standard combined impact and rolling abrasion test. Commonly used as a specification parameter
Aggregate – Bitumen Adhesion		D1664	Tests for assessing adhesion of bitumen to aggregate in water

A3. Pavement design tables

Design tables are provided in this Appendix for the following pavement and surface types.

Pavement and surface type	Appendix
Gravel pavement	A3.1
Sealed granular pavement	A3.2
Sealed armoured gravel pavement	A3.3
Unreinforced concrete pavement	A3.4

A3.1 Gravel pavement

This pavement is a layer of gravel that is used as a combined pavement layer and wearing course.

Table A4 is the design table for a gravel pavement with a capping layer. Table A5 is the design table for a gravel pavement without a capping layer in situations where gravel is locally abundant or a previously constructed gravel pavement is being used in an improved pavement. Table A6 gives the required layer strengths.

In the two design tables, the upper 100 mm is designed to wear away and be replaced during maintenance. It is important therefore to regravel the road before this upper 100 mm has worn away.

Table A4 Gravel pavement design table with a capping layer

Traffic Group A			Traffic Group B		
Subgrade soaked CBR (%)	**Pavement layer**	**Layer thickness (mm)**	**Subgrade soaked CBR (%)**	**Pavement layer**	**Layer thickness (mm)**
2-3.9	Gravel *	200	2-3.9	Gravel *	200
	Capping	250		Capping	300
4-6.9	Gravel *	200	4-5.9	Gravel *	200
	Capping	100		Capping	150
> 7	Gravel *	200	6-7.9	Gravel *	200
	Capping	0		Capping	100
			> 8	Gravel *	200
				Capping	0

* The surface should be regravelled before the gravel thickness is less than 100 mm

Table A5 Gravel pavement design table without a capping layer

Traffic Group A			Traffic Group B		
Subgrade soaked CBR (%)	**Pavement layer**	**Layer thickness * (mm)**	**Subgrade soaked CBR (%)**	**Pavement layer**	**Layer thickness * (mm)**
2-3.9	Gravel	375 (275)	2-3.9	Gravel	400 (300)
4-6.9	Gravel	275 (175)	4-5.9	Gravel	300 (200)
> 7	Gravel	200 (100)	6-7.9	Gravel	275 (175)
			> 8	Gravel	200 (100)

* The first figure is the required construction thickness of gravel. The second figure in brackets is the minimum thickness before the surface is regravelled.

Table A6 Layer strengths for a gravel pavement

Pavement layer	Traffic Group A & B
	Soaked CBR (%)
Gravel	25
Capping	10

The specification for gravel wearing course is contained in the Low Volume Rural Road Standards and Specifications (Part II) as LVRR-1 and is based on the current Lao specification.

The specification for capping is in the current standard Lao Specification for Earthworks, with the additional strength requirement as above.

A3.2 Sealed granular pavement

This pavement consist of a bituminous sealed surface on top of a granular base which can be a medium or high strength gravel, a dry bound macadam or a water bound macadam.

Table A7 is the design guide for a sealed granular pavement with a capping layer and Table A8 is the guide in situations where a capping layer is not being used, for example: where gravel is locally abundant or a previously constructed gravel pavement is being overlain. Table A9 gives the required layer strengths.

Table A7 Sealed granular pavement design table with a capping layer

Subgrade soaked CBR (%)	Pavement layer	Layer thickness (mm)	
		Traffic Group A	Traffic Group B
2-3.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150
	Capping	200	275
4-6.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150
	Capping	100	175
7-10.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150
	Capping	0	100**
> 11	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150
	Capping	0	0

* Seal can be either DBST or double Otta seal

** Capping layer may be omitted if subgrade >10%

Table A8 Sealed granular pavement design table without a capping layer

Subgrade soaked CBR (%)	Pavement layer	Layer thickness (mm)	
		Traffic Group A	Traffic Group B
2-3.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	225	325
4-6.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	175	275
7-10.9	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	225
> 11	Surface	Seal *	Seal *
	Granular base	100	100
	Granular sub-base	100	150

* Seal can be either DBST or double Otta seal

Table A9 Layer strengths for a sealed granular pavement

Pavement layer	Minimum Soaked CBR (%)	
	Traffic Group A	Traffic Group B
Granular base	50 *	80
Granular sub-base	25	25
Capping	10	10

* Gravel with CBR of 25% may be used if there are no trucks (including Kolaos) in the traffic

The following relevant specifications are contained in the Low Volume Rural Road Standards and Specifications (Part II) – Pavement Options and Technical Specifications:

- LVRR-1: Gravel as a base or sub-base layer
- LVRR-2: Dry-bound/water-bound base or sub-base
- LVRR-4: DBST
- LVRR-5: Otta Seal

The specification for capping is in the current standard Lao Specification for Earthworks, with the additional strength requirement as above.

A3.3 Sealed armoured gravel pavement

This pavement is a low or medium strength gravel with an armouring layer of aggregate and a bituminous sealed surface.

Table A10 is the design guide for a sealed armoured gravel pavement with a capping layer and Table A11 is the guide in situations where a capping layer is not being used, for example: where gravel is locally abundant or a previously constructed gravel pavement is being overlain. Table A12 gives the required layer strengths.

Table A10 Sealed armoured gravel pavement design table with a capping layer

Subgrade soaked CBR (%)	Pavement layer	Layer Thickness (mm)	
		Traffic Group A	Traffic Group B
2-3.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150
	Capping	200	275
4-6.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150
	Capping	100	175
7-10.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150
	Capping	0	100**
> 11	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150
	Capping	0	0

* Seal can be either DBST or double Otta seal
** Capping layer may be omitted if subgrade >10%

Table A11 Sealed armoured gravel pavement design table without a capping layer

Subgrade Soaked CBR%	Pavement layer	Layer Thickness (mm)	
		Traffic Group A	Traffic Group B
2-3.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	225	325
4-6.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	175	275
7-10.9	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	225
> 11	Surface	Seal *	Seal *
	Armouring	70	70
	Gravel base	100	100
	Gravel sub-base	100	150

* Seal can be either DBST or double Otta seal

Table A12 Layer strengths for a sealed armoured gravel pavement

Pavement layer	Soaked CBR (%)	
	Traffic Group A	Traffic Group B
Armouring	Refer to the specification	
Gravel base	25	25
Gravel sub-base	25	25
Capping	10	10

The following relevant specifications are contained in the Low Volume Rural Road Standards and Specifications (Part II) – Pavement Options and Technical Specifications:

- LVRR-1: Gravel as a base or sub-base layer
- LVRR-3: Crushed stone aggregate
- LVRR-4: DBST
- LVRR-5: Otta Seal

The specification for capping is in the current standard Lao Specification for Earthworks, with the additional strength requirement as above.

A3.4 Unreinforced concrete pavement

This pavement is a layer of unreinforced concrete on low strength gravel.

Table A13 is the design table for a concrete pavement. Table A14 gives the required layer strengths.

Table A13 Concrete pavement design table

Subgrade soaked CBR (%)	Pavement layer	Layer thickness (mm)
		Traffic Groups A & B
2-6.9	Concrete	150
	Sub-base	150
> 7	Concrete	150
	Sub-base	100

Table A14 Layer strengths for a concrete pavement

Pavement layer	Layer strength
	Traffic Groups A & B
Concrete	28 day cube strength = 20 MPa
Sub-base *	Soaked CBR = 25%

The following relevant specifications are contained in the Low Volume Rural Road Standards and Specifications (Part II) – Pavement Options and Technical Specifications:

- LVRR-1: Gravel as a base or sub-base layer
- LVRR-2: Dry-bound/water-bound base or sub-base
- LVRR-6: Non-reinforced concrete pavement

A4. Shoulder design

Shoulders are an important part of a road, providing lateral support for the pavement layers, allowing water from the carriageway to flow into the side ditches and being occasionally trafficked by passing vehicles. In the case of LVRRs they also provide a relatively safe pathway for non-vehicular traffic.

It is generally too expensive to construct shoulders with the same material as the pavement, except in the case of a gravel wearing course. Shoulder materials that are non-plastic will tend to ravel and lack sufficient cohesion to withstand the abrasive action of traffic and hence may need to be stabilised in some way.

When the pavement construction cannot be extended into the shoulders, the shoulder material should be selected using the same principles as for a gravel surfaced road or a sub-base to carry construction traffic. Thus the material should be strong enough to carry occasional vehicles and should be as cohesive as possible without being too weak when wet. The material will normally be of sub-base quality with a minimum soaked CBR 25%.

If the base material cannot be extended into the shoulders and an impermeable material is used, it is important that water is not trapped without means of discharge. There are three ways of draining this water away. Firstly, the sub-base through the shoulder can be constructed of permeable material. Secondly, drainage grips of free draining graded granular material, 300 mm wide and extending from under the base and for the full depth of the sub-base layer under the shoulder can be constructed every 5 metres. Thirdly, a permeable subgrade can be used to drain the water away vertically.

It is very desirable if at least the outer edge of the shoulder is able to support the growth of grasses which help to bind the surface and prevent erosion.

Un-sealed shoulders often require considerable maintenance if satisfactory performance is to be guaranteed.

A5. Earthworks

Cut-slope and embankment earthwork design is currently outside the specific scope of this edition of the EOD Manual. Earthworks should be designed to comply with current Lao general specification and in line with guidance in the LRDM.

The following points should be noted, however, with specific reference to LVRR earthworks:

1. Adequate compaction of fill materials is essential. The practice of excavation and dumping to fill without adequate compaction through the whole depth of fill must be avoided. Inadequate compaction, particularly in side-long ground, will inevitably lead to erosion and road failure.

2. Excavated material must not be dumped in a location where it is either a danger to life (above a village) or the environment (above a water course).

3. Embankment and cut-slope slope angles must be constructed to be compatible with the material properties of the cut or fill concerned.

4. Adequate cross-drainage should be provided through embankments. This is particularly important on sections of long embankment on low-lying flood-prone area where earthworks can form impediments to flood dissipation and may be seriously eroded in the process.

A6. Drainage and water crossing design

The four main functions of the external drainage system are:

- To convey rainwater from the surface of the carriageway to outfalls (streams and turn-outs)
- To control the level of the water table in the subgrade beneath the carriageway
- To intercept surface water flowing towards the road
- To convey water across the line of the road in a controlled manner

The first three functions are performed by side ditches and the fourth by culverts, drifts and bridges.

In both the design and maintenance of drainage, it is important to interfere as little as possible with the natural flow of water. Culverts on natural water courses should follow the existing alignment as closely as practicable and realignment (often resulting in sharp changes in direction) should be avoided. The surface flows in ditches and culverts should also be kept to a minimum by the use of frequent turnouts where side ditches cannot be discharged to existing watercourses. In sidelong ground, where discharge from the side ditch on the high side passes to the low side, it is best to use frequent small culverts rather than occasional large ones.

A number of drainage measures are recommended for roads which are not selected for improvement during prioritisation. These measures are low cost and help to reduce the rate of continuing deterioration. They include drainage humps – shallow humps, diagonal in plan, across an unformed track which trap water flowing along and eroding the surface and divert it onto the surrounding land – mitre drains – drains which carry water from the side ditch away from the road onto the surrounding land – and scour checks – small dams in side ditches which reduce the speed of water and the erosion that it causes.

Suitable designs for LVRR side ditches and cut-off drains are given in the LRDM. These are summarised below. Designs and specifications for culverts, drifts and bridges will be contained in separate LVRR Standards and Specification documents. Currently, guidance on these topics may be obtained from the following documents:

- TRL Ltd, 1997, Principles of Low Cost Road Engineering in Mountainous Regions
- TRL Ltd, 2000, Overseas Road Note 9, A Design Manual for Small Bridges

Side ditches and cut-off drains

1 General

The following sections on the Specifications for LVRR external drainage have been adopted from the current Lao Road Design Manual (LRDM). Appropriate Figures are cross-referenced to that document for use in LVRR construction.

The recommended types of side ditches and cut-off drains are shown in Figure A1 and listed in Table A15 which gives guidelines regarding the choice of each particular type. These guidelines are based upon general economic and aesthetic considerations. However, the type of side ditch selected must be checked to ensure that it will carry the expected flow without running deep and wetting the pavement or running fast and causing scour.

Due to their location, cut-off drains are usually difficult to maintain and should therefore, whenever possible, be constructed as "natural permanent depressions" with as gentle side slopes as possible.

2 Expected flow in side ditches

The Road Design Manual Part IV, Hydraulic Design, covers the discharge capacity of side ditches as well as the determination of culvert sizes for discharging water crossing the road.

The side ditches must be designed to carry the storm-water run-off originating from the carriageway, shoulders, drains and cut slopes. Where cut-off drains are not provided, any run-off from beyond the cut slope must also be included. The expected flow, or run-off, should be estimated using the formula:

$$Q = 0.278\ C.I.A.$$

where:

Q is the expected flow (m^3/s)
C is the run-off coefficient (suggested value 0.9 for pavement, shoulder, drain and cut slope)
I is the intensity of rainfall (mm/h) for a 5 minute storm with a return period of 2 years (determined in accordance with an approved method)
A is the area drained (km^2)

3 Capacity of side ditches

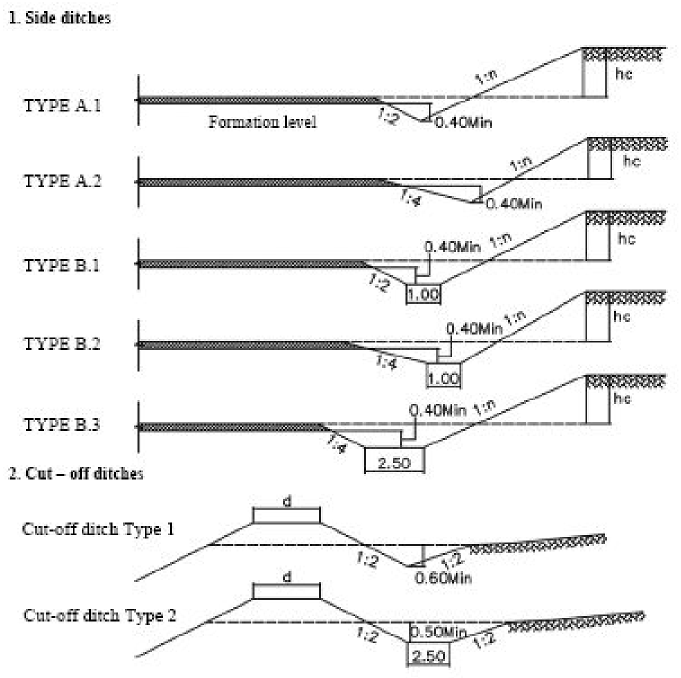
The capacity of a side ditch should be estimated using the Manning Strickler formula (metric):

$$Q = K.A.R^{2/3}.S^{1/2}\ A.V$$

$$\text{or } V = K.R^{2/3}.S^{½}$$

where:

Q	is the capacity (m^3/s)
A	is the cross-sectional area of water (m^2)
V	is the velocity of flow (m/s)
K	is the Roughness Coefficient
R	is the hydraulic radius, A/P where P is the wetted perimeter
S	is the longitudinal slope of flow in metres per metre (H/L)



- Table relating to design of side ditches and cut - off ditches

Height of Cut hc	Slope (1:n) of cutting in Earth (1)	Distance ,d, between edge of cutting and cut-off ditch
hc < 1.00	1 : 3	d = 1.0
1.00 < hc ≤ 3.00	1 : 2	d = 4.0
hc > 3.00	1 : 1.5(2)	d ≥ 5.0

(1) In rock the slope 1:n will vary from 1 : 0.33 to 1 : 0.10
(2) If earth not stable at 1:1.5 the slope maybe decreased to 1 : 2
If natural slope steeper than 1:1.5 then the natural slope may be used as the cut slope
(3) The slopes in to the ditch should be as indicated or flatter

Figure A1 Side ditches and cut-off drains

Table A15 Guidelines for the selection of side ditch and cut-off drain types

Side ditch type	To be used under the following condition	Remarks
Al	Hilly to mountainous terrain with heavy earthwork.	Back slope to be varied according to stability of cut material. Slope should be stable and enable vegetation to establish.
A2	Rolling terrain with moderate earth work. Hilly to mountainous terrain where flatter ditch than Al is required due to capacity and/or velocity limitations.	As for Al
B1	Hilly to mountainous terrain where flatter ditch than Al is required due to capacity and/or velocity limitations.	As for Al, width may be increased if fill material is required
B2	Rolling terrain with mode-rate earthwork where a flatter ditch than A2 is required due to capacity and/or velocity limitation.	As for B1
B3	Flat terrain with little earthwork. Rolling terrain with moderate earthwork where a flatter ditch than B2 is required to capacity and/or velocity limitation.	As for B2
Cut-off drain type	**To be used under the following conditions**	**Remarks**
1	Moderate catchment area and little chance of siltation.	
2	Large catchment area and in areas liable to silting and/or damage to the drain profile by pedestrians, cattle etc.	

Limiting values for the velocity of flow (v) to prevent scour, together with the corresponding Roughness Coefficients, are given in Table A16 for the different types of drain material which will normally be encountered.

Table A16 Allowable velocity in ditch and corresponding roughness coefficients

Ditch material	Maximum allowable velocity (m/s)	Roughness Coefficient
Sand, loam, fine gravel, volcanic ash	0.6*	45
Stiff clay	1.1*	50
Coarse gravel	1.5	40
Conglomerate, hard shale, soft rock.	2.0	25
Hard rock	3.0	25
Masonry	3.0	40
Concrete	3.0	60

* In areas where good grass cover is guaranteed, these values may be increased up to a maximum of 1.5 m/s; in such cases a Roughness Coefficient of 30 should be used. Where grass cover is expected but not guaranteed a maximum velocity of 1.1 m/s should be used with a Roughness Coefficient of 30.

4 Scour protection

It is important to note that a side ditch will only perform as designed if the design cross-section is maintained, i.e. excessive scour must be prevented. In practice, due to local inconsistencies in roughness and surface level, side ditches in all but the hardest of materials will suffer from scour. Thus, for long lengths of side ditch at gradients in excess of 4-5%, scour checks should be considered.

A7. Realignment

This Appendix provides guidance on short realignments around difficult sites. Additional guidance should be used when establishing the alignment of a new road and taking into account aspects such as development objectives, national policies and detailed terrain evaluation.

One way of providing safe and reliable access past a site which is unsafe or in poor condition may be to realign a short length of the road past the site. The cost of the new road construction may be less than large improvement works and the resulting access may be safer, more reliable and easier to maintain than the access through the improved site.

In many cases a road was originally a footpath when its alignment was established, often with sections which were suitable for pedestrians but which are no longer suitable for a wider cross section and motor vehicles. In such cases, realignment past a problem site is reasonable.

Typical sites where short realignment should be considered include:
- Unsuitable water crossing sites which are eroding or unstable
- Steep hills
- Areas which flood
- Crossing steep or unstable slopes
- Sites where the road affects natural land drainage
- Swampy areas with weak soil

Typical sites to which the road could be realigned include:
- Areas of good soil with good natural drainage
- Routes along or just below a ridge line

In all cases, the whole life asset costs of the site improvement and the realignment should be compared, as described in 2.9. The final decision between the alternatives should balance the whole life cost comparison with a consideration of the safety and reliability of the access provided by each.

A8. Safety measures

An important aspect of providing access is to ensure that it is as safe as possible. The situation is particularly important when low volume rural roads are being improved for four reasons:

1. Improved road conditions can encourage drivers to drive at speeds that they may not be used to and that may be too quick for the width and the curvature of the road
2. The road may have been improved from an unformed track which was established without consideration of the safety issues affecting motorised vehicles
3. Many people live close to the roads and use them as part of their daily lives
4. Pedestrians and users of bicycles and animal carts are vulnerable to injury from motorised vehicles

Whenever low volume rural roads are being improved, the safety concerns relating to the current condition and the likely condition after improvement should be considered and all appropriate measures should be taken.

Safety concerns may be given a priority criteria of 1, where road users or others are at high risk of injury or the injury is likely to be severe, or 7, where road users or others are at medium risk of injury or the injury is likely to be slight.

Table A17 includes the various safety concerns which may occur on low volume roads and gives likely improvement measures.

Table A17 Safety concerns and safety measures

Safety concern	Risk	Safety measure
Unprotected steep or high drop alongside the road	Vehicles fall down the drop, particularly when passing on a narrow road	Edge barriers to prevent vehicles leaving the road Edge marker posts to indicate the edge of the road
Unstable slope above a village	Soil and rock, often dumped during construction, slide down onto the village	Better site management and spoil disposal Slope protection
Motorised traffic near a village, school or place of work	Pedestrians, cyclists and other vulnerable road users are hit by motorised traffic, often travelling fast	Traffic calming: speed bumps, narrowed village entrances, Separate path for vulnerable road users
Tight curve	Vehicles are unable to turn the tight curve under control and leave the road	Realignment to a larger radius
Slippery surface	Vehicles slide off the road, especially on a hill	Improved surface
Poor visibility around curve	Vehicles collide because of inadequate sight distance	Removal of visual obstructions inside the curve
Poor visibility over a crest	Vehicles collide because of inadequate sight distance	Removal of crest in the road
Narrow road	Vehicles are unable to pass safely	Wider road
Dust	Vehicles collide because of poor visibility due to the dust Dust harms the health of road users	Improved surface
Dangerous sites without warning	Drivers are at risk because they are not aware of dangers ahead	Warning signs of curves, steep drops, villages, etc
Area next to the road used as a bus stop	Bus users are hit by motorised traffic	Off carriageway bus stops
Area next to the road used by market traders	Market users are hit by motorised traffic	Off carriageway markets

A9. Slope stabilisation

Cut and embankment slope stabilisation is currently outside the specific scope of this edition of the EOD Manual. However, a separate research programme (SEACAP 21) has produced guidance on this issue. Two separate volumes are now available for use: A Slope Maintenance Manual and a Slope Maintenance Site Manual.

The *Slope Maintenance Manual* has drawn extensively on road construction and maintenance experience in south-east and south Asia over the past twenty years. The emphasis is on practical guidelines for the prioritisation and maintenance of existing slopes and retaining walls, particularly those that are undergoing or have undergone severe distress or failure.

The manual is intended mainly for use in the Provincial Departments of the Ministry of Public Works and Transport (MPWT) by field engineers. The accompanying *Slope Maintenance Site Handbook* has been written to provide guidance to field supervisors and is available in both English and Lao.

A10. Exercises and examples

The following exercises and examples are provided in this Appendix.

Exercises and examples	**Appendix**
Traffic analysis exercise	A10.1
Subgrade design strength and pavement design example	A10.2
Road and pavement design exercise	A10.3
Whole life asset cost exercise	A10.4

A10.1 Traffic analysis exercise

Question

Two-way traffic was counted from 6 am to 6 pm over 3 days and averaged to give the figures in Table A18 below. The Seasonal factor is 1.1, it is assumed that diverted and generated traffic will add 30% to the count as soon as the road is opened, annual growth rate of all vehicle types is 5% and the design life is 12 years.

Table A18 Example traffic count

Pedestrian	23	4WD	2
Bicycle	11	Minibus	5
Animal	5	Kolao	24
Motorcycle	25	Isuzu	3
Tuk-tuk/Jambo	3	Gaz 66	1
Farm tractor	31	Medium bus	1
Car	2	Large truck	1
Pick-up	7	Large bus	0

Refer to the Traffic Analysis Form.

What is the carriageway and shoulder width of the road? Is the traffic in Group A or B?

If the use of the road is restricted so that large trucks and large buses cannot travel, what is the carriageway and shoulder width and is the traffic in Group A or B?

Answer

The traffic counts by Traffic Category are as follows:

Category 1:	39
Category 2:	59
Category 3:	40
Category 4:	5
Category 5:	1

With Category 5 vehicles using the road, the LVRR standards do not apply.

We now assume that the traffic count of Category 5 is reduced to 0.

- With a count from 6 am to 6 pm, the Daily factor is 1.2
- The seasonal factor is 1.1
- The diverted and generated traffic equates to a factor of 1.3
- With annual growth of 5% and a 12 year design life, the Traffic growth factor is 1.8

Therefore the traffic counts should be multiplied by:

1.2 x 1.1 x 1.3 x 1.8 = 3.1

The final year counts by Traffic Category are as follows:

Category 1:	121
Category 2:	183
Category 3:	124
Category 4:	16
Category 5:	0

Refer to Table 3: LVRR standards apply
Refer to Table 4: The traffic is in Traffic Group B
Refer to Table 9: Carriageway width = 3.5 metres
Shoulder width = 1 metre

A10.2 Subgrade design strength and pavement design example

This example shows how results from DCP tests and laboratory soaked tests are used to determine the subgrade design strength and then to design improved pavements and surfaces.

The results come from an early trial of this manual in northern Lao on a road whose subgrade had been prepared but not yet compacted.

During earlier assessments and surveys, the following had been decided:
- The entire road would be improved.
- Most of the road passes through farmland and has gradients of 0-3%. A gravel surface was appropriate for these lengths of road.
- Four sections were prioritised for further pavement and surface improvement, due to being either on a gradient steeper than 6% or in a village.
- Two of these sections were divided into sub-sections. Pavement types were selected for all prioritised sections and sub-sections on the basis of available materials and skills and in order to trial a variety of pavements.
- Traffic was estimated as being Traffic Group B.

Table A19 collates the results from the DCP and laboratory soaked tests for the prioritised sections. The DCP results are for the weakest layer within the top 500 mm that is thicker than 50 mm. The laboratory soaked test was carried out at 95% of maximum dry density under modified compaction. Grey cells indicate that a test was not carried out at that chainage.

DCP results are affected by the density of the subgrade. It is acknowledged that the lack of compaction of the subgrade and the lack of density measurements may make the correlation between the in situ and laboratory strengths more difficult.

Section	Chainage	DCP test		Laboratory soaked test
		Left wheeltrack	Right wheeltrack	
	0+000	12	26	No test
1	0+100	10	14	8
	0+200	8	13	6
	0+300	15	15	9
	1+250	10	21	7
2	1+350	11	10	10
	1+400	25	19	No test
	1+500	16	13	13
	1+600	21	19	No test
	1+650	No test	15	12
	1+700	9	No test	No test
	1+750	16	14	9
	1+800	22	29	No test
	1+950	No test	4	No test
3	2+000	7	No test	5
	2+050	21	No test	No test
	2+100	No test	No test	18
	2+400	12	15	7
4	2+450	5	7	No test
	2+500	12	20	23

Sections 1 to 4 were then analysed and designed using the pavement design charts. The analysis and design of each section is presented in the following paragraphs. For each section a graph shows the results from the DCP tests in the left and right wheel tracks (LWT & RWT) and from the soaked tests. A table then gives the selected pavement type, the subgrade design strength (in terms of the appropriate range on the relevant pavement design table) and the resulting pavement design. The subgrade design strength is determined by comparing the three sets of data on the graph and referring to Appendix A1.

The road was due to receive a 150 mm wearing course of gravel with a soaked strength of 25%. It was assumed that for logistical reasons this layer would be provided along the entire road, including the four sections prioritised for further improvement. This gravel layer is therefore substituted into the pavement designs of the four sections. The final column in the table gives the layers that are required on top of the gravel wearing course in order to match the pavement design. In most cases, the gravel substitutes for 100-150 mm of either capping or sub-base, but in two cases it is allowed to substitute for 175 mm of capping because the percentage strength increase is much greater than the percentage thickness decrease, as described in 2.8.2.

Since design tables are available for pavements with and without a capping layer, the designs are repeated for each alternative, although this is not done for Section 1 because capping is not specified for use under a concrete pavement.

After the analysis and design of Section 4, Table A27 summarises the required pavement layers for the four sections. Other design details to add include shoulders and transitions at either end of each sub-section.

Section 1

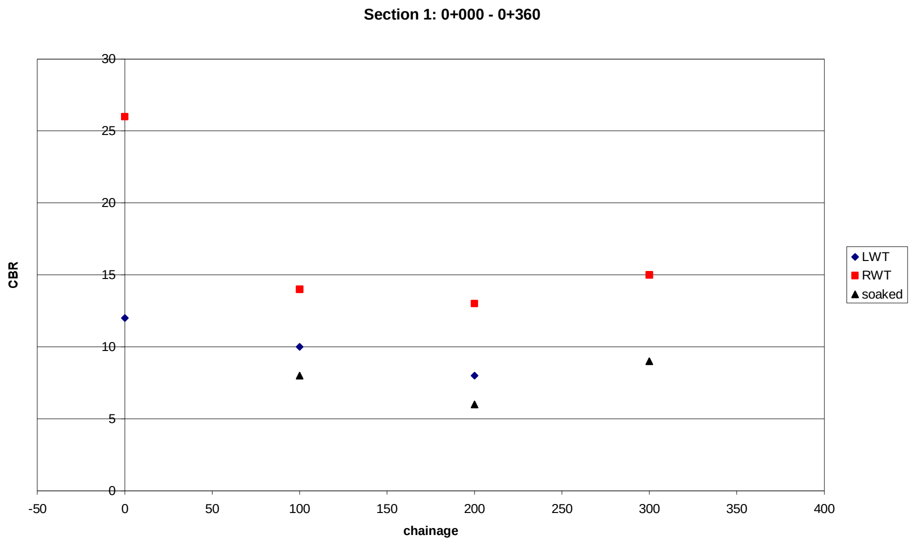


Table A20 Section 1 Pavement design

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
0+000 – 0+360	Concrete	> 7	150 mm of concrete 100 mm of sub-base (25%)	150 mm of concrete

Section 2

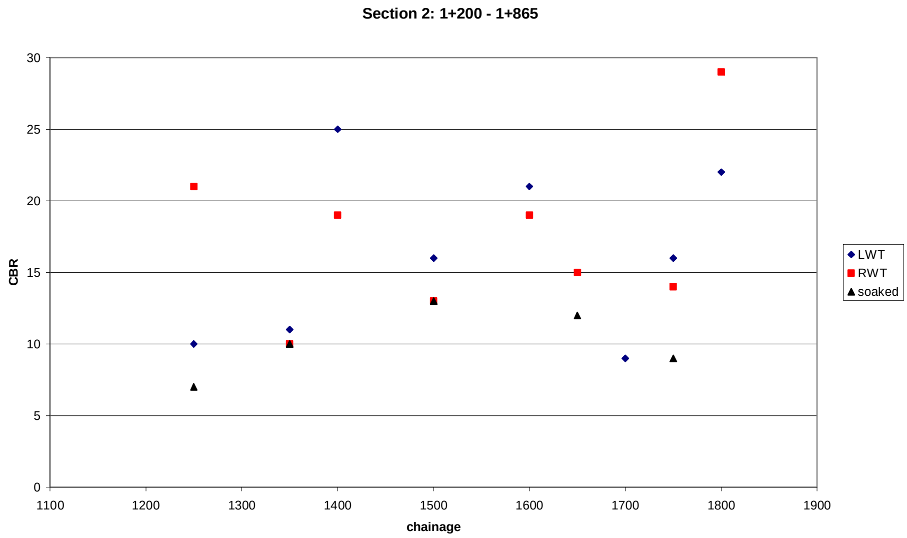


Table A21 Section 2 Pavement design with capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
1+200 – 1+400	Sealed gravel	7 – 10.9	Seal 100 mm of base (80%) 150 mm of sub-base (25%) 100 mm of capping (10%)	Seal 100 mm of base (80%) 100 mm of sub-base (25%)
1+400 – 1+700	Sealed gravel	> 11	Seal 100 mm of base (80%) 150 mm of sub-base (25%)	Seal 100 mm of base (80%)
1+700 – 1+865	Sealed armoured gravel	7 – 10.9	Seal 70 mm of armouring 100 mm of base (50%) 150 mm of sub-base (25%) 100 mm of capping (10%)	Seal 70 mm of armouring 100 mm of base (50%) 100 mm of sub-base (25%)

Table A22 Section 2 Pavement design without capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
1+200 – 1+400	Sealed gravel	7 – 10.9	Seal 100 mm of base (80%) 225 mm of sub-base (25%)	Seal 100 mm of base (80%) 75 mm of sub-base (25%)
1+400 – 1+700	Sealed gravel	> 11	Seal 100 mm of base (80%) 150 mm of sub-base (25%)	Seal 100 mm of base (80%)
1+700 – 1+865	Sealed armoured gravel	7 – 10.9	Seal 70 mm of armouring 100 mm of base (50%) 225 mm of sub-base (25%)	Seal 70 mm of armouring 100 mm of base (50%) 75 mm of sub-base (25%)

Section 3

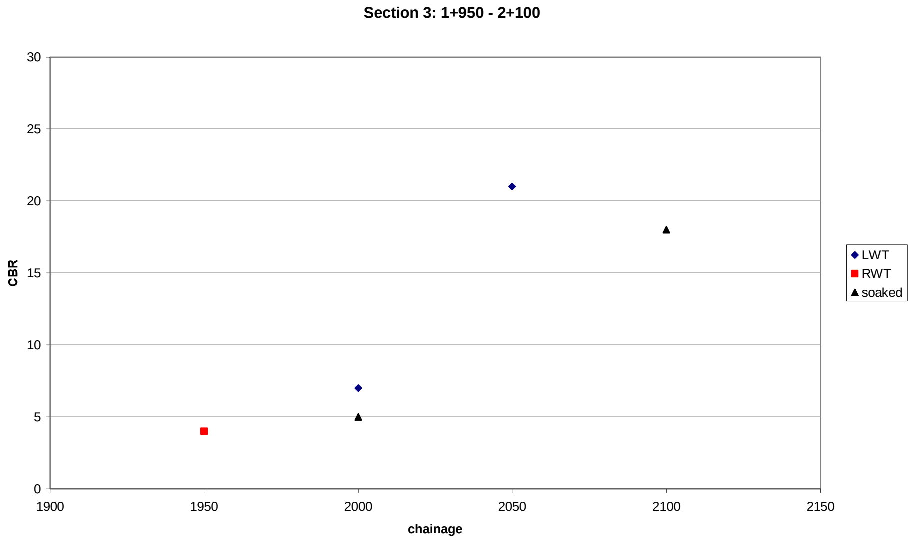


Table A23 Section 3 Pavement design with capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
1+950 – 2+025	Sealed gravel	4 – 6.9	Seal 100 mm of base (80%) 150 mm of sub-base (25%) 175 mm of capping (10%)	Seal 100 mm of base (80%) 150 mm of sub-base (25%)
2+025 – 2+100	Sealed gravel	> 11	Seal 100 mm of base (80%) 150 mm of sub-base (25%)	Seal 100 mm of base (80%)

Table A24 Section 3 Pavement design without capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
1+950 – 2+025	Sealed gravel	4 – 6.9	Seal 100 mm of base (80%) 275 mm of sub-base (25%)	Seal 100 mm of base (80%) 125 mm of sub-base (25%)
2+025 – 2+100	Sealed gravel	> 11	Seal 100 mm of base (80%) 150 mm of sub-base (25%)	Seal 100 mm of base (80%)

Section 4

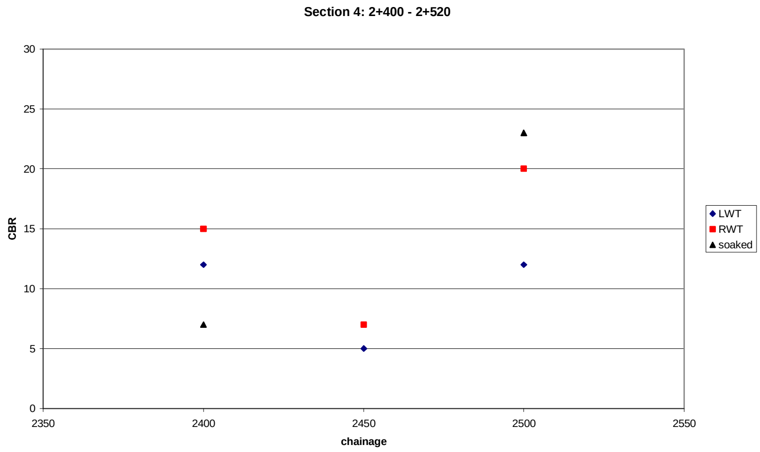


Table A25 Section 4 Pavement design with capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
2+400 – 2+520	Sealed armoured gravel	4 – 6.9	Seal 70 mm of armouring 100 mm of base (50%) 150 mm of sub-base (25%) 175 mm of capping (10%)	Seal 70 mm of armouring 100 mm of base (50%) 150 mm of sub-base (25%)

Table A26 Section 4 Pavement design without capping

Chainage	Pavement type	Subgrade design strength	Design	Required pavement layers
2+400 – 2+520	Sealed armoured gravel	4 – 6.9	Seal 70 mm of armouring 100 mm of base (50%) 275 mm of sub-base (25%)	Seal 70 mm of armouring 100 mm of base (50%) 125 mm of sub-base (25%)

Table A27 Summary of required pavement layers

Section	Chainage	Required pavement layers
1	0+000 – 0+360	150 mm of concrete Shoulders (est.)
2	1+200 – 1+400	Seal (DBST) 100 mm of base (80%) 75 mm of sub-base (25%) Shoulders (est.)
	1+400 – 1+700	Seal (DBST) 100 mm of base (80%) Shoulders (est.)
	1+700 – 1+865	Seal (DBST) 70 mm of armouring 100 mm of base (50%) 75 mm of sub-base (25%) Shoulder (est.)
3	1+950 – 2+025	Seal (DBST) 100 mm of base (80%) 125 mm of sub-base (25%) Shoulders (est.)
	2+025 – 2+100	Seal (DBST) 100 mm of base (80%) Shoulders (est.)
4	2+400 – 2+520	Seal (DBST) 70 mm of armouring 100 mm of base (50%) 125 mm of sub-base (25%) Shoulders (est.)

A10.3 Road and pavement design exercise

Question

Design the geometric cross section, geometry and pavement of a road for the following situation. Assume that there is no financial restriction.

- The road is in poor condition and the improved road will follow the same alignment
- The road is 7 km long
- The total rise and fall of the road is 685 metres
- The traffic for most the road is as given in the traffic analysis exercise above, with no vehicles in Traffic Category 5
- In two villages along the road, the traffic in Traffic Category 1 is assumed to be three times that on the rest of the road, the traffic in Traffic Category 2 is assumed to be two times that on the rest of the road and the traffic in Traffic Categories 3 and 4 is assumed to be the same as that on the rest of the road
- The rainfall is 1700 mm per year
- Most of the road has a gradient of less than 4%, but there are occasional hills up to 50 metres long with gradients of 10%
- Realignment around these hills would be expensive
- Flooding is not a problem along the road
- Ground water is always more than 0.5 metres below ground level
- The subgrade, when soaked, has a CBR of 5.5% along the entire road
- Gravel which can achieve a soaked CBR of 65% is available
- A local soil which can achieve a soaked CBR of 13% is also available
- Strong aggregate, suitable for chippings and armouring, is available
- Contractors are capable of constructing gravel layers and bituminous seals
- The VMC is able to successfully maintain a gravel road and is expected to be able to maintain a bituminous seal

Answer

The design process for the improvement of an existing road will be used. The relevant steps are described below.

1. Screening
- The project is acceptable from a budget, traffic and maintenance perspective.

2. Site visit and rapid survey
3. Assess traffic
- LVRR standards apply for the entire road
- The traffic is in Traffic Group B for the entire road

4. Assess terrain
- Total rise and fall per kilometre = 98 metres
- Therefore the road crosses approximately 20 5-metre contours per kilometre
- The terrain is therefore classed as Rolling

5. Assess annual rainfall
- The annual rainfall comes in the range 1500-2000 mm per year

6. Assess local materials
- With medium gravel, chippings, armouring and a soil which could act as a capping layer available, a gravel and a sealed armoured gravel pavement may be appropriate

7. Assess construction and maintenance capacity
- Local capacity appears capable of constructing and maintaining a gravel road and a bituminous seal

8. Initial design work
- For most of the road, carriageway width = 3.5 metres and shoulder width = 1 metre
- For the road in the two villages, although the traffic in Traffic Categories 1 and 2 is higher, the carriageway and shoulder widths remain at 3.5 metres and 1 metre
- Sections that have a gravel surface must have, unless there are good reasons for exception:
    - a carriageway camber of 6%
    - a shoulder camber of 6%

  - a minimum horizontal radius of 70 metres
  - a minimum vertical crest radius of 900 metres
  - a minimum vertical sag radius of 250 metres
  - a minimum sight distance of 100 metres
  - a maximum gradient of 6%
- Sections that have a bituminous or concrete surface must have, unless there are good reasons for exception:
  - a carriageway camber of 4% (bituminous) or 1-2% (concrete)
  - a shoulder camber of 6%
  - a minimum horizontal radius of 60 metres
  - a minimum vertical crest radius of 500 metres
  - a minimum vertical sag radius of 250 metres
  - a minimum sight distance of 70 metres
  - a maximum gradient of 8% for hills longer than 300 metres
  - a maximum gradient of 15% for hills shorter than 300 metres
- Adverse camber removed on curves with a horizontal radius of less than 500 metres.

9. Main survey
10. Data collection
11. Selection of improvements
12. Pavement and surface design

- It is assumed that the road has been surveyed and that a pavement will be constructed along the entire length of the road with the geometric cross section and geometry as above
- An unsealed gravel pavement is suitable for most of the road with gradient less than 4% and rainfall of 1500-2000 mm per year, although the traffic level of Traffic Categories 3 and 4 is higher than ideal for a gravel road
- An improved pavement is required on the short hills and through the villages
- A sealed gravel pavement is not suitable because gravel with the required soaked CBR of 80% is not available
- A sealed armoured gravel pavement will be used on the short hills and through the villages
- DBST will be used as the contractors are familiar with it and have no experience of an Otta seal
- Additional slope protection, safety and environmental measures will be constructed as required

13. Estimate costs
14. Prioritisation

15. Prepare contract documents

- These steps are not relevant for the question – it is assumed that the selected pavements are the most appropriate and have the lowest whole life costs

The pavement designs are summarised below. All materials must meet the relevant specifications. Note that both pavements meet the requirements for the height above ground water given in Table 11.

Gravel pavement – refer to Tables Ax and Ax

- Gravel layer, 200 mm thick with a minimum soaked CBR of 25%
- Capping layer, 150 mm thick with a minimum soaked CBR of 10%
- Regravel before the gravel thickness is less than 100 mm

Sealed armoured gravel pavement – refer to Tables Ax and Ax

- DBST
- Armouring, 70 mm thick
- Gravel base, 100 mm thick with a minimum soaked CBR of 25%
- Gravel sub-base, 150 mm thick, with a minimum soaked CBR of 25%
- Capping layer, 175 mm thick with a minimum soaked CBR of 10%

A10.4 Whole life asset cost exercise

Question

Which of the two pavement types below has the lowest whole life asset costs over a design life of 12 years and with a discount rate of 10%?

All costs are given per kilometre and are for this example only. The currency is not stated.

Gravelled pavement

Construction cost:	11,000
Annual routine maintenance cost:	700
Regravelling cost in years 4, 7 and 10:	6,500
Residual value after 12 years:	8,000

Sealed gravel pavement

Construction cost:	18,500
Annual routine maintenance cost:	900
Resealing cost in year 8:	4,000
Residual value after 12 years:	16,000